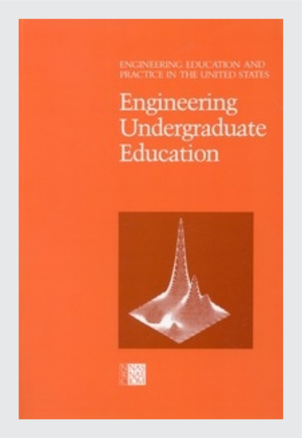

Engineering Undergraduate Education

DETAILS

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Engineering Undergraduate Education

ENGINEERING EDUCATION AND PRACTICE IN THE UNITED STATES

Panel on Undergraduate Engineering Education
Committee on the Education and Utilization of the Engineer
Commission on Engineering and Technical Systems
National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Preface

This report of the Panel on Undergraduate Engineering Education is one in a set of companion reports that formed the basis of the overall study by the Committee on the Education and Utilization of the Engineer, performed under the auspices of the National Research Council.

The work of this panel occurred during a period in which the engineering educational resources of the nation were subject to severe stress, primarily as a result of forces outside the control of the engineering educational community. First-year enrollments doubled in a relatively short period of time, acute faculty shortages developed in several important disciplines, and fluctuating economic conditions influenced the support structure of engineering education. These factors, combined with the relatively rapid changes in technology, created an awareness that there were limits to the viability of our system of engineering education.

Consequently, the direction of the panel's work was influenced by these factors, and its scope included topics that bear on the viability of the system. Hence, the quality, size, and diversity of the prefreshman pool was included, as well as consideration of those factors most important in the effective utilization of faculty resources. Because of the strong influence of graduate study and research on undergraduate engineering education, the panel examined the forces that have led to the creation of a two-tiered system of engineering programs (i.e., in research institutions versus low-research institutions) and the consequences of this system.

Although the panel considered the overall forces that have shaped and constrained engineering curricula, no attempt was made to conduct a detailed review and assessment of the various curricula. Matters of curricular development and possible reform were not central to the purpose of the overall committee effort, and such a review and assessment are most properly within the domain of the individual disciplines and those organizations responsible for maintaining standards.

The material in this report provides the comprehensive substantive background for the work of the full committee pertaining to undergraduate education. The panel is pleased to see that many of its most significant findings, conclusions, and recommendations are included in Chapter 4 of the full committee report,* and that its work is reflected prominently in the recommendations which appear in the Executive Summary of that report. This is evidence of the pivotal role of undergraduate engineering education in the techno-economic future of our nation.

This report results from the work of the panel members who so generously contributed their time and professional expertise to this major effort. I would like to thank them for their valuable contributions and assistance. Finally, I wish to thank Jerrier A. Haddad for his stimulating guidance to the entire committee effort and Vernon H. Miles and William H. Michael, Jr., whose staff support was vital to the work of the panel and to the production of this report.

EDMUND T. CRANCH
CHAIRMAN

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* *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future* (Washington, D.C.: National Academy Press, 1985).

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ENGINEERING EDUCATION AND PRACTICE IN THE UNITED STATES

Engineering Undergraduate Education

Executive Summary

The Panel on Undergraduate Engineering Education prepared this report as part of the overall effort of the National Research Council's Committee on the Education and Utilization of the Engineer. The panel was charged with studying the academic preparation of engineers for practicing their profession. Summarizing the analysis of its research, the panel prepared findings and recommendations (see next section). Its major conclusions are these:

1. Student preparation for college-level study of engineering should be substantially strengthened if the pool of students is to supply enough engineers of the quality required to meet the nation's future needs.
2. The growing demand for engineers will require that engineering programs attract a greater percentage from the decreasing number of high school graduates. The educational system also must attract increased numbers of women and minorities as students and as faculty in order to provide the number and quality of engineers that will be needed. Finally, the system must provide and draw from nontraditional educational tracks (e.g., transfer students) to support the broadening of its pool of students.
3. To meet substantial current and future needs, the educational system must attract and prepare a larger pool of engineering faculty than is now available.
4. The content, pattern, and presentation of future curricula—e.g., cross-disciplinary studies closely related to current developments in

engineering and related fields—must be modified to incorporate the potential of new technologies.

5. Engineering schools have great need of additional laboratory facilities and equipment, as well as needing a clear understanding of the vital purpose of study in the laboratory, in order to prepare engineers for experimentation in the field with the aid of new technologies.
6. Faculty acceptance of and funding for educational technology are necessary to enhance the quality of undergraduate education by using the many new pedagogical tools it offers.
7. Support for engineering from its users—mainly business and government—has focused on research, thereby creating two major tiers of education: (1) research institutions and (2) undergraduate colleges. It is essential that a balance of support be achieved between research institutions and the undergraduate colleges that educate half of the nation's engineers.

Despite the extreme demands on our nation's system of undergraduate engineering education, the system has been remarkably responsive to these demands, although several severe strains have developed. The panel's findings—

- of a shrinking pool of qualified students to respond to the growing need for engineers,
- of the weak attraction of engineering education for potential faculty,
- and of the outdated facilities and teaching equipment—

demonstrate a chronic neglect of the system. Such neglect threatens the economic and strategic strength of our nation through the next quarter of a century. In the section that follows, the Panel on Undergraduate Engineering Education presents its findings and recommendations, which should guide the preparation of engineers into the next century.

FINDINGS AND RECOMMENDATIONS

1. By 1992 major demographic changes are likely to cause a substantial drop in the number of qualified students entering engineering colleges in 38 states. Half of all B.S. graduates now come from 45 engineering schools that have 400 or more graduates each year. Fifteen of those schools are in New York, New Jersey, Pennsylvania, and Massachusetts—states where the high school population will decline by an average of 40 percent between 1982 and 1993. Twenty-seven of the 45

engineering schools are concentrated in the 13 frost-belt states, which will all experience an appreciable decline in high school population. Compounding this geographic problem is the demographic projection of a 22 percent decline in the total number of high school graduates between 1982 and 1991. (See Chapter 2.)

If the flow of engineering graduates is to be maintained despite major demographic changes, a very substantial effort will be required to increase the number of high school students who are qualified and motivated to study engineering. Both the traditional sources and the increasing pool of women and minorities must be nurtured to maintain the present quality of engineering students.

2. There has been a serious erosion of content and standards in elementary and secondary school systems in the last two decades. This problem is shared by the colleges that set the standards for admission and the society that prepares its children for life. In addition, there are critical shortages of science and mathematics teachers in almost every state. And half of the newly employed science, mathematics, and English teachers are not qualified to teach these subjects. This erosion, especially in mathematics and science, now threatens the base of the qualified engineering manpower pool. (See Chapter 2.)

   To improve the qualifications of students intending to study engineering, the engineering schools and engineering professional societies must actively encourage government and industry to join them in an effort to improve the mathematical, scientific, and technological content in America's school systems. This effort will require additional sources of talent and funds.

3. Blacks, Hispanics, and native Americans are greatly underrepresented among engineering school applicants (both graduate and undergraduate) and in the engineering workplace. This underrepresentation has social, economic, and educational origins, the latter being evidenced in grades K-12 by a loss of interest and lack of success in science and mathematics. Despite recent increases in minority enrollments at engineering colleges, the potential representation of these populations remains unmet, and once they are admitted, their rate of attrition is disproportionately high compared with that of traditional engineering students. Because a growing fraction of minority populations are in urban centers where many engineering colleges are also located, there may be a growing gap between the number of available spaces and the number of engineering applicants from urban areas. (See Chapter 2.)

   Extensive efforts by schools, companies, and engineering societies are needed to bring more minorities into engineering. For example, *precollege programs such as those operating in a few major cities and regions of the country must be expanded and funded to prepare and motivate minority students to pursue college study and careers in engineering.*

4. Because few women studied engineering in the past, the profession did not have access to a substantial fund of human resources. The traditional pattern resulted from social differentiation originating in the family, society, and schools. Studies show that women and men have equal aptitude for engineering education. During the past decade the concept of social equality has changed markedly; the number of women studying and practicing engineering has increased dramatically—from 1 percent in 1970 to at least 15 percent of the engineering enrollment in 1984. As a result, both the size of the engineering pool and the quality of engineering students have increased. (See Chapter 2.)

   To achieve the full potential that this human resource offers, colleges of engineering, school systems, government, industry, and the engineering profession must continue to work to increase the number of qualified women who study for a career in engineering. A key requirement is the need to encourage the study of mathematics and science by female secondary school students.

5. Enrollment capacity in several engineering disciplines is completely filled. Restoration of elasticity in enrollment capacities is possible through increased use of dual-degree programs and transfer programs with community colleges. For at least two decades these dual-degree relationships between liberal arts and engineering colleges have enabled a few students, some of them from minorities, to earn B.S. degrees in engineering. (See Chapter 4.)

   To increase elasticity in enrollment capacities and diversity of educational background of engineering enrollments, a pilot group of colleges and engineering schools should be funded to demonstrate effective structures for dual-degree programs. Experience gained from this pilot group could then be applied, if needed, to a wider group of institutions. In addition, the experience gained would be relevant to the often-debated model of preprofessional followed by professional engineering education.

6. Engineering "co-op" programs have traditionally performed a valuable role in engineering education. They help students focus on interpersonal skills that practicing engineers need. They also provide a motivational component, namely, a means to help finance a college education. In addition, they give students experience in the practice of

engineering, an aspect that has been greatly deemphasized in contemporary engineering curricula. They have an important orientational value, helping enrich and focus the classroom learning experience. Despite their usefulness, however, these programs attract a small fraction of students (<10 percent) and traditionally suffer from fluctuations in the economy and inconsistent support by industry. (See Chapter 2.)

To increase their effectiveness and enhance their role, co-op programs need to be strengthened and made more attractive to students. A considerably stronger commitment from industry is required to eliminate the "boom or bust" character of the programs that reflects a fluctuating economy. If industry adopted a revised posture toward co-op education and committed itself to a shared responsibility for the educational process, a very significant and innovative dimension could be added to the education of the engineer.

7. About half of the B.S. engineering graduates come primarily from undergraduate-oriented colleges (those awarding about 14 or fewer Ph.D. degrees per year), which face severe funding problems. Since both government and industry focus on increasing their funding for graduate study and research, these colleges have been forced to depend on other, smaller sources of funding. Despite this vulnerability, industry will continue to depend on the graduates of these colleges for at least half of its work force. (See Chapter 6.)

   If the quality of engineering education at undergraduate-oriented colleges is to keep pace with the quality at graduate research centers, these colleges must have access to special, new sources of income.

8. The current and persistent shortage of Ph.D.s and faculty of sufficiently high quality is a serious problem for engineering education. In some disciplines it is *the* limiting factor in both the quality and the scope of engineering programs. The economics of the marketplace limits the flow of the most talented students into teaching, yet the shortage of such talent is in turn a serious problem for the nation's economy. (See Chapter 2.)

   In addition to support for graduate education, engineering schools and professional societies must create and maintain an active campaign to emphasize the advantages of an academic career. Industry, government, engineering schools, and professional societies must encourage and support master's-level programs, combined B.S.-M.S. programs, and release time to enlarge and develop the pool of potential faculty.

9. Although the shortage of faculty will probably remain a serious problem, resolution of the issue of the Ph.D.-versus the M.S.-degree requirement for undergraduate teaching is unlikely in the foreseeable future. Meanwhile, the tenure track is excluding possible sources of capable faculty. (See Chapter 3.)

   Colleges of engineering should identify and utilize faculty other than those in tenure tracks—military retirees, persons reentering or shifting careers, and adjunct faculty, and other professionally qualified persons, with or without Ph.D.s, who welcome short-term contracts or second careers.

10. The pace and character of technological change and the great increase in engineering enrollments in many disciplines require both promotion of faculty versatility to overcome obsolescence, and relief from excessive undergraduate teaching loads. (See Chapter 3.)

    Engineering schools must create specific faculty development programs with shared institutional, industrial, and governmental funding.

11. The increasing concentration of curricula on theory, combined with the pace of technological change, has resulted in a deemphasis of the practice of engineering in the curriculum. Although part-time or adjunct faculty with relevant expertise have been used both to teach selected courses and to give regular courses when a faculty shortage exists, they have not been used to any appreciable extent to provide a practical, experiential educational component. (See Chapter 3.)

    Colleges of engineering and professional societies should promote the use of Professors of Professional Practice. This could be done by appointing either adjunct faculty or, preferably, full-time resident faculty for specific periods of time. The cooperation and support of industry in providing loaned staff are essential to achieving the educational goal of greater emphasis on practical aspects of engineering. The use in industry of regular faculty on complementary leaves would also support this goal.

12. Although engineering education has been flexible and adaptable, as is reflected in the introduction of new subdisciplines, the combination of disciplinary constraints, concentration in research funding, and peer perceptions has resulted in perpetuating considerable rigidity in the structure of curricula and in stifling educational experimentation. (See Chapter 3.)

    The ability of engineering education to adapt to change depends on encouragement and toleration of curricular and faculty flexibility.

Shared teaching across departmental boundaries should be encouraged. The need for educational experimentation must be recognized and given institutional support. The Accreditation Board for Engineering and Technology could play a supportive role in such developments.

13. New information-generating and-processing capabilities and the revolution in communications are causing continued, major changes in both the substance and modes of delivery of engineering education. (See Chapter 3.)

    The engineering profession should undertake a comprehensive study—and should immediately implement its findings—about how to make educational technology more efficient and how to improve both the process of education and the learning experience. Funding by government, foundations, and industry is essential to achieve this result.

14. The decrease in laboratory instruction in most engineering curricula is educationally unsound. (See Chapter 5.)

    It is of primary importance that the role and significance of laboratory instruction in undergraduate engineering education be emphasized. Colleges of engineering must address this priority need and, together with industry and government, provide the funding to achieve the goal of integrating laboratory practice in engineering education.

15. Laboratory equipment used in engineering education has deteriorated over a long period of time. Governmental and industrial equipment-support programs have been sporadic, resulting in a serious mismatch between the need for up to date equipment and the level of support. Such support seldom provides for maintenance of equipment, which is becoming increasingly complex. (See Chapter 5.)

    A national program of government-industry-college matching grants is needed to address the problem of replacing outdated equipment and maintaining increasingly complex experimental equipment. Industry, academe, and the professional societies need to join forces in promoting tax legislation to facilitate gifts of laboratory equipment to colleges of engineering.

16. The aging of engineering facilities, including "bricks-and-mortar," is a significant and growing problem. The condition of these facilities is worsening at a time when the importance of engineering education to regional and national economic development is recognized. (See Chapter 6.)

    A comprehensive government-industry-college program is needed to address the rapidly growing problem of aging facilities. The use of matching grants should be encouraged.

17. The complete integration of computers into the curriculum will enhance the quality of engineering education, although this will require enlisting both faculty and administrators to create and implement an effective policy. (See Chapter 3.)

    Faculty must weave computer use into the fabric of engineering curricula. Administrators must treat this incorporation of computers as a "mainline" activity by allocating a percentage of the budget to the endeavor.

18. Because government and industry focus on research and graduate education grants, there has been a transition to a two-tiered configuration of engineering colleges: research institutions versus "low-research" institutions. (See Chapter 6.)

    If the program quality of low-research institutions is to keep pace with that of research institutions, faculty at the former will need to gain access to some of the facilities and programs of the major centers of research.

19. Swings in enrollments profoundly affect the quality of engineering education, the careers of the faculty who offer it, and the services and equipment that support it. Current enrollments, which almost doubled from 1977 to 1982, have reduced the vitality and balance of the engineering education system. Faculty are distracted from scholarship and pedagogical growth by overcrowded classes, and laboratories and facilities cannot sustain the pressure of use. (See Chapter 3.)

    Not only must engineering schools examine and use strategies that will maintain quality under the pressure of the demand for quantity, but they must also plan for the long term to maintain elasticity in the system by encouraging flexibility in faculty and other educational resources.

1

The Goals of Undergraduate Engineering Education

The goals of undergraduate education in engineering are these:

- To prepare graduates to contribute to engineering practice by learning from professional engineering assignments;
- To prepare them for graduate study in engineering; and
- To provide a base for lifelong learning and professional development in support of evolving career objectives, which include being informed, effective, and responsible participants within the engineering profession and in society.

These goals recognize that engineers who move into various job assignments, either in engineering or in management, need continuous education. In general, undergraduate engineering curriculum is not intended to prepare the B.S.-degree candidate for a particular job in a particular industry. Gaining specific skills in the engineering practices of a given company requires on-the-job experience best gained through a professional apprenticeship. While a particular undergraduate engineering curriculum cannot lay the foundation for all of the areas that an engineer will need to master in a professional lifetime, it should provide a base for lifelong learning.

Within the framework of the general educational goals listed above, the objectives of undergraduate engineering curricula are as follows:

1. To provide an understanding of fundamental scientific principles and a command of basic knowledge underlying the student's field.

2. To convey an understanding of engineering methods such as analysis and computation, modeling, design and experimental verification, as well as experience in applying these methods to realistic engineering problems and processes.
3. To provide the student with the following:

a. An understanding of social and economic forces and their relationship with engineering systems, including the idea that the best technical solution may not be feasible when viewed in its social, political, or legal context;
b. A sense of professional responsibility developed through consideration of moral, ethical, and philosophical concepts; and
c. Mastery of the ability to organize and express ideas logically and persuasively in both written and oral communications.

These objectives are met mostly through formal undergraduate curricula, which include design and laboratory courses and access to computers. Important complements to these activities are experiences gained through summer jobs, co-op programs with industry, and faculty-supervised projects that often foster the ability of graduates to work in groups or as a team.

