

