CURRICULAR CHANGE

Undergraduate engineering curricula are constantly evolving. Evolution occurs through the introduction of advanced material from graduate courses or from technological advances in professional practice. At times the rate of change is extremely rapid and appears to be revolutionary. Such changes cause either compression of existing course content to make room for the new material or complete displacement of previously taught material to make way for the new material. Changes can also result from shifts in emphasis, such as those that occurred when engineering courses were restructured to emphasize the scientific basis of engineering and when increased emphasis on design and manufacturing influenced the curriculum.

Revolutionary change in the curriculum is brought about by the creation of entirely new fields or by substantial revision of existing fields. For example, the creation of materials science as an independent discipline represented the appearance of an entirely new engineering field. The current revolution in electrical engineering results from the development of semiconductor materials and the growth of computer science, and revolutionary changes may occur in chemical engineering if biotechnology becomes an important industrial force.

FACULTY ROLE

Engineering faculty play a critical role in the introduction of the kinds of curricular change discussed above. Faculty unfamiliar with the research frontier will lag in the introduction of important new material into the curriculum; faculty far removed from advances in industrial practice will miss important opportunities to tailor the curriculum to crucial industrial needs—which will be to the disadvantage of their students. Thus, to preserve current relevance and vigor, it is essential that engineering faculty participate continuously in professional development.

2

Undergraduate Students

DEMOGRAPHIC FORCES

The number of engineering graduates who will seek employment in the decade ahead is very difficult to predict. It is a complex function of many variables, some of which are confirmed, some partially understood, and some conjectured. There are three principal elements in the supply of engineering graduates: (1) the high school graduates' population (the potential base); (2) the percentage of qualified applicants from that base who enter engineering programs; and (3) the retention of engineering students.

The Population Base

The number of 18-year-olds in the U.S. population through the year 2000 rests on well-established projections. Only the migratory drift of families will further affect regional populations. It is generally thought that, barring unforeseen political or economic events, the current pattern of migration will produce a minor but reinforcing effect on the existing population-age characteristics already established in each region.

The Western Interstate Commission for Higher Education published a projection of high school graduates through 2000 (McConnell and Kaufman, 1984) that indicated a 22 percent decrease nationwide between 1982 and 1991, roughly approaching the low point of the period. All but 10 states share in the decrease, which in absolute numbers is a decline of approximately 590,000 high school graduates from a base of 2.712 million. Figure 1 shows that the decrease in graduates varies widely among regions of the country between 1984 and 1999.

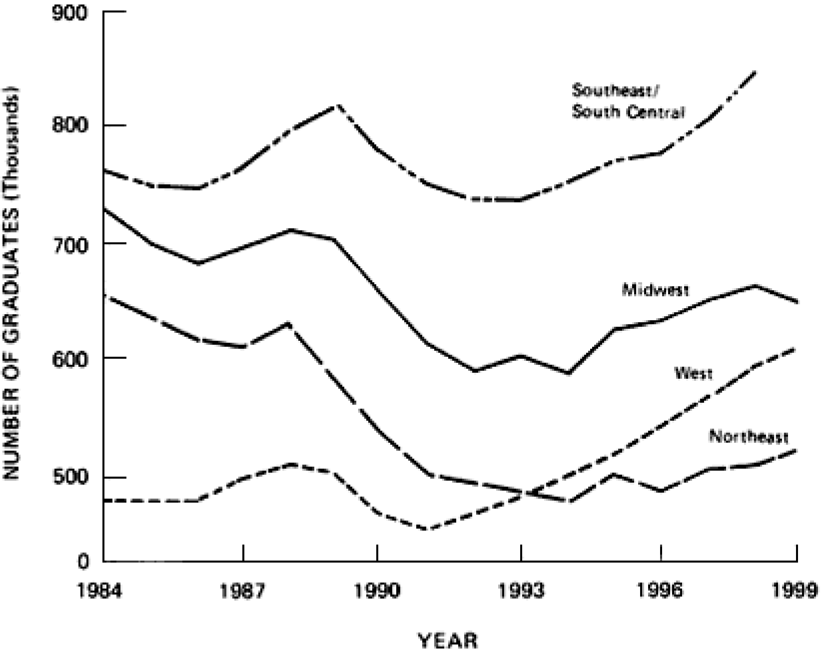

Figure 1
U.S. high school graduates: projections for 1984–1999. Source: Based on McConnell and Kaufman (1984).

Comparison of the future population of high school students with the current geographical distribution of engineering students reveals a new dimension of the problem that lies ahead. In 1981–1982, half of the B.S. degrees in engineering nationally were awarded by only 45 schools, all of them graduating more than 400 engineering students. Of those schools, about 60 percent are located in the North Central and Northeastern regions of the country, where population decreases are projected to be the most severe. Fifteen of the 45 colleges are in Massachusetts, New York, New Jersey, and Pennsylvania, states in which the high school population will decrease an average of 40 percent between 1982 and 1993. Thus, these highly industrialized and often "high-tech" North Central and Northeastern areas could be severely affected by the projected demographic shifts.

Engineering colleges in the North Central and Northeastern regions must either recruit outside their regions, as some already do, or work intensively to increase the percentage of qualified regional high school graduates who apply for engineering programs. Admissions experience of independent and public institutions, with the exception of a very few national universities, shows that the vast majority of students attend a college within a 250-mile radius of their homes.

Applications to Engineering Programs

Engineering enrollments, when charted since World War II (see Figure 2) rise and fall appreciably and are almost independent of the high school population (see the key to the figure, which associates enrollment peaks and valleys with national forces). Enrollments between 1945 and 1982 responded to the perceived market for engineering manpower. These historical swings indicate considerable elasticity in the interest in engineering among potential college applicants.

As shown in Figure 2, the current surge of undergraduate enrollment is explained in part by a new factor—in addition to the traditional source (male applicants), the pool now includes women, minorities, and additional foreign nationals. (Asian-American minorities have been strongly represented for many decades.)

In 1975, 8.7 percent of college-bound high school seniors intended to pursue engineering, while in 1982 that number reached 14.4 percent. Of college-bound seniors in 1982 whose Scholastic Aptitude Test (SAT) scores were over 1000 (the top 30 percent of the total tested), 21 percent indicated that they intended to study engineering. If the existing applicant pool is to be maintained, that percentage of 21, assuming that it is evenly distributed, would have to reach about 35 percent in those regions where the high school population base will shrink by 40 percent. Nationwide, with a future high school applicant pool at 78 percent of its 1982 level, about 28 percent of college applicants will need to be interested in engineering programs for 1982 applicant levels to be maintained.

The Panel on Undergraduate Engineering Education recommends that, *if the flow of engineering graduates is to be maintained despite major demographic changes, a very substantial effort will be required to increase the number of high school students who are qualified and motivated to study engineering. Both the traditional sources and the increasing pool of women and minorities must be nurtured to maintain the present quality of engineering students.*

1. Returning World War II veterans
2. Diminishing veteran pool and expected surplus of engineers
3. Korean War and increasing R&D expenditures
4. Returning Korean War veterans
5. Aerospace program cutbacks and economic recession
6. Vietnam War and greater space expenditures
7. Increased student interest in social-program careers
8. Adverse student attitudes toward engineering, decreased space and defense expenditures, and lowered college attendance
9. Improved engineering job market, positive student attitudes toward engineering, and entry of nontraditional students (women, minorities, and foreign nationals)
10. Diminishing 18-year-old pool

A *Manual on Graduate Study in Engineering* issued, based on 1945 Committee Report chaired by L. E. Grinter

B ASEE Evaluation Report recommends greater stress on mathematics and science and the engineering sciences.

C ASEE Committee on the Development of Engineering Faculties recommends the doctorate for future engineering faculty.

D ASEE *Goals of Engineering Education* recommends the master's degree for the majority of those who complete their undergraduate degree in the coming decade.

Figure 2
Engineering degrees and first-year enrollments: historical factors affecting engineering enrollments. Source: LeBold and Sheridan (1986).

Influences on Admissions

The engineering admissions process varies considerably among institutions —between public and independent institutions and between large, public multiuniversities and public state colleges—and among states. Highly selective engineering colleges have entering freshmen with median combined SAT scores in the 1200 to 1400 range. In many states, colleges of engineering are required to accept all high school graduates above a given rank in class or record on achievement tests. In states with good school systems, setting the class rank sufficiently high results in extremely well-qualified students.

While the applications: admissions ratio is often taken as a measure of selectivity, a self-selection process is also at work in engineering education. That is, students who have a weak background in science and mathematics do not usually enter the admissions competition, so that almost all applicants possess the minimum requirement, which is sometimes as low as a 450 SAT score in mathematics. Furthermore, admissions standards can vary with the perceived size of the applicant pool. In periods of low interest in engineering, some schools lower their standards of admission in order to "fill the freshman class." In periods of high interest in engineering, many schools raise their admissions standards, thereby increasing their selectivity. Clearly, policy determinations and practices of admissions staff exert a strong influence on the numbers and quality of students entering engineering.

Elasticity

On a national or regional basis, the variety in types of institutions increases students' opportunity for access to engineering education. As long as at least some institutions have space, this diversity of opportunity gives the system elasticity. As the last 10 years have shown, with a relatively modest increase in the resources allocated to undergraduate education, this ability of the system to absorb additional students reached a factor of 2 before saturation.

Transfer Students

First-year enrollment is one path to engineering education; a second is the transfer student route. Again, the process varies among institutions. In some cases transfer students compensate for attrition during the first two years of engineering study. The size of this flow is characteristically in the range of 10 percent per year, although some colleges may admit as many as 30 percent transfer students each year. In general, the transfer process is more selective than that of freshman admissions. (Experience shows that transfer students do as well as other engineering students.)

Especially in the public sector, many states have established a feeder system whereby pre-engineering students begin in two-year programs or institutions and, if successful in those, transfer to upper-division engineering curricula. The number of such transfer students is essentially limited by the number of upper-division places available in given curricula. As cost factors become more critical, particularly for students, two-year programs will probably become major feeders to four-year engineering schools.

Dual-degree programs were begun in the 1960s. Their major purpose has been to add a combined liberal arts/engineering dimension to higher education rather than to contribute to the central flow of undergraduate engineering manpower. These programs are usually of the "3 + 2" type: the student obtains both liberal arts and engineering degrees in five years. Dual-degree programs have been utilized to a limited extent to increase the entry of minority students and women into engineering. Overall, dual-degree programs have not produced a significant flow of engineering graduates because the demand has not been significant and because few of these programs dovetail effectively.

FACTORS AFFECTING THE QUALITY OF HIGH SCHOOL GRADUATES

Between 1978 and 1984, at least 20 comprehensive studies of U.S. school systems* cited major deficiencies: loss of basic purpose, absence of clearly identified goals, and low expectations of students. Most striking is their fundamental unanimity on the keynotes sounded in *A Nation at Risk* (Gardner et al., 1983), the 1983 report to the nation and the Secretary of Education by the National Commission on Excellence in Education.

These studies present virtually conclusive evidence that, because of weaknesses in its educational system, our nation is dangerously at risk in several ways. For example, our technological supremacy erodes as other nations expand their own capacities. One threat to our ability to compete results from a shortage of skilled engineers and scientists and from a lack of scientific and mathematical literacy (Education Commission of the States' National Task Force, 1983). Such literacy will be

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* Davidson and Montgomery (1983) summarize 17 of these reports.

essential if citizens of this nation are to support a technologically advanced society.

From 1964 to 1981, the percentage of high school students completing courses in science and mathematics declined as follows: in biology from 80 to 77 percent, in chemistry from 34 to 32 percent, in general science from 61 to 37 percent, in algebra 1 from 76 to 64 percent, in geometry from 51 to 44 percent, and in algebra 2 from 35 to 31 percent (Adelman, 1983). This loss of interest is alarming, considering that Japan and the Soviet Union recognize that world leadership depends on technological superiority. It has been said that "the technological battle with the Japanese is really an industrial equivalent of the East-West arms race" (Julian Gresser, quoted in Grayson, 1983. See also Stata, 1983).

Insufficient Time Commitment

The United States has long depended on its schools to educate its citizens for world leadership. However, a minority of U.S. high school students study mathematics for three years, whereas other industrialized nations require *all* students to start mathematics (other than arithmetic or general mathematics), biology, physics, and geography in grade 6. The class hours spent on these subjects in other industrialized countries is about 3 times that spent even by U.S. students who select four years of science and mathematics in secondary school (Gardner et al., 1983:20). Hurd (1982:2) found "that 93 percent of the seniors completed one or more years of mathematics, 67 percent two years or more, and 34 percent three years." The consensus of the recent studies of schooling is that *all* students should have three years of mathematics; some studies recommend four years, at least for those who plan to attend college (Hurd, 1982).

Only 41 percent of students in academic programs study science for three years in high school (and only 13 percent of general-studies students and 9 percent of vocational-studies students). The consensus among the studies referred to here is that all students should have three years of science, and some of the reports recommend four years of basic science courses for college preparation. Hurd (1982) finds students begin with biology and follow with chemistry (37 percent) and physics (19 percent); others "complete their three years of science with a selection from biology 2, earth science, physiology, space science, aeronautics, oceanography, physical science, geology, ecology, environmental science, or from a host of one semester courses." This jumble is what *A Nation at Risk* describes as curricula "homogenized, diluted, and dif fused to the point that they no longer have a central purpose. In effect, we have a cafeteria-style curriculum in which the appetizers and desserts can easily be mistaken for the main courses" (Gardner et al., 1983:18).

Low Expectations of Students

The reports on U.S. school systems show that our nation's schools and colleges are not demanding enough of students. "Homework for high school seniors has decreased (two-thirds report less than 1 hour a night) and grades have risen, yet average student achievement has declined. In 13 States, students are given freedom to choose half or more of the units required for high school graduation. Given such freedom to choose the substance of their education, many students select less demanding personal service courses, such as bachelor living" (Gardner et al., 1983: 19–20).

Under such conditions, College Board achievement scores in academic areas such as English and physics have declined in recent years. Nearly 40 percent of 17-year-olds cannot draw inferences from written material, only one-fifth can write a persuasive essay, and only one-third can solve a mathematics problem requiring several steps. Science achievement scores of U.S. 17-year-olds as measured by national assessments of science in 1969, 1973, and 1977 have declined steadily (Gardner et al., 1983).

The pattern of courses that high school students take and their low achievement are greatly influenced by college and university admissions requirements. Whatever the causes (e.g., the growing intensity of competition for a declining pool of students or other influences), these requirements in many cases are so low that students are not prepared for college work: One-quarter of the mathematics courses in collegiate institutions are remedial (Gardner et al., 1983:8). Nor are many high school graduates prepared for an occupation. Business and military leaders complain that without remedial work in reading, writing, spelling, and computation, many high school graduates cannot even begin the sophisticated training they need for their work.

Lack of Student Interest in Science and Mathematics

The list of reasons why so many students fail to master the skills they need for the study of science, mathematics, and other academic subjects grows with each analysis. The causes include lack of discipline in the classroom, overemphasis on socialization, automatic grade promo tion, teacher disillusionment, tolerance of absenteeism, emphasis on educational opportunity without equal attention to quality, grade inflation, lowering of college entrance requirements, unfavorable study environments in the home, lack of homework, loss of public confidence in and support for schools, and unclear educational goals and policies. For whatever sociological or educational reasons, too many students lose interest in learning and simply evade it.

U.S. students' dislike of science courses is acquired early—nearly half of them dislike science by the end of the third grade, and 79 percent by the eighth. The popularity of mathematics declines from a high of 48 percent in grade 3 to a low of 18 percent in grade 12. This loss of interest clearly affects the nation's pool of scientists and engineers, as shown, for example, in a study by Aldridge and Johnson (1984) that traces the loss of scientific talent from the 4,170,000 members in the freshman high school class of 1977–1978:302,400 of these students (7.3 percent) entered study of science and engineering (engineering—115,300) as college freshmen in 1981–1982; an estimated 83,100, or 2 percent of the original high school class, would graduate in those fields (32,300 in engineering). At the graduate level, an estimated 0.4 percent of the freshman high school class of 1977–1978 (16,680) would earn M.S. degrees, and 0.1 percent (4,170) would earn doctorates in science and engineering.

Of the total 71,470 engineering baccalaureates projected for 1985, 32,300 would be from the original pool of 1977–1978 high school freshmen. The remaining 39,170 would include approximately 13,000 foreign nationals and 26,000 other Americans who had been out of high school for more than four years. The latter group comprises mostly transfer students and students who had left and returned to engineering programs. Of 32,000 M.S. degrees projected to be earned in 1987 in all fields of engineering, science, and mathematics, nearly 17,000 will be awarded to U.S. students who graduated from high school in 1981; 6,000 will be awarded to foreign nationals; and 9,000, to other American students. Of the 7,700 Ph.D. degrees expected in these fields in 1989, 4,200 will go to students from the high school class of 1981; 2,300, to foreign nationals; and 1,200, to Americans who did not pursue engineering or scientific studies continuously after high school graduation.

One reason for the loss of such a high proportion of talent from the original high school pool is the inappropriateness of high school science and math courses for the 92.7 percent who will not become scientists or engineers. Current courses are often obsolete and of questionable value for the 7.3 percent who may do so, since these courses largely ignore the computer, modern electronics, and much of the new knowledge that has been generated so rapidly over the past 10 years. Present courses focus on pure science and are largely devoid of practical applications, technology, or the relevancy of science to society's problems, such as acid rain, nuclear wastes and disposal, or improper nutrition.

Diminished Incentives

Although only implicitly stated in the literature, another reason for diminished interest in education is that students lack incentives to learn. Few of them, including some of the most talented, discover the pleasure of learning for its own sake. In the past, incentives for American students included living up to parents' expectations, meeting teachers' expectations and receiving rewards for their efforts, and in some cases having the opportunity to attend college. Students now have little reason for developing the self-discipline to learn which the work ethic imbued in their Puritan or other immigrant forebears. The belief that education would guide their hard work to success was inculcated in their parents, and that same conviction is evident today in many of the Oriental engineering students whose families insist on education as the road to success in America.

Since incentives are not as strong as they once were, engineering societies and social agencies have attempted to provide them. The Junior Engineering Technical Society (JETS) sponsors clubs, national team competitions, science fairs, and precollege programs. Other incentives programs are usually offered in inner-city environments, where educational problems are acute. These model programs, which include Mathematics, Engineering, Science Achievement (MESA) in California; Philadelphia Regional Introduction for Minorities to Engineering (PRIME) in Philadelphia; and Massachusetts Pre-engineering Program for Minority Students (MassPep) in Boston, offer encouragement and guidance to students who are talented in mathematics and science and who want to enrich their schooling. Such programs were designed to bring into engineering those underrepresented minorities who accept the challenge to education. They demonstrate efforts that might be made or adapted in all schools and systems to inspire the scholarship that is needed.

MESA was one of the first model programs to state its goals, which included "Encouraging students from the target minority groups to acquire the academic skills they need to major in mathematics, engineering, and the physical sciences at a university; Promoting career awareness . . . and Striving to institutionalize the educational enrich ment activities that prepare minority group students. . . ." Its activities include tutoring; independent study groups; academic, university, and career counseling; and summer enrichment and employment. MESA offers scholarship incentive awards, and has high expectations in terms of student performance.

MassPep in Boston offers a Saturday Lab Program supported by scientists, weekly club meetings to discuss technical issues and projects, and has conducted a successful summer program. The organization is planning to hold monthly assemblies of students and teachers for lectures, contests, and exchange of information. Its computerized records track students' academic and personal progress for use in counseling. The students involved in the program know individuals who care about and encourage their progress.

Teacher Shortages

The studies of U.S. schools referred to at the beginning of this section agree that there are too few qualified teachers of science and mathematics. As indicated in *A Nation at Risk* (Gardner et al., 1983:22–23), too many teachers come from the lowest quarter of their classes. Since about 41 percent of the time of elementary school teacher candidates is spent in education courses, less time is available for subject matter courses. Moreover, in 1981, 43 of 45 states had shortages of mathematics teachers, 33 of these states reported critical shortages of earth science teachers, and all lacked physics teachers. Half of the newly employed mathematics, science, and English teachers are not qualified to teach these subjects. These shortages exist despite widespread publicity about an oversupply of teachers.

Many good students turn away from teaching because of the poor condition of the profession. The public is well aware of the problems of classroom management, including the burden of administrative as well as disciplinary duties. Furthermore, teachers lack control over such basic academic matters as curricular design and selection of textbooks (Sizer, 1984).* More personal detriments to undertaking a teaching career are the low pay and limited career line. If the low beginning salary and the national average salary of $17,000 per year after 12 years of teaching do not tempt math and science teachers to jump to industry, the limited career line often does. A teacher has roughly the same

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* The Sizer (1984) study examined high schools, but the statement applies to school systems as well as to individual schools.

responsibility at the end of a professional lifetime as he or she had on the first day of work.

Failure of Leadership

The failure of the teaching profession to attract its share of talented high school and college graduates results, as do many other problems that our schools face, from a lack of leadership at many levels. One analyst declares, "The United States lacks national goals, public policies, or an agenda to focus discussion and debate in the reconstruction of science and mathematics education. . . . If [a policy of high-level scientific, technological, and computer literacy for all citizens] is to be a goal of science and mathematics education at the pre-college level, parents, teachers, and school administrators must first recognize its significance" (Hurd, 1982:7).

Research studies on school effectiveness have found repeatedly that academically effective schools have clear goals related to student achievement and that the teachers and parents of students at such schools have high expectations (Purkey and Smith, 1982). However, the goals of high schools are numerous and seem to continue multiplying with little regard for the severe limits imposed by a lack of school staff, equipment, and time (Boyer, 1983).

To be effective, a school and the board that guides it must have a clear and vital mission. Educators and the public they serve need a shared vision of what they must accomplish together. Every school should establish clearly stated goals—purposes that are widely shared by teachers, students, administrators, and parents. The future development of our nation depends upon our agreement as to the mission and importance of our schools.

The Panel on Undergraduate Engineering Education recommends that, *to improve the qualifications of students intending to study engineering, the engineering schools and engineering professional societies actively encourage government and industry to join them in an effort to improve the mathematical, scientific, and technological content in America's school systems. This effort will require additional sources of talent and funds.*

THE INCREASING ROLE OF WOMEN IN ENGINEERING EDUCATION

Within just a few years, women have become a significant fraction of the undergraduate engineering population, and their numbers con tinue to increase. Female enrollments in engineering rose from about 1 percent of total enrollment in 1970 to about 16 percent in 1983. The increase is not uniform across schools: In 1982 the percentage of B.S. degrees awarded to women from the 50 institutions having the largest number of undergraduate engineering students ranged from a high of 29.5 percent (General Motors Institute) to a low of 8.9 percent (Iowa State University). The largest number of B.S. degrees awarded by one school to women in 1982 was 203 (15.6 percent) from Texas A&M University, which graduated the largest total engineering class that year. The numbers also vary across engineering fields: In 1982, 29 percent of industrial engineering students (the highest percentage) and 24.5 percent of computer engineering students were women, while 10 percent of mechanical engineering students (the lowest percentage) and 13 percent of civil engineering students were women. The retention rate of female students in undergraduate programs is similar to that of male students, about 70 percent.

Preparation for Engineering

The percentage of women in engineering programs appears to have no inherent limit. There are as many young women as men in high school who study mathematics and science through trigonometry and chemistry. However, almost twice as many young men as women take high school physics, calculus, and introductory computing (although undergraduates in the field of computer science are about 25 percent women, as indicated above).

Apparently an interest in physics is an important factor leading to a career in engineering; men are attracted to engineering mainly by taking high school physics, while women are attracted to engineering through chemistry and biology. High school women often feel tracked away from physics; very few physics teachers are women, and course content and quality are quite variable, often not appealing to women. Educational experiments indicate that nontraditional approaches to the teaching of both physics and introductory computer subjects in sex-balanced classes result in their increased appeal to women students. Both men and women are attracted by mathematics and problem solving in general, but women more so than men. Of all high school subjects, only mechanical drawing and physics attracted a greater percentage of undergraduate men than of undergraduate women into engineering.

Aptitudes

Several factors indicate that the increase of women in engineering may continue as barriers such as those discussed above are eliminated. In 1983, the mathematics SAT score of women intending to enter engineering was slightly higher than that of prospective male engineering students: 549 versus 540. These same women students scored considerably higher on both the verbal and analytical parts of the Graduate Record Examination (GRE)—492 versus 442 and 590 versus 522, respectively; on the quantitative portion of the GRE, they scored slightly lower: 653 versus 658. The scores show that as the pool of women with adequate preparation is enlarged, additional academically talented women are available for engineering.

In addition, the profession of engineering will grow in directions that will make it even more attractive to women: The importance of biology and chemistry in engineering will increase; and the nature of engineering work itself will change—the increased use and role of computers will attract more women into engineering, and the importance of communication and verbal skills continues to grow. Women will feel increasingly welcome in science and engineering (as this happens, more women can be expected to become teachers of high school physics and mathematics), and the image of successful women engineers will be more evident to young women.

Professional Acceptance

In the past, women have been virtually invisible within the engineering profession. The 1968 "Goals Study" of the American Society for Engineering Education (ASEE) made no mention of women students, faculty, or engineers: All high school statistics were about male graduates; all faculty and practicing engineers were described as male. In spite of calling for a substantial increase in enrollment of engineering students among the nation's graduating high school students, the possibility that some of this increase might include women students was not mentioned. For the most part, the profession was blind to the potential of women students. Various factors may have contributed to the change in women's participation in engineering. But whether it is due to universities' active recruitment of women into engineering during the dramatic decrease in engineering enrollments of the early 1970s, or to the rising aspirations of women for meaningful professional careers, their participation in the profession has changed.

Need for Support

The increased enrollment of women in engineering suggests that various factors—financial, societal, emotional, and environmental—influence women's choice of engineering. Women students have come into engineering because of potential job opportunities and recent assurances from both industry and universities that they will be treated fairly with respect to jobs and salaries. Most senior women engineers can recount personal sagas of unpleasantness and insensitivity toward women in the profession. However, recent changes have considerably improved the climate for women in engineering. Freed from these past burdens, women engineers have demonstrated that they can do the work and that engineering is an attractive career for women.

The increased number of women students has helped make engineering schools a more attractive environment for them. Despite recent improvements, however, women students still report feelings of isolation, lack of acceptance by faculty and male student peers, and lack of acceptance of their career goals by friends, family, and their universities. Many women students still find engineering schools to be stressful environments, and they need support to help them deal with the difficulties that they encounter. But they do not form a homogeneous group, and their needs vary. For example, some report significant problems in adjusting to a strongly male environment; some find a supportive environment in a particular department; and many find support in a confidant, sometimes a close male friend. Some of these are problems that will lessen over time as the number of both women students and women faculty increases.

Special Problems of Women Students

While increased use of foreign nationals as graduate teaching assistants and as faculty members is often cited as a problem because of language barriers, the practice also brings special problems for women students. Anecdotal evidence suggests that students and faculty from cultures in which the role of women is subservient may not be sensitive or sympathetic to the career aspirations of American women engineering students.

Minority women attempting to prepare for or to pursue undergraduate engineering education may have very special problems that are not shared by all members of their minority group or by majority women. For example, the situation of minority women today in high schools preparing for possible entry into careers in engineering is not encourag ing. The falloff of women as compared with that of men in high school physics and calculus increases the handicaps these young women face in inner-city schools. Separate data for women are not available, but they are not likely to be comforting.

It is also difficult to trace minority women in engineering because of a lack of data. The percentage of doctoral degrees in engineering awarded in 1981 to native-born minority women, including Asian women, was 0.19 percent. Not only are their numbers small, but the data for minority women are usually included in the total for minorities (and likewise are hidden in the data for women).

Incentives

According to available data, starting salaries for men and women in a given engineering specialty at the entry level are roughly equal, with women having a slight edge. Some data also indicate that after 10 years women in engineering have fallen behind men in salary and position. Since the number of women engineers in the work force is still quite small relative to the number of women engineering students currently in school, this trend, while worrisome, may change over time. Data also indicate that starting salaries for women with advanced degrees are less than those for comparably educated men. At the Ph.D. level women average only 80 percent of the starting salaries of men. While generalizations about progress at this advanced-degree level are difficult in the absence of correlations with professional experience, such differences do not seem to explain the 20 percent salary differential.

The Panel on Undergraduate Engineering Education recommends that, *to achieve the full potential that this human resource offers, colleges of engineering, school systems, government, industry, and the engineering profession continue to work to increase the number of qualified women who study for a career in engineering. A key requirement is the need to encourage the study of mathematics and science by female secondary school students.*

CO-OP EDUCATION

Although only 8.2 percent of engineering students participated in such programs during 1983, cooperative education would seem to be an attractive way to learn engineering, since it offers students an opportunity to learn while producing in a field that exists to serve the world's practical needs. (It is not surprising that engineering was the first field to try co-op education when that long tradition began in 1906.) The advantages of co-op education seem to benefit all parties: Students learn by doing and can help pay for their education while learning; companies gain highly motivated workers at lower cost without the usual, expensive search process; and engineering schools can increase their capacity. Strengths and weaknesses of co-op education more subtle and numerous than these obvious attributes are discussed below.

Co-op Students

While it would seem that students would enter co-op programs mainly to finance their education, all studies of co-op education show that this reason is not dominant and that it subsides once students have begun their schooling. Only those co-op students who depend heavily on financial aid (about one-third) continue to see income as an important reason for cooperative education. More than three-quarters of coop students mainly seek to acquire skills and experience to support their career objectives through these programs. On average, their academic performance is better than that of their non-co-op classmates, although no cause-and-effect relationship has been established. Experience in the workplace increases their awareness of career possibilities and gives them an opportunity to develop their skills, and often they find co-op placements that prepare them for specific occupations. Two-thirds of these students perceive co-op education as a way to find employment after graduation (Porter, n.d.).

The main benefit of such training is learning on-the-job skills. Co-op education nurtures personal characteristics, or affective skills, that come mainly from experience—positive attitudes, interests, values, needs, and motives. As shown in the ranked lists of goals below, these skills are interspersed among academic goals by students, faculty, and administrators, but they head the list for industry (co-op students and graduates and their industrial supervisors) (Smith et al., 1981):

Goals—Academe	Goals—Industry
1. Problem-solving skills	1. Practical judgment
2. Engineering judgment	2. Interpersonal competence
3. Communication skills	3. Oral communication
4. Engineering fundamentals	4. Managerial skills
5. Planning skills	5. Preciseness
6. Technical skills	6. Written communication

7. Interpersonal awareness methods	7. Understanding problem-solving
8. Professional ethics	8. Scientific-technical knowledge
9. Organizational skills	9. Persuasiveness
10. Self-confidence building	10. Creativity and originality
11. Creative expression	
12. Leadership skills	

Employers rate co-op students high on motivation and ability to work with other people and to follow instructions.

Co-op students find employment more readily than do non-co-op students, and nearly two-fifths of the former already know their employers from their co-op experience. They are more likely to find work that is directly related to their college major, and they progress more rapidly toward their career objectives. For the first three years of employment, their earnings are significantly greater than those of their non-co-op counterparts. They report greater job satisfaction than do non-co-ops, and they often have greater responsibility in their first jobs because they already know the work and how to work with fellow employees.

Employers

The employment of co-op students offers employers the opportunity to cut costs by filling regular jobs with preprofessionals. Employers can also save by identifying and recruiting some of these workers, whose abilities and performance they can predict more reliably from on-site observations than they could do through the usual search for prospective employees. While the cost of supervising these students is reported to be about 7 percent greater than that for supervising regular employees, a majority of employers find them more productive than their regular co-workers. Most employers report less time spent on evaluation of co-ops and a lower turnover rate among them.

More than half of co-op employers find students more able than regular employees to follow instructions and to work with other people. Nearly all employers report comparable or better customer relations when comparing the work of these students with that of regular workers. Co-op students represent a working basis for direct relationships of industry with regional educational institutions. Co-op education also provides industry with specific contacts and means for communicating regularly with academic institutions about changing personnel requirements.

Institutional Considerations

The integration of academic and career development offers academic institutions the opportunity to enhance their students' motivation. Not only do co-op students see the value of the knowledge gained from their studies, but they also stimulate classmates by sharing the experience gained from their field work. The experiences of students on the job also encourage faculty to keep the curriculum current by modifying course content and program options. Senior administrators see cooperative education as a means of attracting students as well as a way to support the placement of graduates.

Problems With Co-op Programs

Problems that students may find with co-op programs include the longer time to graduation, although program formats can be as short as four years or as long as five and one-half years. The national average for all engineering students is four and one-half years. (There are three coop program formats: (1) the traditional alternating format, in which students rotate between full-time campus study and full-time employment; (2) the parallel, or concurrent, plan, which splits the student's day into full-time campus study and part-time employment; and (3) the field program, in which all students leave campus at the same time and have only one work experience a year.) Another problem that students may have is finding co-op employment unrelated to their academic interests. And scheduling the co-op experience can also be a problem.

The problems related to co-op education for institutions result mainly from the differences between co-op and more traditional institutional programs. The philosophy of cooperative education is different from the classical view of education. The difference is highlighted by the need for institutional changes to accommodate co-op programs, e.g., modification of the calendar, special scheduling of courses, and possible curricular changes.

The most serious problem for all partners in cooperative education results from a depressed economy. Any doubts that employers may have about co-op make it an early candidate for cost cutting and termination. Since the time constant is so different between industry and academe—the fiscal year or "as of today" compared with the student's measure of the time to earn a degree—termination of a cooperative education program is one of the most vivid examples of where industry and academe diverge. Termination of a co-op program causes considerable stress on campus, not only for the students involved, but also because it disrupts faculty and administrative commitment to the programs and interferes with the tightly organized study and financial aid plans of students.

Conversely, when the economy is booming, industry is eager to attract co-op students, and the impression is created that industry wants "to fill a job" and is not really sensitive to the overall academic nature of the endeavor. The resulting cyclic "boom or bust" characteristic leads academicians to be wary, so they are reluctant to make a deep commitment of time to enhance co-op programs academically.

The requirement that co-op students be absent from the campus for substantial blocks of time detracts from their overall academic experience. They lose contact with classmates and campus life and cannot participate in certain extracurricular activities. For some students this is an important deterrent.

Possible Improvements

One or more of the parties involved in cooperative education could help to improve certain aspects of the system. Employers sometimes need to clarify co-op job responsibilities, and they need to work closely with faculty to develop supervision and training of students (Wilson and Weinstein, 1982:22). This relationship depends on frequent telephone contacts and occasional on-site visits.

Employers must commit themselves to sustained support of the coop program through good times and bad so as not to disrupt tight student scheduling and in order to encourage strong faculty commitment to the program.

Some engineering educators consider the true potential of co-op education to be as yet unrealized. If industry were to adopt a revised posture toward co-op education and commit itself to a 12-month-per-year shared responsibility for the education of the engineer, it could make a significant impact. Such a partnership could help provide the engineering practice component that has been steadily reduced in the curriculum during the last 25 years. Further, an integrated approach would bring an innovative and constructive dimension to the education of the engineer. The challenge remains unaddressed.

The Panel on Undergraduate Engineering Education recommends that, *to increase their effectiveness and enhance their role, co-op programs be strengthened and made more attractive to students. A considerably stronger commitment from industry is required to eliminate the "boom or bust" character of the programs that reflects a fluctuating economy. If industry adopted a revised posture toward co-op education* *and committed itself to a shared responsibility for the educational process, a very significant and innovative dimension could be added to the education of the engineer.*

FACTORS INFLUENCING GRADUATE STUDY

During their first two years of undergraduate study, the vast majority of students do not have any clear intention of pursuing graduate work. But, upon entering senior year, those with good to excellent academic records begin to think seriously about the trade-offs between industrial employment and graduate study. Many who choose industrial employment intend to pursue graduate study either while employed or at some later time.

Faculty Influence

Studies (e.g., Consortium on Financing Higher Education, 1983) show that parents and faculty members both exert strong influence in a student's decision to undertake graduate study. Faculty are intimately familiar with the performance and quality of their students. Generally, students in the top 10 percent of their class are urged to continue study toward a graduate degree, but those in the top one-third of their class are also considered suitable candidates. Thus, performance at the undergraduate level is the primary determinant of which students continue for graduate study.

Because of the strong faculty role in the decision process, the attitude of faculty members toward graduate study is extremely important. Faculty tend to presume that graduate study is preparation for an academic career, but it is now necessary preparation for many industrial careers as well. Faculty who view an academic career as exciting and meritorious transmit this perception to their students. On the other hand, their lack of enthusiasm for academic careers or their belief that the professoriat is disadvantaged compared with colleagues in industry will also be communicated and will discourage students from pursuing graduate work.

Stimulating Interest in Graduate Study

Faculty members can increase interest in graduate study by playing a more positive, active role in advising their students. They could do much more in this regard by involving undergraduate students in research projects and intermittent teaching opportunities. Recognition of achievement motivates further achievement.

In order to attack the faculty shortage problem by encouraging the best students to consider careers as engineering faculty members, the ASEE's Engineering Deans' Council has adopted the following policy statement:

> At least 1000 intelligent and highly motivated individuals with doctoral degrees in engineering will be needed every year as faculty members in institutions of higher learning in the United States. Charged with the critical responsibility of educating prospective engineers, these individuals must enjoy the challenges and satisfaction of teaching, the excitement of research at the very frontiers of knowledge and the freedom of self direction. The opportunities for a lifelong, productive, satisfying and rewarding career are unlimited.*

In addition, the Deans' Council has prepared an attractive brochure for use by faculty and students to encourage the best students to seek academic careers.

Financial Considerations

The main reason cited for the decision to forgo graduate study is the substantial difference between graduate stipends and industrial salaries. One 1980 survey found that the average annual, part-time salary of graduate assistants was $4,200, as compared with $24,000 reported for full-time, entry-level jobs of B.S. graduates at that time. Such a differential results in lost income that takes many years to recover. Consequently, graduate stipends need to be increased to at least half of the starting salaries of B.S. graduates. With regard to those who ultimately pursue an academic career, American Association of Engineering Societies (AAES) salary survey data ("Mean Salaries of Engineers in Industry and Academia: 1983") show that the salaries of full professors (on a 12-month basis) compare favorably with salaries of their counterparts in industry. With the possibility of additional earnings from summer work and consulting, an academic career is in a strong competitive position. Nevertheless, academic salaries for assistant and associate professors are a key problem and need to be improved in many institutions in order to be competitive.

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* Policy statement endorsed in January 1984 by the Executive Committee of the Engineering Deans' Council, American Society for Engineering Education.

The Consortium on Financing Higher Education has studied the question of whether undergraduate and/or graduate student loan debt accumulation is a disincentive to the pursuit of graduate education. Their most recent study (1983) shows that, except for its effect on some minority students, undergraduate educational loan debt burden has essentially no effect on the decision to pursue postbaccalaureate study.

The Panel on Undergraduate Engineering Education recommends that, *in addition to support for graduate education, engineering schools and professional societies create and maintain an active campaign to emphasize the advantages of an academic career. Industry, government, engineering schools, and professional societies must encourage and support master's-level programs, combined B.S.-M.S. programs, and release time to enlarge and develop the pool of potential faculty.*

THE ROLE OF MINORITIES: PRESENT AND FUTURE

The Minority Share in Engineering

The minority engineer is one of the scarcest professionals in American society. In 1970 blacks, Hispanics, and native Americans made up about 2.4 percent of the U.S. engineering work force; by 1982 that percentage had doubled. Percentages of the total U.S. population for these minorities were 16.1 percent in 1970 and 25.2 percent in 1980. At the opposite extreme are Asian/Pacific Islanders. The 1980 census showed this group made up 2.7 percent of the U.S. population, while their 1983 proportion of the U.S. engineering work force was 4.8 percent. Thus, Asian/Pacific Islanders' 9.2 percent of the intraminority population in 1980 provided 50.9 percent of the minority engineering presence in the work force in 1983. Comparable percentages (intraminority population/ engineering presence) for blacks, Hispanics, and native Americans were 50.5/20.4, 27.2/25.8, and 1.5/5.4, respectively. Table 1 shows that, overall, the potential talent for engineering within a substantial part of the population has remained dormant.

The statistics in Table 1 and those from other sources show progress, but not nearly enough. Clearly, except for Asian-Americans these particular minorities have not achieved representative participation in engineering. The profession will need talent from these minorities as well as from other sources to keep abreast of technological change as demographic trends and weak educational practices shrink the pool of talent. Finally, minority engineers can be an important American

TABLE 1 Minorities' Participation in Engineering

		Engineering Baccalaureates Awarded							
		In 1983		In 1973		1983 Engineering Doctorates		Practicing Engineers in 1983	
Minority	1980 Census Percentages	Number	%	Number	%	Number	%	Number	%
Black	14.1	1,862	2.6	657	1.5	19	0.6	35,400	1.8
Hispanic	7.6	1,383	2.6	566	1.3	41	1.4	44,100	2.3
American Indian	3.2	97	0.1	32	0.07	0	0.0	9,500	0.5
Totals[a]	24.9	3,342	5.3	1,255	2.9	60	2.0	89,000	4.6
Asian-American	2.7	3,098	4.3	684	1.6	173	5.7	92,400	4.8
Grand Totals	100.0	72,471	100.0	43,429	100.0	3,023	100.0	1,940,000	100.00

[a] These totals may include persons who could report as both black and Hispanic.

SOURCES: Richardson (1979), p. 13. Degree data are from the Engineering Manpower Commission; employment data are from the National Science Foundation.

resource for international relationships and Third World development; if well educated, they might become the most effective of our nation's representatives to the Third World.

Loss of Interest in Science and Math

The greatest barrier to increasing the pool of talent for engineering is students' loss of interest in science and mathematics at all stages in their education. As indicated earlier in this chapter, by grade 3, slightly more than half of all students show an interest in science, and 48 percent are interested in math. By grade 8, 21 percent like science, and by grade 12 only 18 percent like math. Furthermore, a national longitudinal study (Berryman, 1983:66, 68) of the high school class of 1972 showed that only 37 percent of the males and 30 percent of the females originally enrolled in a science field had obtained a B.A. degree in science or were enrolled in a science field by 1976.

The policy implications of such statistics as those cited above are (1) the need to develop strategies to increase the size of the initial scientific/mathematical pool of minorities before and during high school and (2) the need to decrease attrition from the pool at every stage of the educational process. While individual intellectual development cannot be programmed, schools can determine the amount of time that students spend on different subjects, the quality of their curricula, and the performance standards for grade promotion and high school graduation. In these areas of control, public elementary and secondary schools do not serve many children well in science and mathematics. The deficiencies matter most for those youth (i.e., females and minorities) who do not have compensating resources and encouragement outside of school.

Blacks are more likely than any other group to leave the educational pipeline, except between the baccalaureate and the master's degree. Hispanics drop out more frequently than do whites at each stage in the pipeline through college entry. This may result in part from their immigration from countries with different school systems or from family mobility. Their dropout rate is average or lower than average after college entry. American Indians have a very high dropout rate between entering college and earning the B.A. degree. These different patterns imply that the needs of subgroups vary at different points in the pipeline. The dropout rate for another minority group, Asian-Americans, is *lower* at each stage than that of any other group, including whites; the Asian-American share of the pool increases at each level.

Asian-Americans

Asian-Americans are the most inclined of any group to pursue quantitative studies:

> In 1979, a randomly selected Asian-American was 17 times more likely to earn a quantitative Ph.D. than a randomly selected black from the appropriate age group. . . . Asian-Americans chose [quantitative studies] at almost twice the [16%] national average; whites and Hispanics, at about the national average; American Indians, at about 80 percent of the national average; and blacks, at about 60 percent of the national average. [Berryman, 1983:49]
>
> Asian-American college freshmen are clearly high achievers from high achieving families. They have the highest percent of second generation college —a third, for example, have at least one parent with graduate education; the highest average high school performance (B +); and the highest average educational expectations—three-quarters plan a postgraduate degree. . . . Forty-eight percent attend universities, and of those 60 percent are in the most selective universities. Thus, almost a third of all Asian-Americans in postsecondary institutions are in the most selective universities, and another 13 percent are in the nation's most selective four year colleges. [Berryman, 1983:94–95]

Because of their achievement, Asian-Americans have a higher percentage of participation in engineering than any other group.

Barriers to Entry Into Engineering

With regard to quantitative study, the major barriers to non-Asian-Americans' entry into the engineering profession are insufficient preparation in mathematics and science, little awareness of and motivation toward engineering, lack of money, lack of self-confidence, and personal problems (Landis, 1982).

To overcome the lack of academic preparation, it is necessary "to *identify* promising students early in their academic careers, give them appropriate *guidance* in choosing a program of study, and ensure the availability of quality *curriculum* and *instruction*" (Richardson, 1979:7). The lack of a math sequence and of other precollege courses is "compounded for the inner city student by the familiar problems of inadequately informed teachers and guidance counselors, absence of role models, unengaging curriculum, and an atmosphere not particularly supportive of academic achievement" (Theodore Lobman, quoted in Richardson, 1979:7). Students need to perceive their educational experiences as coherent and continuous over many years to develop their academic aspirations and behavior.

To overcome the lack of information, engineering as a profession must be presented clearly to students and their parents. Minority individuals have generally tended to enter professions in which they work alone, such as medicine or law, or in which they work with other minorities, for example, teaching and social service. Prospective students and their parents need to be convinced of the marketability, the personal, human, social, and economic attractiveness of science and engineering careers. Knowing that financial aid is available for successful students is another strong motivator for families without adequate funds for education (Richardson, 1979:5).

Attrition is a greater problem for non-Asian-American minorities than for white students in college. Minorities need support systems: counseling, especially by minority faculty members; tutoring by faculty or students; short courses in specific techniques; study groups; videotaped instruction; and modules for self-paced study. They sometimes need to be given flexibility in their academic progress through "stretch-out" programs, reduced course loads, and leaves of absence, although, of course, they must ultimately be capable of meeting all of the kinds of demands that will be made of them and their fellow graduates as engineers (Richardson, 1979:11).

Institutional factors can also discourage minorities. For example, minority students may have great difficulty adjusting to the environment of a predominantly white institution. Elitist attitudes, poor teaching, and a general insensitivity to students affect the performance of *all* students but may have an especially negative effect on minority students. Many students, especially those who commute, find the institutional environment impersonal, and they often feel isolated and even alienated. Minority students can mistakenly attribute their sense of isolation and alienation to being in a minority, not realizing that other students experience similar feelings (Landis, 1982: 714, 718).

Minority students need a special kind of support to ease their transition from high school to college. The college environment is demanding, fast paced academically, less structured than high school, and socially permissive at the very time that studies require a new single-mindedness and intensity of purpose. Some colleges offer summer programs to introduce minority students to collegiate study of calculus, physics, chemistry, and the humanities.

Support of Minorities

More than one organization is focusing its efforts on the precollege level—junior and senior high school—to identify minority persons with the apparent aptitude to succeed in engineering. Minority Engineering Education Effort, Inc., provides the names of such students to colleges and universities. The National Society of Black Engineers invites students and their parents to a spring event to discuss engineering, co-op and summer job opportunities, and the educational demands of college.

Consortiums in densely populated areas use a wide variety of communication methods, including classroom demonstrations, career days, science fairs, and field trips to engineering schools and industrial sites. Minority engineers and minority engineering students who work with secondary school students act as role models by introducing the students to the field of engineering and the methods and products of technology (Richardson, 1979:6). The centers for these activities are often connected with a university (e.g., Mathematics, Engineering, Science Achievement (MESA) with the University of California at Berkeley and schools in other states, and METCON with Howard University in Washington, D.C.) as well as with staff and resources of local industries and government agencies. They offer Saturday morning and/or afterschool programs, laboratory study, weekly club meetings, monthly seminars of all participants, summer programs of study and summer employment, math and science contests, and scholarships.

At the collegiate level, the Minority Engineering Program (MEP) operates statewide from the same Berkeley center as MESA. It offers a full program of assistance with matriculation, academic counseling, particular emphasis on orientation and adjustment to the institutional environment, a concerted motivational program, the development of a supportive environment, a component for building study skills, a comprehensive and accessible tutoring program, close monitoring of student progress, personal counseling, a mechanism for social interaction, and career development. MEP builds a strong sense of belonging by arranging various exercises to help students get to know each other and through which they learn to value each other's help. Exercises are organized, for example, to develop study skills, to teach students how to use their time effectively, and to motivate them by study of career possibilities. Finally, MEP places students in summer jobs in which they gain first-hand knowledge about engineering and the environment that engineers work in, and also develop confidence that they can work in that environment (Landis, 1982:714, 715, 717).

Education of minorities is supported in part by efforts of the National Action Council for Minorities in Engineering (NACME), which enlists substantial funding from fewer than 50 companies. A survey of NACME scholars (LeBold et al., 1982) found that 96 percent of the graduates indicated that they were planning some type of postbaccalaureate graduate education. In order to retain more minorities in engineering, the graduates recommended more tutoring, financial aid, counseling and advising, and improved precollege preparation (Richardson, 1979:13).

Standards of Performance

Special attention for minority students is necessary to help them overcome barriers to the expression of their talent, but it must not mislead them about the professional demands they face. Lindon E. Saline, manager of the Professional Development Operation of General Electric, prepared a list of key conditions of employment for professionals from minority groups (Richardson, 1979:14, 15, 22):

1. Hire minority engineering graduates only if they are qualified for real tasks, not for purposes of show or tokenism.
2. Minority engineers, in accepting the opportunity to compete, should know their responsibilities and be measured and rewarded fairly.
3. Minority engineers must be expected to develop new technical, economic, and political knowledge to apply to evolving design, production, and application needs through new interpersonal and process skills.
4. Engineers must have the flexibility and resilience to cope with uncertainty and change in engineering employment.
5. All parties must have patience and persistence to see the minority engineering effort through to a successful conclusion.

And, finally, Saline states that we need a national initiative to

1. Establish long-range goals and objectives [for attracting minorities to engineering education and practice];
2. Accelerate expansion of the pool of prepared, motivated minority high school students;
3. Identify localities where programs are needed; develop strategies, both general and specific; and assign responsibilities;
4. Obtain adequate funding; and
5. Develop continuous monitoring of program progress and effectiveness.

The one-fourth of our population that now provides less than 6 percent of our engineers—namely, the black, Hispanic, and native American segments of the population—could significantly enlarge the pool of engineering talent. Of even more importance, such an increase would expand the portion of Americans who participate in their nation's most important source of power and individual well-being—its economic life.

The Panel on Undergraduate Engineering Education recommends that *extensive efforts by schools, companies, and engineering societies are needed to bring more minorities into engineering. For example, precollege programs such as those operating in a few major cities and regions of the country must be expanded and funded to prepare and motivate minority students to pursue college study and careers in engineering.*

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3

Faculty

STUDENT:FACULTY RATIOS

Between 1975 and 1981, undergraduate engineering enrollment in the United States increased by 60 percent, while the number of engineering faculty increased by only about 10 percent. Graduate enrollment dropped 10 percent because of declining numbers of American students. During those years, institutional support did not rise in proportion to the increase of the student:faculty ratios in engineering departments. Furthermore, many faculty positions went unfilled.

The high student:faculty ratios and the number of unfilled but authorized faculty positions have not been uniform in all engineering disciplines. The 1982–1983 surveys by the Accreditation Board for Engineering and Technology (ABET) show ratios as high as 25:1 to 30:1 in such fields as aeronautical, chemical, and electrical engineering, and 11:1 in agricultural engineering, with an average of 22.25 to 1 in all departments of member schools. This average ratio compares with an overall institutional average of 16.65 to 1 at the same locations at that time.

The percentage of vacant faculty positions has been highest in electrical engineering and computer science (EE/CSI). In the fall of 1982, a survey of engineering deans reported about 17 percent of EE/CS positions unfilled; in the other engineering disciplines, unfilled positions ranged from 6 percent to 9 percent of authorized positions. Not only are there unfilled positions, but the number of authorized positions is below the perceived need at many universities, which reflects financial constraints and an unwillingness or inability to reallocate resources.

It is not possible to establish a desired ratio of undergraduate students to faculty for all institutions because they vary widely in goals and purposes, range of activities expected of faculty, types of education offered, and size of graduate schools. For example, some large urban universities with relatively small full-time graduate schools have student:faculty ratios of 38 to 1; state-supported engineering schools, such as those at Purdue and Texas A&M universities, have ratios of about 24 to 1; private universities with large graduate schools, such as the Massachusetts Institute of Technology (MIT) and Stanford University, have ratios of 6 or 8 to 1. But all institutions, no matter what their base of support, have experienced increases in student: faculty ratios.

Consequences of High Student:Faculty Ratios

The increase in undergraduate enrollment coupled with the shortage of faculty has educational costs that extend throughout the system. Increased enrollment has meant that individual faculty members must teach substantially greater numbers of students. In many cases, it has meant larger class sizes with less personal attention available to students; canceled courses; the use of nonfaculty and adjunct faculty as classroom teachers; and crowded laboratories, with larger groups using the same limited equipment. The intellectual renewal that is required to keep courses and laboratories up to date and to develop new courses often has to be postponed, and textbooks organizing important recent advances have not been written.

Increased student:faculty ratios have also increased the amount of time needed by full-time faculty members to advise students. This is caused partly by the greater numbers of students they teach, but also partly by the use of adjunct faculty: while adjunct faculty are available to teach courses, they often are not available to answer student questions, and they usually play little or no role as academic advisers. In some cases, faculty are responsible for the academic, career, and personal advising of some 50 students. Because of the numerous duties of faculty, such a responsibility cannot be met with quality.

Faculty Activities

In addition to classroom teaching and student advising, engineering faculty have various other roles, most of which relate directly to maintaining their own long-term value as professional educators and to supporting the long-term effectiveness of engineering educational programs. In varying degrees depending on the type of institution to which they belong, faculty are responsible for the following activities: frontier research and technology transfer in their engineering disciplines; the education and research supervision of graduate students; interaction with industry in consultative and collegial relationships; performance of public service in the form of national, state, and local committees dealing with professional issues; review and editing of journal articles; review of research proposals and engineering projects of peers; development of new curricula and writing of textbooks; keeping up to date in related disciplines; exploration of new teaching and research areas; and raising funds to help support their own research and equipment needs as well as a portion of their salaries. When the immediate activities of classroom teaching and student advising monopolize the time of faculty members, neglect of these long-range activities erodes their professional base and that of the engineering system.

The pressures just discussed also reflect on the attractiveness of teaching as a career, and could deter from academic careers even the best of the graduate students who saw and suffered through such an environment as students.

A Role for Educational Technology

Clearly, new technology offers some promise (1) of making more efficient use of the human capital engaged in teaching engineering and (2) of improving the effectiveness of engineering courses. New uses of the computer in interactive teaching and the sharing of courses by video and satellite transmission promise to relieve engineering faculty from much routine classroom teaching. And yet this opportunity arises when the amount of faculty time to develop its use is severely limited and when young faculty who might be more receptive to and conversant with the new possibilities are in short supply. (See section below on "Educational Technology in Teaching.")

A Role for Accreditation

While the diversity of institutions precludes setting a single standard for the student:faculty ratio as an accreditation requirement, the Accreditation Board for Engineering and Technology might nevertheless gather information on student: faculty ratios; these data could be used with the other information that ABET analyzes to determine eligibility for continued accreditation of particular programs. The qual ity of departmental programs could be evaluated not only on the content of the courses and the current quality of faculty and facilities but on the access that students have to faculty and on the ability of the faculty to fulfill their long-term responsibilities for a strong program.

A related accreditation issue is the minimum number of faculty required for accreditation of a given engineering program. With the great demand for engineering programs, particularly in EE/CS, schools with very little background, depth, or previous experience in engineering education will find it attractive to offer such degrees. Whether or not a viable EE/CS program can be provided by three or four faculty members, and thus without access to a complete range of disciplinary offerings, is an important issue.

The Panel on Undergraduate Engineering Education recommends that *engineering schools not only examine and use strategies that will maintain quality under the pressure of the demand for quantity, but that they also plan for the long term to maintain elasticity in the system by encouraging flexibility in faculty and other educational resources*.

DIFFICULTIES IN MAINTAINING FACULTY VERSATILITY

Maintaining the versatility of engineering faculty is an important long-term problem for universities. Because student interests and industrial demands change, it is impractical for a university to add permanent staff to respond to periodic shifts in enrollment. Ideally, versatility within and among departmental faculties would allow institutions to respond to these shifts in a timely and creative manner. However, departmental boundaries within the university's organization are so confining that faculty find few opportunities to change fields. University departments see enrollment pressure as an opportunity to hire new faculty members, not to permit existing faculty members to shift fields.

Disciplinary Specialization

Although some disciplines experience sudden change, most engineering fields change more steadily and gradually. Significant shifts of educational content within most fields occur over a 5-to 10-year period. Faculty must meet the ongoing requirement of staying current in their respective fields through involvement in research and advanced study.

The abilities to advance to the research frontier and to make significant contributions there are the essence of the requirement for the award of the Ph.D. degree. It is expected that once this research process is learned during doctoral study, it will be repeated throughout the professional life of a faculty member. For this reason, the Ph.D. is almost a universal requirement for the permanent faculty member in engineering departments. However, this very process of continued research leads to a depth of specialization that inhibits versatility not only within individual fields but also among different engineering disciplines.

Lack of Support

It is assumed that versatility is achieved through the ongoing professional development of individual faculty members. However, few universities take specific steps to support this aspect of faculty and institutional development, which means that in addition to their heavy teaching and advising responsibilities, most engineering faculty are expected to take full responsibility for their own continued professional development. Not only are they expected to accomplish research and scholarly activity, but they are also expected to raise the funds for their activities and those of their graduate students, including funds for professional travel, equipment, and other research expenses. (See section below on "Faculty Development Programs.")

Departmental Boundaries

Faculty are locked in to a departmental structure which not only protects the special territory that the department has defined as its field but that also keeps its members from moving into areas across departmental lines. This self-imposed isolation is sometimes bemoaned, but it continues.

By the time a faculty member is awarded tenure and senior status, he or she has a considerable investment in a particular specialization in a particular department. The continual need for raising research funds depends on this investment and its accompanying reputation, but it makes major shifts of field difficult if not unwise. Minor shifts are possible, but a major change requires competing for limited research funds with already-established experts in a field. Thus, an individual may stay with a given line of research beyond the point of diminishing intellectual return.

Departments also have a considerable investment in the individual faculty member. There is little acceptance of professional peer relationships across departmental lines—of individuals who were not hired, promoted, tenured, and managed by a given department. Department heads may even discourage extradepartmental activities, and faculty who pursue such relationships are suspect and apt to suffer in terms of salary and access to university resources. The result is a system that promotes in-depth specialization and strongly discourages the generalist's approach to achieve versatility.

Since faculty versatility is an educational essential in rapidly changing areas of engineering, this problem must be addressed. To do so requires strong leadership. Individual deans will have to induce their departmental faculties to develop academic and personnel policies that support interconnections within and beyond the traditional engineering fields. During its visits to engineering schools, ABET might also raise the question of what is being done to prepare for the promise of the future.

The Panel on Undergraduate Engineering Education recommends that, *since the ability of engineering education to adapt to change depends on encouragement and toleration of curricular and faculty flexibility, shared teaching across departmental boundaries should be encouraged. The need for educational experimentation must be recognized and given institutional support. ABET could play a supportive role in such developments.*

OBSOLESCENCE AMONG FACULTY MEMBERS

Short-term considerations in engineering education override long-term concerns. The heavy work loads associated with increased undergraduate enrollment, while manageable in a crisis mode year by year, have created conditions that can easily lead to obsolescence among faculty members. As noted earlier in this chapter, the daily need to meet large classes and to see large numbers of individual students displaces research activities and professional development.

Changing Fashions

One of the responsibilities of the faculty is to advance scholarship in their disciplines. To be successful in this endeavor requires that faculty be excellent in their specialties, which has the effect of concentrating the research focus of engineering faculty. However, as shifts in research support occur, some areas fall out of fashion. For a school to respond to the new challenges that continually arise requires a healthy institutional presence in a wide variety of disciplines. Thus, faculty who have maintained quality research programs through difficult times provide considerable strength to their institutions as new demands arise. Therefore, the distinction needs to be made between faculty obsolescence and changes in outside funding or fashion. University administrators must avoid declaring faculty obsolete when they are unable to maintain the expected amount of outside funds.

Avoiding Obsolescence

One response of faculty who find themselves "out of fashion" is to move into related fields. Some do this with considerable success, in both a personal and an institutional sense. As mentioned previously, however, departmental protection of territory discourages such efforts to maintain vitality.

Another response by faculty to being "out of fashion" is to attempt to move into interdisciplinary areas. Unfortunately there are few opportunities for interdisciplinary research in the university environment. In addition to the inherent difficulties of organizing such research, federal mission agencies which occasionally support these efforts are also quick to discontinue them on relatively short notice, creating difficult situations for the faculty and students who are engaged in such ventures.

There are no simple answers to the questions of how to avoid obsolescence or how to utilize faculty better. The pressure of tenure and the strictures of departmental boundaries coupled with the demands of professional specialization all work against the movement of faculty into areas where there are high student: faculty ratios. In departments that have particularly high student:faculty ratios, team teaching by departmental faculty and engineering faculty from outside those departments could both alleviate the high ratios and help transfer some of the emerging technologies to less crowded departments. But as long as departments can translate increased enrollments into pressure for hiring new faculty, high student:faculty ratios will be seen as valuable currency not willingly shared with departments whose faculty are underutilized. Healthier institutions will result, however, if emerging areas of high interest are dispersed among several university departments through shared teaching and project work. Curricula will become more relevant to today's students in all departments if faculty share some of the increased student numbers. Although administrators have not introduced incentives to facilitate such sharing, they should do so in order to create a measure of flexibility in the system and to reduce the financial burden of underutilized disciplines.

FACULTY DEVELOPMENT PROGRAMS

Few universities have specific faculty development programs. The assumption is that individual initiatives for professional development together with access to the research and course offerings at the university will enable faculty to lead, or at least to be current, in their fields. For some institutions, this may be a valid assumption. If a university has vital ongoing research programs and strong graduate courses in most of the important and emerging fields and if the faculty have the time and the opportunity to include these activities as part of their normal work load, then they should be able to remain current as educators and as researchers.

Institutional Commitment

Few universities meet the requirements noted above. High student: faculty ratios and greater difficulty in raising support for program development and research leave little release time for continuing faculty development. Patterns of research funding suggest that in the future only a few universities will have an on-campus environment in which there can be faculty development through access to the latest equipment and strong research programs and with the assistance of direct administrative support.

All universities will need to provide more formal mechanisms to ensure both the continued development of their faculties and the vitality of their educational programs. Such support would include the following activities: travel to other universities for cooperative research, short courses, and sabbaticals; periods of residence in industry and government laboratories where there are equipment and expertise not found in the universities; release time on campus for course and laboratory development, taking courses, and internal educational fellowships; and team teaching in emerging areas by combinations of specialists and experienced faculty. While recognizing the problem, rather than initiating such formal mechanisms most universities have hoped that it would be solved through individual faculty and departmental initiatives without the universities' payment of the costs.

Attractiveness of Academe

Potential faculty members should find out what mechanisms a university has to help them continue their professional development. Many industries recognize the wisdom of using available human resources more efficiently and of providing specific programs for professional development; potential professional employees expect these things. If universities are to compete successfully with industry in their effort to obtain new faculty, they need to recognize the developmental needs of their teachers and researchers —they need to protect their investment as jealously as industry does.

A Role for Accreditation

The Accreditation Board for Engineering and Technology could play a helpful role in the area of faculty development. Recognizing that the continued vitality of undergraduate engineering programs requires a more formal approach to continued professional development of engineering faculty, ABET might gather data on existing mechanisms for professional development, on how many faculty are involved in these programs each year, and on what professional activities are supported. This information, together with other data gathered, could contribute to improving the quality of current undergraduate programs and their future vitality.

The Panel on Undergraduate Engineering Education recommends that *engineering schools create specific faculty development programs with shared institutional, industrial, and governmental funding*.

Special Problems

Even those institutions with organized faculty development programs face special problems. First, emerging areas in engineering education and research require large amounts of equipment and sufficient numbers of faculty in various specialties to work as a team. Second, increased competition for decreased federal funding has further concentrated research facilities and expertise in a smaller number of institutions (see Chapter 6 in this report). New patterns of research and education will be required to make this environment more available to the entire engineering education community; appropriate mechanisms would include summer programs, cooperative use of courses developed to utilize advances in educational technology, university research consortia, students' residence on such campuses for part of their research program, and visiting professorships.

USE OF PART-TIME OR ADJUNCT FACULTY

The use of part-time or adjunct faculty is a frequent practice in higher education. The four primary uses of these faculty are (1) to substitute for faculty who are on a special assignment or on sabbatical leave, (2) to staff recitation sections in courses with large enrollments, (3) to teach selected courses where special expertise is required, and (4) to teach regular courses when a faculty shortage exists. The last two categories are particularly pertinent to this study on engineering education.

Current Practice

Part-time and adjunct faculty have been widely used during the recent period of faculty shortages. While their use is limited by geographical considerations, a sufficient pool exists near many engineering colleges. When chosen carefully and properly monitored, adjunct faculty have been very effective at both the undergraduate and graduate levels. They represent the first line of defense in periods of overenrollment and/or faculty shortage.

At the undergraduate level there are some inherent disadvantages in using part-time or adjunct faculty. Often they are neither available nor sufficiently informed to advise students properly on curricular matters. Also, they usually do not participate in either the academic life of an institution (departmental) meetings, for example) or in its governance (committee assignments). Another frequent observation is that such faculty underestimate the extent of the work load and of the commitment that is required.

In spite of the disadvantages, these faculty can play an important role, especially at the upper-class undergraduate and graduate levels. Some practicing professionals are well qualified to provide the design and experiential imperative in engineering education. In fact, in some countries and on many U.S. campuses there is a conscious effort to use adjunct faculty on a continuing basis because they are thought to be better qualified to teach in areas in which current practice is important.

Professors of Professional Practice

As a result of curricular trends of the past 25 years, the strong tendency to emphasize the theoretical has resulted in the deemphasis of things practical. One could almost state it as a theorem: The pure drives out the applied. This trend prompted the move to restore the role of design in engineering education and to make it an explicit requirement for ABET accreditation. However, there has not been a strong complementary move to include this academic component through the conscious and continuing use of practicing professionals as adjunct faculty.

An opportunity exists to achieve an important educational goal through the structured use of practicing engineers in the educational process. To achieve the desired level of involvement and recognition, such adjunct appointments could be made with the title Professor of Professional Practice. If this opportunity was pursued in a conscious manner, a cadre of such professionals could have significant impact on engineering education.

The Panel on Undergraduate Engineering Education recommends that *colleges of engineering identify and utilize faculty other than those in tenure tracks—military retirees, persons reentering or shifting careers, adjunct faculty, and other professionally qualified persons, with or without Ph.D.s, who welcome short-term contracts or second careers.*

Colleges of engineering and professional societies should promote the use of Professors of Professional Practice. Such appointments could be either as adjunct faculty or, preferably, as full-time resident faculty for specific periods of time. The cooperation and support of industry in providing loaned staff are essential to achieving the educational goal of greater emphasis on practical aspects of engineering. The use in industry of regular faculty on complementary leaves would also support this goal.

OVERENROLLMENTS IN ELECTRICAL AND COMPUTER ENGINEERING

About five years ago enrollments in electrical and computer engineering programs began to rise markedly. The students in these two disciplines now comprise 40 to 50 percent of the student population in some engineering schools. Although part of this surge has been in response to a strong demand (jobs), it results mainly from the perception that successive revolutions in communications and circuit technology, combined and integrated with computers, are creating a new technological age. Many engineering educators believe that a structural change in engineering education is indeed occurring. During this transitional period the profession must recognize the need for change and respond accordingly.

The result of the recent increase in enrollments is appreciable overenrollment in electrical and computer engineering programs. These academic areas have the most severe faculty shortages. Courses are oversubscribed. Laboratory facilities and staff are overextended, and building and classroom space is inadequate. In response, schools have applied a patchwork of corrective action. Part-time instructors and even undergraduate students have been utilized to teach courses. Caps have been put on course enrollments, or extra sections have been sand wiched in. Laboratories are pressed into use evenings and Saturdays, and laboratory setups are added. However, because of the inherent time constants of higher education, institutions have been unable to respond adequately and to reallocate resources. Quality has suffered. The strains have become so acute that many schools are either taking or seriously contemplating defensive actions.

Alternatives to Overenrollment

Although there have been other periods of overenrollment in engineering education, their duration was relatively brief and their extent limited. Not since World War II has the dislocation been so severe. This structural change is a new phenomenon, one that engineering institutions are ill-prepared to face.

An obvious alternative to overenrollment is somehow to restrict the number of students permitted in these disciplines. If this is done at the time of matriculation, however, students must elect their engineering major while they are high school seniors. Moreover, experience shows that, with free choice, at least half of the members of the freshman class change their intended major subject. Such restriction imposes the added educational disadvantage of prematurely narrowing the scope of engineering education. For several decades there has been a strong movement to keep curricula as broad as possible for as long as possible—even to the end of the sophomore year.

Enrollments could also be restricted by establishing a performance threshold for entry into electrical or computer engineering. This would normally be done at the beginning of or during the sophomore year; a test or course grade would determine eligibility. This has the disadvantage of separating students by achievement and thus of creating at least two classes of students. One can further envisage the difficulty in deciding between a B + or an A-student, not to mention that perhaps space would be available only for A students anyway. Nor can such separation reconcile the disappointment and frustration of the excluded student who, regardless of indices, *wants* electrical or computer engineering. Faculty committees are often frozen by indecision when required to choose between such unattractive alternatives. They suspect that there is an inadequate base of knowledge upon which to make such judgments about the lives of others. Performance criteria are not all that trustworthy, nor are the roles of motivation or ultimate career success that well understood.

Nevertheless, assuming that the change is indeed structural and that institutions cannot in a short time period add sufficient new resources to eliminate the problem, some difficult decisions will have to be made. Although different schools will respond in different ways, combinations of the policies and procedures outlined below are likely to be implemented.

1. Give explicit preference in other fields to those applicants who declare that they will not study electrical or computer engineering.
2. At the time of acceptance, commit 40 percent or so of the available slots to those desiring the two preferred disciplines. Simultaneously, introduce performance criteria necessary to maintain one's place in the preferred categories during the freshman year.
3. Based on course performance in the freshman year, make up the remaining 60 percent portion of the class in the two preferred disciplines. Introduce performance criteria during the sophomore year to maintain one's place in the preferred categories.
4. During the summer of the sophomore year, give courses required only for those who previously have been denied entrance but who could now be admitted as a result of openings created by those not continuing in the two preferred disciplines.
5. Severely restrict the entry of transfer students to the two preferred disciplines.
6. Because new electrical and computer technology is strongly influencing all sectors, move portions of the subject matter to other "nearby" disciplines. The most likely candidate is electromechanical engineering. In fact, there is already an unmistakable electromechanical trend in mechanical engineering. If pursued in an explicit and attractive fashion, this would meet the needs of many students.
7. By forceful and continued administrative action, resources could be reallocated to the two favored disciplines in the structural change. At the same time, care must be exercised not to deprive other disciplines if these two cease to be favored by supply and demand.

While none of these alternatives is especially appealing, a combination of them would effect an element of control while maintaining a measure of administrative flexibility. Though our knowledge of students' disciplinary preferences and our understanding of criteria for selection of the best candidates is incomplete, the problem of overenrollment must be dealt with aggressively while it continues to be studied.

THE ROLE OF WOMEN AND MINORITIES

Minority and women engineering faculty have an important contribution to make to the solution of the current faculty shortage, to the environment for minority students who are U.S. citizens and for women students, and to the environment for majority male faculty and students. Yet the number of minorities and women on engineering faculties is very small—sometimes only one or two in a school. National Science Foundation (1982:71) statistics show the surprisingly small participation of women faculty in schools of engineering in 1981:

	Men		Women		
	%	Number	Number	%	Women: % of Total
Professors	55.1	7,183	29	19.7	0.4
Associate Professors	27.9	3,644	40	27.2	1.1
Assistant Professors	14.3	1,864	76	51.7	3.9
Other	2.7	352	2	1.4	0.6
Total	100.0	13,043	147	100.0	6.0

In 1982, 4.4 percent of the Ph.D. degrees in engineering, or 126 degrees, went to women. Of the 2,887 engineering doctoral degrees awarded in 1982, 11 (0.4 percent) went to blacks, 26 (0.9 percent) to Hispanics, 2 (0.1 percent) to American Indians, and 124 (4.3 percent) to Asian-Pacific minorities. Engineering faculties also include those whose Ph.D. is in science, so that the pool of potential faculty is somewhat larger than the pool of new engineering Ph.D. recipients.

The small number of minority and women faculty in engineering schools is due in part to their historically small number available for faculty positions and in part to the relative invisibility of professionals in these groups. If they are to become members of university faculties, active efforts to search out women and minorities for faculty positions are required. Aggressive recruitment by universities to capture a substantial share of the 126 new women Ph.D.s in 1982, for example, might have provided a noticeable increase in the percentage of women faculty.

In addition, neither women nor minorities fit the preconceived image of a potential engineering faculty member for a department expanding its staff. They are often invisible as potential candidates for such faculty positions.

In the case of women, current data show that female graduate students are less likely to have research assistantships in engineering and are more likely to pay their own tuition. Thus, some women graduate students may not be receiving the kind of financial and intellectual support that is required for access to and success in a faculty position.

Such causes affect the role of women in engineering education, especially their role as models for female engineering students: It is unlikely that the 147 women faculty among the 13,043 men that made up the nation's total engineering faculty in 1981 can begin to play the needed role for more than 55,000 women undergraduates in engineering.

Experiences in the University Environment

Once hired, minority and women faculty may find difficulty in achieving their professional goals in the university environment. Engineering research is often done in teams. Without strong university support, women and minorities may simply be left out when faculty join together on research proposals—it is no one's responsibility to see that they are included. Senior faculty often take responsibility for helping junior faculty form ties with the outside world for research support or to protect their time so that they can concentrate on research. They may be less inclined to provide this support and protection for women and minority faculty.

In the competition for internal funds, space, and work load, women and minorities may be at a significant disadvantage. A typical incident concerned a junior female faculty member who was constantly asked by senior faculty to teach their classes when they left the campus to consult. She felt that she could not refuse and was left with a significant teaching overload. How will these same colleagues vote when she comes up for tenure?

Because of their special status, women and minority faculty are often overloaded with committee assignments: They serve on departmental committees, university committees, search committees, personnel committees, thesis committees, outside committees, professional society committees, and so on. Department heads often do not give adequate career counseling with regard to the priorities in accepting or declining committee assignments. Also, women and minority faculty often feel a strong responsibility to represent their group on all committees. In a university with few women and minority faculty, they are often burdened with excessive committee assignments.

A Special Resource

Despite these difficulties, it is important that universities succeed in bringing women and minorities into full participation on university faculties. There is no substitute for women and minorities in the classroom as role models and mentors for women and minority students. An often-overlooked but equally important function is their leadership role for white male students. How can majority male faculty be expected to give adequate support to the aspirations of women and minority students without the experience of working in peer relationships with women and minority faculty? If today's undergraduate women and minority students are to achieve supervisory and senior management positions in industry and senior faculty positions in universities, then a significant number of today's majority students must become accustomed to minorities and women in leadership roles in engineering, in this case as professors.

EDUCATIONAL TECHNOLOGY IN TEACHING

The enormous influence of technology on our society will have "little or no effect in the near term on education unless educators do much more than they are now doing to adapt and exploit technology." Some compare the unresponsiveness of our present educational system to that of smokestack industries. The hope is that "the needs of education for information technology are so strong that [it] will ultimately be adopted" (Deringer and Molnar, 1979:iii).

Present Barriers to Adoption

The present barriers to the adoption of technology in education are social, economic, educational, and, understandably, personal. Educators find it almost impossible to adopt information technology that is not compatible with existing educational systems. The large initial investment in hardware, software, and courseware, for instance, is recoverable only through widespread utilization of the result. Schools, on the other hand, are small, decentralized, diverse, and independent organizations accustomed to "cottage industry" production and development methods. They do not buy complete instructional systems: they hire faculty. Further, faculty feel threatened by labor-saving instructional systems.

Faculty need rewards and assistance to develop educational technology (E-T). They respond to bonuses and other incentives to attract and retain qualified personnel. Faculty who have aptitudes in needed disciplines need assistance in making midcareer changes to help enhance their productivity and quality.*

Finally, lukewarm interest in educational technology results in a

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* Much information in this paragraph and the rest of this section is from Baldwin and Down (1981), which concentrates on instructional television.

lack of coordination of resources despite great effort to provide such coordination. Well-documented courses covering standard material are not generally exchanged among universities despite the existence of the Association for Media-Based Continuing Education for Engineers (AMCEE), which produces a catalog of more than 500 courses. The professional prerogative of designing one's own course materials handicaps these legitimate opportunities to increase productivity while maintaining quality.

Instructional Goals

The most common instructional goals for educational technology in engineering are

1. To enrich, improve, and individualize instruction
2. To reduce or contain costs (of teachers and/or administrators)
3. To serve the unserved or enlarge coverage

To reach these goals, a systems approach to E-T is needed—educators must know the institutional or programmatic goals, adapt appropriate technologies to them, and be able to measure their accomplishment through E-T.

Theory of Educational Technology in Teaching

The first teaching machines were based on B. F. Skinner' principles:

1. Reinforce the student's responses frequently and immediately.
2. Give the student control of the learning rate.
3. Make the student follow a coherent, controlled sequence.
4. Require participation through responses.

When self-paced instruction (e.g., the Personalized System of Instruction (PSI), "the Keller Plan") is mediated by instructional television (ITV) or any other E-T, it should include the following components:

1. Self-pacing by ability and demands on the student's time
2. Unit perfection required to advance to the next unit
3. Motivational rather than simply informational lectures and demonstrations
4. Stress on written word and teacher-student communication
5. Use of proctors for repeated testing, immediate scoring (feedback), tutoring, and personal-social dimension

Simplicity and active participation are essential to the effectiveness of educational technology.

Delivery Systems

The first modern educational technology, though now little used despite its proven effectiveness, was radio. Other audio transmission systems are recordings (records and tapes) and telephone. Telephone lines can also be used for document and video transmissions. Delivery was a problem in the older ITV systems—tapes, examinations, and papers required transportation. Now courses can be sent over any distance and used throughout any area if a large, aggregated audience can justify the expense of using a satellite. Subcarriers of the signal can deliver examinations. Even the problem of aggregating a large audience can be solved by taping the signal at each receiving location for later broadcast.

The Appalachian Community Service Network uses satellite transmission to offer college courses and adult education in more than 2.5 million homes. AMCEE can distribute videotaped courses to engineers throughout the nation. The Public Broadcasting System uses lower power signals received by special antennas for its National Narrowcast Service to carry a wide variety of both postsecondary and precollege programs (Grayson, 1982:24–25). The National Technological University published its first bulletin for the 1984–1985 academic year. It included 100 master's-level courses, of which 24 were listed in its class schedule for fall 1984. They were scheduled to be offered at 7 of the 15 institutions (including the University of Alaska) that indicated the intention of cooperating in the venture (Baldwin, 1984).

Costs of Instructional Systems

The costs of video and computer-based instructional systems can be great, but so can the savings in time and the effectiveness for learning. Costs for live production increase greatly when a lecture, demonstration, or course is produced for repeated use—the time required can be multiplied by as much as 100, or by even more for the commercial quality required for nationally broadcast programs (Grayson, 1983). However, the economies of scale are likewise multiplied. In 1980 about 500 colleges and universities enrolled 20,000 students in courses that were based on the viewing of such programs as *The Ascent of Man* and supported by additional course materials (Licklider, 1979:4–5).

The costs of computer-assisted instruction (CAI) can be even greater than those of instructional television, although with CAI the investment is in professional time rather than in hardware and visual resources; most producers will not make the effort required. It takes 100 to 1,000 hours of development time to create one hour of high-quality CAI tutorial materials, and techniques have not been discovered to reduce the creation time significantly while maintaining high quality. And in cases of rapidly changing subject matter, massive revisions can keep costs high. However, in most cases programs can be upgraded progressively, year after year, without attenuation due to forgetting. And the very best programs—unlike the best human teachers—can be replicated inexpensively and distributed widely.

Uses of Video-Based E-T

While the applications of instructional television are as varied as human ingenuity permits, the basic applications parallel instructional activities: lectures, demonstrations, laboratory work, tutoring, reviewing, off-campus teaching, presentations and critiques, and job placement interviews and career guidance.

The only difference in the effectiveness of instructional television from that of live lectures and presentations is flexibility of viewing (time, place, and numbers of viewers). While this flexibility allows students to review lectures or to view some for the first time, students sometimes stop viewing the lectures after the novelty of ITV wears off. The attitude of undergraduates is frequently unenthusiastic even though learning has been proved to be unimpaired, and is sometimes even enhanced by outstanding instruction, when material is presented on television.

Classroom demonstrations are possible through ITV during lectures and recitations. In large lecture rooms, oversized screens are mounted on either side of the hall for close-up viewing by all students. In laboratory courses, ITV allows close viewing of microscopic experiments and simulations of experiments, machinery, and processes that cannot be duplicated on campus. A special, related technique is the "electronic blackboard" (see Gupta, 19811), which is a method of sending television images to remote classrooms that are wired for two-way discussions between students and instructors. The advantages are participation in many locations; taping and reuse of discussions; and, after the capital outlay, cost savings. It is difficult for instructors to relate to remote students, but this can be done to some extent via the electronic blackboard since instructors can speak directly with students. Electronic blackboards also incur additional costs—for delivery of homework and exams, counseling, and administrative coordination; in addition, each link in the network costs $30,000 per year to operate.

ITV offers a convenient way to present off-campus graduate and continuing education at the work site and at other locations. Junior colleges that have agreements to articulate their programs with senior colleges might begin to offer the senior college courses to students who are still on the junior college campuses. High schools in remote areas can receive precollege math and science from ITV. Off-campus uses of E-T offer some of the best opportunities for innovation, since these sites are so new and are rarely under the direct control of the institution's regular system of governance. The cardinal rule for this kind of arrangement is "Pay as you go"—i.e., maintain self-sufficiency so that the use of E-T for off-campus purposes does not face the same financial constraints it faces in other academic programs (Baldwin and Down, 1981:32, 41, 73).

Review of lectures and other course work with a tutor through the use of ITV during recitation or in small tutoring sessions (as is required in PSI) is an improvement over the discussion of a lecture that must be recalled from memory.

Project presentations can be videotaped for the student to review with an evaluator. The same sort of technique is useful in practicing for or in actually doing interviews during career placement to help graduates polish their job-searching techniques. Videotapes of interviews with leading engineers and other key people (e.g., employers, students, guidance counselors) and documentary information about the profession can also encourage students to investigate careers in engineering.

Audio-Based E-T

Audiocassettes have prompted the eerie image of a classroom with a cassette player on the teacher's desk facing a room full of corresponding cassette recorders, but the idea also suggests that students and teachers alike are at home with at least one medium of educational technology. The taping of speeches and musical events is commonplace. The use of cassettes appears to be limited only by the limits of ingenuity. Some faculty, for instance, require a blank audiocassette with each laboratory or other report. The instructor uses the cassette to record comments, which are keyed on the student's written report by red-penciled numbers and underlined passages. Voice tone adds a personal dimension to the tutoring. More important, the relative speed of speaking versus writing makes the task less time-consuming and more complete.

Computer-Based E-T

In the 18 months preceding May 1982, the number of computers available for instruction in elementary and secondary schools increased by one-third, to 97,000. Market surveys indicate that the number will increase by over 300 percent by 1985. Manufacturers are now offering large discounts on personal computers to universities that are committed to using them extensively and/or are undertaking major experiments in the application of computers to education and related endeavors. Apple Computer has established the "Macintosh Consortium," with discounts of 60 percent to 24 institutions. IBM and Digital Equipment Corporation alone and together are supplying, and sometimes working with, groups of universities and individual institutions on special projects.

Barriers to Computer Use

In spite of the developments referred to above, wide use of computers lags behind its potential because most faculty have yet to master computer use and not enough of them are involved in development of software. Software development requires large expenditures of money and faculty time, and dissemination of hardware is limited. To overcome such barriers, CONDUIT, a nonprofit university consortium, has established a national clearinghouse for microcomputer-based instructional materials to collect and evaluate instructional programs and to disseminate information about them (Grayson, 1982:15).

Potential for Learning

A 1980 review of 59 studies of computer-based collegiate education showed that the computer made a small but significant contribution to the effectiveness of teaching students at all aptitude levels, raising scores on examinations by about one-quarter of a standard deviation (Grayson, 1983:364). Whether or not computer-assisted instruction is significantly better than other teaching techniques, its main value is for individualized learning. Computers can focus the student's attention on central problems rather than on routine calculations: For example, in a word processing mode the emphasis is on composition and revision rather than on routine correction and retyping.

Computers foster the discovery and organization of ideas. Computer languages give students new approaches to thinking, new ways of dealing with information and knowledge. Their requirement of specificity forces concreteness on otherwise vague or abstract ideas. Computer modeling permits students to concentrate on the individual parts of a complex concept and then to put the parts together without losing track of any of the parts. Beyond these immediate advances is a longer-term development—that of human adaptation to some of the complex information structures and formal languages that are "natural" to the computer. Heretofore, natural languages have dominated human efforts to preserve and transfer knowledge and have been challenged only on narrow fronts—by the languages or symbolism of mathematics and the special terminology of scientific or technical fields. But the computer appears to be introducing powerful new ways of representing ideas and relationships among ideas; these new representations may someday be as significant to education as the computer itself (Licklider, 1979:6).

Educational Uses of Computers

Among the simplest and most time-saving uses of the computer in teaching and learning are drill and practice in certain types of skills, particularly in mathematics. Fully computerized instruction has been used successfully in such courses as accounting, calculus, and computer programming, and its use will increase, at least in appropriate subject areas. As it does, it will become more and more possible to offer student-managed home study (Licklider, 1979: 7).

Another important use of computers in education is that of accessing not only the catalog of the local library but also, through international computer networks and the interlibrary loan system, many of the holdings represented by the collective catalogs of most of the world's major libraries. The greatest problem with this use of computers is the cost to libraries; without sufficient support from public and private agencies, the user will have to pay for such service (Rosenberg, 1983).

Computers can also store data and documentary information as a base for case studies, which helps the student practice investigation and analysis and find the best solutions to real-life problems. Furthermore, interactive computers can allow an instructor's intervention to influence the unfolding of such "real-life" situations—gaming.

Another flexible use of CAI that is especially important for the education of engineers is interactive graphics for computer-aided design/computer-aided manufacturing (CAD/CAM) design applications. Interactive graphics offers pedagogical and industrial advantages that are particularly helpful to human intervention in complex designs. Not only is interactive graphics useful for practice in analysis and synthesis, but it also helps develop intuitive and visualization skills; and it allows testing, trial and error, and correction in design.* Computer graphics encourages intuition, rather than exact calculation, because of the instantaneous reporting of results. The industrial advantages are reductions in design time, in expensive experimentation, and in time between design and production.

Simulation is closely related to interactive graphics. Once a student has separated chemicals from a mixture several times in a laboratory, simulations can reinforce procedures learned there by allowing the student to analyze many other mixtures. While the computer does not wet the hands of the undergraduate hydrodynamicist, it costs much less than a real physical model, flow laboratory. Simulation is certain to play an important role in engineering education of the future (Alameda, 1983:107).

Many people question whether the benefits of the undergraduate laboratory justify the effort required of both students and faculty—they describe undergraduate laboratory work as an infinite sink for time and effort—and some look to the computer as a substitute that will make the work more manageable. The computer can remove the tedium of data acquisition and data reduction for many experiments without eliminating student effort in the analysis of the results. That analysis aims at the goal of undergraduate study, namely, understanding of the principles and methods of science and engineering. Furthermore, automated laboratory systems can sometimes detect, report, and react to subtle changes in experimental conditions better than unaided systems can. Computer-aided instruments are also capable of producing greater precision, accuracy and reliability in data taking, and the data collected are in digital form, ready for postrun computer processing. Ultimately, however, educational technology must be viewed as an effective supplement, not as a substitute, for learning laboratory procedures. The computer is best used to enhance learning in the laboratory and to refine experimental findings there (Saltsburg et al., 1983:81–83).

Computer-managed instruction (CMI) is a further dimension of this educational technology. The Educational Testing Service has investigated how computers can simultaneously test a student's ability and provide instruction by encouraging the student when he or she arrives at correct answers or by giving hints and allowing the student to try again when errors are made (Grayson, 1983:362). Such interactive

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* See Baldwin and Down (1981:66–68), summarizing M. J. Wozny, "Interactive Graphics for Engineering Education," *Professional Engineering* 48(June 1978):14–18.

techniques can also show the instructor when many students in a class have not mastered a concept; course materials can then be revised as needed. Also, the more advanced word processors can identify punctuation and grammatical errors, freeing the teacher to concentrate on substance, writing style, clarity, and organization of ideas.

The systems described above have great potential for elaboration. Some have demonstrated that they can score tests, keep records of each student's mastery of major objectives, prompt students and refer them to sources of help, flag student problems for instructors, keep track of supplemental assignments, manage course assignments efficiently, and provide data for evaluation of course results (Grayson, 1984:13–14).

The Panel on Undergraduate Engineering Education recommends that *faculty weave computer use into the fabric of engineering curricula. Administrators must treat this incorporation of computers as a "mainline" activity by allocating a percentage of the budget to the endeavor.*

Combined Technologies

Random-access videodiscs give ITV the same interactive and feedback capability that computers have. They also allow forms of visual instruction beyond the text and graphics of CAI. The videodisc resembles a long-playing record and can store 30 or 60 minutes of full-motion video on each side. The optical or laser disc can store 54,000 slides, one-half hour of continuous-motion pictures, or a combination of the two, because it can code and display each of its frames individually. The disc lends itself to a dynamically programmed format for stand-alone use or in conjunction with an external computer in an interactive mode.

IBM has one of the most elaborate videodisc training systems in its 36 Guided Learning Centers for small-business-systems customers. Each center offers 20 training programs of one to five days on three videodisc players, remote control units, TV monitors, audiocassette recorders, and surrogate computer terminals for completing student exercises. During the first year of operation of this program (1980), 21,000 customers completed 40,000 student-days of instruction (Grayson, 1984:28–30).

Twenty-one engineering colleges and universities have joined under AMCEE to produce and distribute videotapes of courses, seminars, and other materials for off-campus use. One type is the "candid classroom," which allows the viewer to hear and see everything that the on-campus students do. The other type is produced in a television studio.

General Electric Company has produced a series of nine videotaped courses on electronics applications for the continuing education of its engineers and engineering managers throughout the world. By 1982, after less than two years of operation, 7,000 people had enrolled in these courses (Grayson, 1984:28–30).

Conclusions

To enter fully into the current age of technology and to take full advantage of the powerful resources offered to education, there must be encouragement—in the form of policy and fiscal support—from federal and state governments, from private sources, and from educational institutions. Faculty participation in the development of educational technology is also essential. Such participation is difficult for many faculty members, and, for some faculty (for reasons already cited) the change will be slower than is acceptable. Engineering education will have to depend on the professional pride of some faculty to respond once they are convinced of the advantages of bringing the new technologies into their classrooms. Student acquaintance with technology through videogames and aggressive advertising by hardware manufacturers will probably spur this pride more quickly than has been the case in the past.

Once convinced of its importance and of the need for it, we must define the place of educational technology within the educational process in order to take full advantage of it. An overall systems approach to the use of educational technology must be developed so that it is known what goals are being sought, how technology will support these goals, and how their accomplishment will be measured. Such an approach is essential, since the costs associated with implementing educational technology will be exceptionally high.

The Panel on Undergraduate Engineering Education recommends that *the engineering profession undertake a comprehensive study—and immediately implement its findings—about how to make educational technology more efficient and how to improve both the process of education and the learning experience. Funding by government, foundations, and industry is essential to achieve this result.*

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4

The Curriculum

There have been dramatic changes in engineering curricula in the past 30 years. A review of this evolution clearly exposes persistent tensions within engineering education.

A RECORD OF CHANGE

An examination of the textbooks in a given engineering discipline over the past 30 years reveals changes striking in both nature and extent. The trend is toward a deeper, more fundamental understanding of the subject, combined with greater dependence on mathematical analysis and modeling. In fact, the undergraduate textbooks of one decade reflect some of the research papers and graduate texts of the previous period. One concludes that a considerable body of knowledge has flowed from the graduate to the undergraduate level.

Furthermore, a review of the engineering college catalogs over the same 30-year period reveals the unmistakable trend of increasing science and engineering science content with a compensatory decrease in topics associated with engineering practice. Such catalogs also indicate a trend toward greater curricular flexibility, which includes time explicitly devoted to the humanities and social sciences. Like the textbook evidence, catalogs are the printed summary of extensive and often heated debates within engineering faculties. They also reflect the additional dimension of "outside" influences of accreditation bodies such as the Accreditation Board for Engineering and Technology (ABET) and of industrial trends.

The broad goals of undergraduate engineering education—to prepare students for practice, graduate study, and lifelong learning—are the underlying reasons for these curricular changes. With regard to the first goal—preparing students to contribute to contemporary professional engineering assignments—the curriculum is necessarily part of a dynamic process. As professional engineering practice changes, the educational base must change; the rate of change in most areas of professional practice since World War II has caused curricular stress. The second goal of undergraduate engineering education—preparing the student for graduate study—imposes an additional curricular dimension that is not always compatible with preparation for professional practice. The conflict appears not only in the approach and substance of particular courses, but also in the time devoted to what appears to be an ever-broadening range of subjects. The third goal—providing a base for lifelong learning in support of evolving career objectives—has a subtle and open-ended purpose. It attempts to address the fact that, during the active career life of an engineer, he or she is apt to take on increasing supervisory responsibilities, which often lead to important management positions having a strong economic component. Thus, the three-dimensional nature of the goals, together with the dynamic interaction among them, shapes the undergraduate engineering curriculum.

SCIENCE VERSUS ENGINEERING

The dramatic termination of World War II not only established that technology was the determining factor in that conflict, but, of equal importance, it resulted in recognition of the science-based nature of that technology. The role of fundamental science both in changing traditional fields of engineering and in creating whole new technologies has been illustrated many times in subsequent decades. While the underlying motivation for change is often economic or results from the unending drive to improve the quality of life, the cycle of movement from scientific understanding to pilot-state experimentation to initial technological application to mature technologies is an unmistakable feature of our technological age.

The curricular consequences of these postwar developments have been major and have led to wrenching experiences in some disciplines. For example, the first freshman-year courses eliminated or forced to atrophy were the so-called shop practice courses. This change was rapidly followed by a reduction in drafting. Although these courses clearly provided motivation to the fledgling engineer and some knowledge of what was then "current practice," the claim for more science and mathematics was given higher priority. However, in recent years these very topics have reemerged and have been transformed as a result of the science-technology cycle cited above. Computer-aided design (CAD) and computer-aided manufacturing (CAM) now appear as well-accepted topics in modern engineering curricula.

CURRICULAR COMPRESSION

The expansion of graduate education in the 1950s and 1960s imposed additional pressure on curricula as some of its topics were moved back to the undergraduate years. Laboratory work was compressed and deemphasized. Over a period of time this reduction reached the point where in some cases the residual laboratory experience was educationally marginal. While some immediately protested this trend, only recently has the seriousness of letting laboratory work vanish from the undergraduate curriculum been recognized. In a manner analogous to the incorporation of CAD/CAM, the role of simulation is a topic of current debate.

The need for additional science and engineering science had the further effect of compressing and in many cases eliminating junior-and senior-year design courses. In the traditional curriculum these courses were the capstone of the educational program, because in them, all the previous "fundamentals" joined with engineering practice to give the student the experience of creating a practical device, system, or process. The reduced emphasis on design created severe curricular tensions, which ultimately led ABET to set a minimum required threshold on design content. In addition, the professional societies insisted on playing a more active role in accreditation, which required their representation on ABET accreditation teams.

Presently a kind of moratorium stabilizes the balance between science and engineering. While the partitioning of areas is not absolute, the common view is that the balance among science, engineering, design, and the nontechnological component cannot be changed further without seriously damaging at least one of the four. Nevertheless, pressures do exist for substantial change. For example, how will the imperatives of computers and the information age find room in the curriculum? Or how will time be found for incorporating the field of biotechnology, which is growing within many engineering disciplines? And how is the third goal of undergraduate engineering education—to provide a base for lifelong learning in support of evolving career objectives—to be addressed when engineers encounter several technological revolutions during their careers and when they are further called upon to bridge the gap from technology to society?

THE FOUR-YEAR CONSTRAINT

In spite of the constant pressure to include additional subject matter, the undergraduate curriculum has generally followed the standard 4-year time period (although in practice the average engineering student requires 4 1/2 years to complete the bachelor's-degree requirements). To some, this constraint has not appeared to be entirely rational, especially when one considers that in Western Europe at least 5 years are devoted to what is considered in the United States to be college-level material. However, others view the 4-year constraint as desirable, because it forces the setting of curricular priorities. Furthermore, industry has been outspoken in stating its desire to keep the first professional degree within the 4-year time period. This is partly because of the diverse nature of industry's job demands, but a second consideration is the perceived cost to industry if more years are required. In the public sector, cost considerations are also a factor in the state legislatures, as well as for families with students in independent institutions.

However, because of the obvious problems that result from trying to fit more and more content into a fixed time period, there have been attempts to lengthen the time to undergraduate degree to five years. After World War II there was a serious, and for that time farsighted, attempt to introduce a five-year undergraduate program. For example, all engineering curricula at Cornell University were changed to a five-year base, and five or six other schools moved in the same direction. The five-year program did permit greater depth in individual areas of specialization and added enrichment in nontechnical fields. However, there was no concerted effort to adopt this approach, and industry opposed the concept.

Simultaneous with this five-year experiment was the rapid development of graduate education in engineering. Thus, an increasing number of students did in fact continue for at least a fifth year, but the degree awarded was at the master's level. One difficulty with the five-year experiment was that when graduate students coming from other schools were enrolled in the same upper-level courses as undergraduates, the undergraduates were doing essentially the same work for unequal recognition.

Gradually one school after another discontinued the five-year pro grams, so that by the early 1960s the experiment had come to an end. In hindsight the five-year concept was far in advance of its time, but it did not anticipate the rapid rise of graduate education in engineering. The fact that the concept was not adopted by the profession has tended to suppress its reconsideration in recent years.

RECENT PROPOSALS

Another approach to broadening undergraduate engineering education has been the introduction of the so-called 3 + 2 curriculum. In these programs the student takes an initial three years in a liberal arts setting, studying enough physics, chemistry, mathematics, and perhaps engineering science courses to be able to transfer to engineering with minimum dislocation in time. The final two years are spent in an engineering setting; the student usually receives two undergraduate bachelor's degrees.

The 3 + 2 approach has never been widely adopted, and the number of students in these programs has remained small. Such students represent an aberration in a liberal arts environment, and from the engineering side they have been more tolerated than encouraged. Neither liberal arts nor engineering faculties have ever seriously addressed the purpose of the 3 + 2 programs. While such programs are often described as trying to strengthen the third goal of engineering education (providing a base for lifelong learning in support of evolving career objectives), this attribute has never been seriously addressed in the sense of a structured 3 + 2 curriculum.

Another approach to undergraduate engineering curricula has at times been advocated by several groups within professional engineering societies. This approach divides the entire educational process into preprofessional and professional components, resulting in a first engineering degree after at least five and more probably six years. Advocates of this approach claim that it is the only way to resolve the conflicts inherent in the four-year program. The advantages of this type of approach, according to advocates, are that the broad, nontechnical base can be established in a coherent manner, and the in-depth technical component can be added in an environment dedicated to professional education. Although medicine and law have long experience with the preprofessional model, engineering education has not adopted this approach.

One might consider 3 + 2 programs as an experimental approach to the preprofessional model. Conceptually, this line of reasoning introduces a structured 3 + 2 program which, with sufficient curricular integration, could address the goals of engineering education in a purposeful and comprehensive fashion. However, neither the professional societies nor liberal arts and engineering educators have approached 3 + 2 programs in this light.

In conclusion, over the past 30 years there have been major changes in engineering curricula. The science and engineering science content has increased appreciably, with a concomitant decrease in topics associated with engineering practice. In addition, more time is devoted to the humanities and social sciences, and there is greater curricular flexibility. During this period undergraduate engineering education has experimented with changing or modifying the four-year norm for the B.S. degree. None of these experiments has succeeded in displacing the traditional approach. The problems of the time to acquire the first professional degree and the nature of that degree remain issues in engineering education.

The Panel on Undergraduate Engineering Education recommends that, *to increase elasticity in enrollment capacities and diversity of educational background of engineering enrollments, a pilot group of colleges and engineering schools be funded to demonstrate effective structures for dual-degree programs. Experience gained from this pilot group could then be applied, if needed, to a wider group of institutions. In addition, the experience gained would be relevant to the often-debated model of preprofessional followed by professional engineering education.*

5

The Role of Laboratory Instruction

By all counts, the amount of undergraduate engineering laboratory instruction has declined drastically in many institutions over a period of years. The decline began in the 1950s and 1960s when shifts in curricular content toward scientific theory resulted in deemphasis on the amounts of time and effort devoted to laboratory work. In more recent years undergraduate enrollments have doubled and the number of faculty has increased by only 10 percent, which has meant even less time available for such instruction. This erosion accompanied a perception among many engineering and science faculty and administrators that laboratory instruction was of considerably less importance than other means of instruction and certainly of less value than their own research. Under these conditions, it was the exception when faculty developed and maintained vigorous, modern, high-quality laboratory courses.

Also affecting laboratory instruction, budget constraints since the early 1970s have reduced funds for equipment to a small fraction of previous allocations, or almost to nothing in some disciplines. As stated in a report by the National Society of Professional Engineers (1982:32):

> Clearly the problems of large class size, high student-to-faculty ratios, deteriorating physical plants, inadequate equipment, and inability to acquire laboratory equipment commensurate with present-day technological advances in industry are too widespread to be ignored. . . . Continuing obsolescence of laboratory equipment and instruments has placed many schools in the position of not being representative of modern professional practice.

In many cases, labs have become so overcrowded that hands-on experience and personal involvement are reduced—often with the result that students lose interest or learn to disdain such work. Faculty do not have enough technical assistance to set up and check out experiments and to provide routine service and maintenance, or even to keep track of the location of equipment. Only those who have developed and taught laboratory courses know that such instruction requires much more time than lecturing does. Faculty become frustrated and discouraged by so many problems and by the perception that lab work is not valued. They feel that their time is better spent earning the rewards of their own research and publication; laboratory instruction yields no rewards. Under these circumstances, "faculty interest in developing, renewing, [and] teaching undergraduate engineering laboratories" steadily decreases (Ernst et al., 1983:203). As a result, the quality of education declines, and students are the losers.

PURPOSES OF LABORATORY WORK

The concept of the undergraduate student as an experimenter is fundamental to engineering education and to the role of a practicing engineer. The undergraduate student should become an experimenter in the laboratory, which "should provide him with the basic tools for experimentation, just as the engineering sciences provide him with the basic tools for analysis" (Ernst, 1983b:4). It is a place to learn new and developing subject matter as well as insight and understanding of the real world of the engineer. Such insights include model identification, validation and limitations of assumptions, prediction of the performance of complex systems, testing and compliance with specifications, and an exploration for new fundamental information. "The laboratory should [also] serve as a means for the continuing professional development of the faculty. . . . The faculty member who develops and continues to revise a laboratory course for engineering students will find this experience to be a learning one" (Ernst, 1983a:52).

FACULTY IN THE LABORATORY

As early as 1967, the Commission on Engineering Education of the American Society for Engineering Education (ASEE) observed, "Interested staff are necessary to the success of an undergraduate laboratory program, yet this fact seems to have gone unnoticed. . . . [Department heads feel] helpless to change conditions in their province because of lack of staff, staff-loading problems, university policies for staff recog nition, publication and research policies, and a lack of conviction of the importance of the undergraduate laboratory program" (Commission on Engineering Education, 1967).

The only hope for using the laboratory to educate undergraduates for engineering in the real world may be if "faculty involved in the development and continuing revision of a laboratory course find this to be a creative activity—one that can be rewarding in terms of the continued professional development of the faculty member. [New laboratory courses] may be related to the research efforts or teaching interests or some other professional interest of the faculty involved, . . . [an approach that offers] laboratory instruction as a career development activity for faculty at all levels" (Ernst et al., 1983:204). Faculty must have the support of the department chairman and the dean to reach this level of interest and commitment.

However, those who evaluate the work of faculty members rarely recognize the value of the laboratory experience in the preparation of an undergraduate to do engineering. Nor do they recognize the burden of work that it imposes. For example,

> [the faculty member must hold] weekly sessions with the TA's to review the lab to be conducted, [monitor] TA's to ensure prompt return of lab reports and appropriateness of grading, [update] written materials for the lab, [purchase] new or replacement items in the lab, even [run] experiments to check for smooth operation. The commitment of time and effort . . . is far greater if a new . . . lab is to be introduced into the curriculum. The latter [tasks] may run the gamut from obtaining funds and equipment from industry, trying out and analyzing various setups, developing courseware, encouraging accuracy and appropriateness of actual results, running tests with students, [even to] designing and building new hardware and developing software, [John, 1983:139]

Deans and department heads need a plan for helping faculty members develop laboratories that have full institutional support. Bradley University chairman Max A. Wessler responded to the shambles he found in his laboratory by retaining a coordinator to oversee and revitalize his laboratory program as soon as a vacancy permitted him to hire a person completing his doctorate. Wessler worked directly with the new lab coordinator to plan the redesign and modernization of the lab and the courses to be taught in it. The considerable time and energy that he devoted to working with the coordinator demonstrated a commitment "to him and to the project and underscored the priority established for the laboratory." The coordinator's trust that his efforts would be rewarded helped him establish good communications within the department. "Because of his success in teaching and laboratory leadership plus an impressive record of research achievements documented by publications, [the coordinator received a] promotion one year before he met normal minimum time in rank requirements" (Wessler, 1983:132–133).

EXPERIENCE FOR A CAREER

In 1966 the Committee for Laboratory Development reported to the ASEE Annual Meeting that "in many cases, facilities for the undergraduate laboratories and the tasks students carry out bear little resemblance to the real world in which the student will later be embedded" (Ernst, 1983b:1). Seventeen years later an industrial spokesman said: "The Engineers should be talking to each other about their activities informally and they should be talking with lab instructors formally. They do not need grades in this. They just need lots of practice" (Halverson, 1983:38). If strong academic leadership can persuade the faculty that its objective is to educate students to do engineering, "the next step is to recognize that skillful use of experimental technology is vital to good engineering. No one can learn that lesson except by *doing* engineering. The faculty must *do* engineering to appreciate the utility and reality of using experimental technology. . . . [I]nvolvement of the faculty, as coaches not as lecturers, with student groups doing realistic projects, is good and adequate education for the faculty" (Dean, 1983:44).

THE INDUSTRIAL VIEW

Robert C. Dean, Jr., president of Verax Corporation and adjunct professor of engineering at Dartmouth College, offered the following observations to his colleagues at a 1983 conference on the undergraduate engineering laboratory:

> [Some industries] are disappointed with the experimental skills of your products. We are also disappointed with their training, in general, in how to *use* their academic learning. Many others have chastised you for being "academic" (Webster: "unconnected with reality"). Your students must be ultimate realists to be good. How can they be good if you educate them primarily in mathematics and applied science taught by scholars? Where is the clinical training that the medical profession insists is essential for the medical practitioner? Why is not such training essential for the technology practitioner too?" [Dean, 1983:43]

Another practitioner, Harley Halverson of Hewlett-Packard's Electrical Engineering Laboratory, explained that engineering "education should involve as much hands-on experience as practical, doing things engineers do—designing, building, testing, redesigning, etc." He cites the example of an engineer working on a new signal generator: He was a radio frequency analog designer starting out on the bench his first day at Hewlett-Packard; he was assigned a mentor who would help him but was expected to be able to design circuits without further training. No one taught him how to solder or to build breadboard circuits or to use the basic test equipment. Halverson's description of hiring at Hewlett-Packard shows how important it is that engineering graduates be able to do engineering as well as think about it:

> When HP is hiring a new engineer, it looks for at least two technical qualities. First, it wants engineers with good theoretical and analytical ability. We do state-of-the-art designs, and we need state-of-the-art designers. At least thirty percent of every design team are engineers who have never designed a new product before. They do not get to practice. It is for real the first time. As a result, engineers need to be prepared to engineer when they come out of school. Second, it looks for engineers who like to work with their hands. They cannot be just theoretical. They need to like to build things. . . . If they have never had the opportunity to design, build, and test something while in school, they have missed what it means to be an engineer. This is not uncommon. Every year we talk to many prospective graduates who have very little idea of what an engineer really does. When they get to their first job they may find that they do not even like being an engineer. So a strong laboratory experience is a vital part of an undergraduate education. [Halverson, 1983:37]

SCIENTIFIC UNDERSTANDING

The issue of laboratory experience in the education of the engineer is basically a matter of the teaching of scientific understanding. "In a laboratory a slice of the world is isolated in such a way that it can be manipulated easily and scrutinized at will. . . . It is also a condensation of real life experience into a manageable amount of time and space. This makes it especially useful as a teaching format" (Graham, 1983:47, quoting Edward Allen, "Things Learned in Lab," *Journal of Architectural Education* 34(Winter 1980):22–25). To those whose emphasis on scientific education of the engineer may urge them to devalue laboratory experience, Edward W. Ernst (1983a:52) puts the issue this way: "The problems are not simply with manipulative skill," he says. "There are difficulties in attitude regarding what science is all about."

PRACTICING ENGINEERS DO EXPERIMENTS

Practicing engineers must put their knowledge of science to use in an interactive cycle of analysis, design, and experiment. We appear to have

> a new realization that the purpose of engineering is to solve human problems. . . . [T]he Japanese have taught us—and scared us—into realizing that the economic world is a tough place where only well-engineered products can survive and prosper the Nation's citizens. [These] products must rest on strong technology bases and must be well tested. The purposes of the engineer's experimental technology are, *first*, to aid powerfully in building the technology base and, *second*, to test definitively in order to prove that the product will meet its specs in service. [Dean, 1983:42]

The engineer's basic tools are information, analytical modeling (mathematical analysis), and experimental modeling. Experimental technology has brought the profession to a turning point in engineering education as well as in practice. In a presentation to the Texas Society of Engineers, Gloyna et al. (1979) said: "The tremendous development of the transistor and later the microprocessor has made possible the application of digital and computer techniques to all fields of measurement. This has made it possible to perform experiments in undergraduate laboratories that were impossible a few years ago with an accuracy that bares the true value of an engineering theory or design." The undergraduate engineer's tools are available; what is needed now is the will as well as the means to purchase them, and the understanding to help students put them to use.

The Panel on Undergraduate Engineering Education recommends that, *since it is of primary importance that the role and significance of laboratory instruction in undergraduate engineering education be emphasized, colleges of engineering must address this priority need and, together with industry and government, provide the funding to achieve the goal of integrating laboratory practice in engineering education.*

A LAB CURRICULUM

Like any other curriculum, one that requires laboratory experience should be based on a theory of instruction. Its designers must understand how learning occurs in the laboratory. They must know how much laboratory will provide that learning, and they must be able to measure the effectiveness of any method used. They should establish objectives of laboratory instruction, such as the following (Pulsifer, 1983:57):

a. Demonstrate and reinforce principles discussed in classroom.
b. Develop proficiency in performing experiments.
c. Gain experience in use of measuring instruments and basic statistical techniques.
d. Give students practice in planning experimental work.
e. Develop proficiency in oral and written presentation of technical material.
f. Expose students to teamwork in technical areas.

Under the present conditions of undergraduate engineering education in the laboratory, there is need of "a different place for the laboratory in the undergraduate curriculum, different characteristics for the laboratory courses, different equipment" (Ernst et al., 1983:206). Faculty and administrators need to think about new approaches to laboratory instruction, new ways for students to learn, and new types of equipment. Says Ernst:

> Deans and department chairmen must be persuaded to exercise their leadership in support of the undergraduate engineering laboratory. In turn, the faculty must support the efforts by campus administrators by also aggressively pursuing all avenues of external support to provide a meaningful laboratory experience for all students receiving an undergraduate engineering education.

In short, a commitment by all those involved is needed to revitalize the role of the laboratory in engineering education.

IMPACT OF HIGH TECHNOLOGY ON LABORATORY EQUIPMENT

To assess the impact of the high-tech revolution on instructional laboratory equipment, we must examine both the purposes of laboratory courses in the undergraduate curriculum and the nature of the revolution that affects them. The revolution in laboratory equipment affects both the sensors and the data acquisition and data reduction equipment. Incorporation of digital rather than analog elements into most laboratory instruments today greatly increases their versatility as well as their complexity. The boundary between the computer and the laboratory instrument has now disappeared. The appropriate role of this equipment in undergraduate engineering curricula must be established, and universities need to keep undergraduate laboratory equipment abreast of such rapid advances.

If the purpose of an experiment is to introduce the student to fundamental physical measurements and an understanding of experimental techniques, sophisticated equipment may actually prevent real involvement of the student in the process. To receive an entire set of data from the push of a single button has no more educational value than receiving a copy of a standard data sheet. On the other hand, when the purpose of the experiment is to introduce the student to the process of test and evaluation as it is used in industry, modern laboratory equipment of high quality is required. In this case, the student needs equipment that will produce, without excessive drudgery, accurate data for critical evaluation and use as a basis for engineering decisions. This latter process does require modern equipment that is at least representative of equipment being used in industry.

KEEPING CURRENT

The cost of revitalizing undergraduate engineering laboratories is substantial, partly because their substance and importance has been neglected and partly because they need modernization. The National Society of Professional Engineers (1982) acknowledged this in a major study which shows that the value of the average laboratory equipment inventory per school declined from $5,810,000 to $856,000 between 1972 and 1981. To bring the equipment of 250 schools with accredited programs back to the 1972 level would cost about $1.25 billion, adjusted for inflation. There is additional need, however, due to the doubling of enrollments, which would increase the cost to almost $2.2 billion. NSPE and others (Shoup et al., 1983) calculate that it will take an investment of about $2,000 per student to correct the present shortfall.

The figures just cited are staggering; policymakers may question them, but if realistic figures are used in any assessment of equipment needs, they will reveal the drastic inadequacy of our laboratories for preparing students for modern engineering practice. The accumulation of neglect spans a quarter of a century. Instead of depending solely on the projection of figures related to past pedagogical practices, perhaps the solution lies in convincing the faculty of the benefits that they and their students will gain by teaching current engineering practice in the laboratory. While the costs to modernize our laboratories will still be high, the renewal process can only occur if the faculty take the initiative in revitalizing laboratory instruction.

CHARACTERISTICS OF FUTURE LABORATORIES

The summation of the 1983 ASEE-ABET conference on the undergraduate engineering laboratory described the characteristics of future laboratories (Ernst et al., 1983:205–206):

1. Faculty involvement will make them challenging, interesting, and constantly changing to be up to date.
2. Students will have considerably less laboratory experience, and some courses will be elective to fit each student's interests.
3. Clearly understood objectives for the laboratory courses will be essential.
4. While fewer laboratory experiences will require less equipment, where practical it will be such as engineers use in the field.
5. The presence of support personnel will allow faculty members to concentrate on continuing development of the laboratory and nonroutine interaction of the students.
6. The laboratory work will serve as a focus of significant individual student-faculty interaction; this should enhance the undergraduate educational program for the student.
7. Each of the above "should increase the stature of the faculty."

The Panel on Undergraduate Engineering Education recommends that *a national program of government-industry-college matching grants is needed to address the problem of replacing outdated equipment and of maintaining increasingly complex experimental equipment. Industry, academe, and the professional societies need to join forces in promoting tax legislation to facilitate gifts of laboratory equipment to colleges of engineering*.

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6

The Two-Tiered System

Beginning in the 1950s, the federal government initiated a comprehensive system of support for academic research and graduate education in the sciences. As the system grew, some engineering fields were included. The purpose of this support system was to develop knowledge and to improve research techniques across a broad spectrum of disciplines, as well as to ensure a flow of graduate-level manpower to meet the research needs of the nation.

Rapid growth in funding occurred during the 1950s and 1960s and remained fairly level from 1969 until about 1975. Then another upswing in the late 1970s slowed to a modest increase in the 1980s. The federal government's support for academic research and development in 1981 was about $5 billion.

EFFECTS OF FEDERAL FUNDING

The impact of this comprehensive program of federal funding has been substantial. Three decades of rising annual funding fostered a group of research universities or institutions whose graduate and research programs became heavily dependent on contract research. This system of government grants and contracts has been of very great benefit to many engineering colleges, but the focus has been almost exclusively at the graduate level, so that government funding has been the driving force in graduate engineering education.

The strong influence of governmental support on faculty and disci plinary efforts affects projects ranging from fundamental research to those with a strong mission orientation. A number of sophisticated laboratories have been established and equipped, so that approximately 20 schools now have several first-rate laboratory facilities. The process has also resulted in a focusing of educational goals and approaches especially at the graduate level, but the influence has been felt at the undergraduate level as well.

INDUSTRIAL SUPPORT

The rise of the government-funded research university also had an effect on industrial support for engineering education. Several companies that had traditionally given graduate fellowships began to reduce these programs. In fact, when some engineering schools attempted to establish joint projects with industry, they encountered a complaint from industry that because of large and continuing government funding, the universities were no longer interested in working with industry. The industrial share of university R&D support dropped significantly from just over 6 percent in 1960 to below 3 percent in 1965. Not until after 1970 did the percentage rise above 3 percent—to 3.8 percent in 1981. In response to the "crisis in engineering education," some major corporations have recently made sizable grants to a relatively small number of institutions. However, many of these initiatives have focused on the graduate research level at the institutions that have been the dominant recipients of government funding. Such industrial support for academic R&D expenditures amounts to about 4 percent of the total. Thus, the federal government plays the dominant role in this area with its 80 to 85 percent funding of academic R&D.

GRADUATE CENTERS—THE FIRST TIER

The major recipients of government-funded graduate education and research enjoy a distinct advantage, which influences both graduate and undergraduate engineering education. Their recruitment of faculty is enhanced because the young assistant professor can continue working in a research environment similar to that of graduate school. Their policies thereby continue and maintain the academic value system. Teaching loads at research universities are relatively low, and a faculty member has a cadre of research assistants. The research infrastructure includes laboratory facilities, access to modern machine shops, and extensive library holdings, and most recently it includes extensive computer equipment. Typically, the benefits include special secretar ial and technical support as well as travel funds. Taken as a whole, these benefits give a powerful emphasis to academic research in graduate engineering education.

THE SECOND TIER

At the undergraduate level, no set of national policies or programs recognizes the important role of undergraduate engineering education in contributing to the imperatives of a technology-based world economy. The focus of government and industry on research and graduate education has created a two-tiered or bifurcated system of engineering colleges. This two-tiered system has had a strong influence on the character of engineering education. For the purposes of this study, the bifurcation index is taken as the point that separates those institutions awarding 14 or more Ph.D. degrees per year in all engineering disciplines (the first tier) from institutions in the second tier.

Approximately half of the B.S. engineering degrees come from programs that are basically undergraduate schools—those that award fewer than 14 Ph.D. degrees a year. Government, industry, and academe will continue to depend upon graduates from these colleges for at least half of their engineering work force. Yet, because both government and industry focus their funding on graduate study and research, these colleges are forced to depend on other, appreciably smaller sources of funding.

THE NEED FOR BALANCE

In order to provide a measure of balance to this two-tiered system, the needs of primarily undergraduate institutions require recognition. Funding for modern laboratory equipment is an urgent need. At the present time, many undergraduate students never have access to the latest equipment and modern data-handling systems. Colleges are experiencing a wave of computerization at the undergraduate level, but they lack the resources to respond in a timely and comprehensive manner. Tax incentives at both the federal and state levels are urgently needed to assist industry with equipment grants to engineering education.

Faculty who carry heavy undergraduate loads need support and access to creative programs of faculty development. Release time is especially valuable because it enables the faculty member to keep current in a professional field and to develop new teaching techniques at the undergraduate level. Recognizing that the number of advanced academic research laboratories will necessarily be limited, faculty members in primarily undergraduate programs need access to major research centers in order to remain vital. Thus, programs and policies are needed to enable these faculty members to take advantage of such advanced facilities.

The separation in the two-tiered system will widen unless both government and industry introduce imaginative programs accompanied by more than token support. Without strong public policy in support of a balanced system, undergraduate education will not be able to maintain the pace required to meet national economic and strategic objectives.

The Panel on Undergraduate Engineering Education recommends that, *if the quality of engineering education at undergraduate-oriented colleges is to keep pace with the quality at graduate research centers, these colleges must have access to special, new sources of income. And if the program quality of low-research institutions is to keep pace with that of research institutions, faculty at the former will need to gain access to some of the facilities and programs of the major centers of research.*

REFERENCE

National Science Foundation. 1982. *University-Industry Research Relationships*. Fourteenth Annual Report of the National Science Board (Washington, D.C.: National Science Foundation).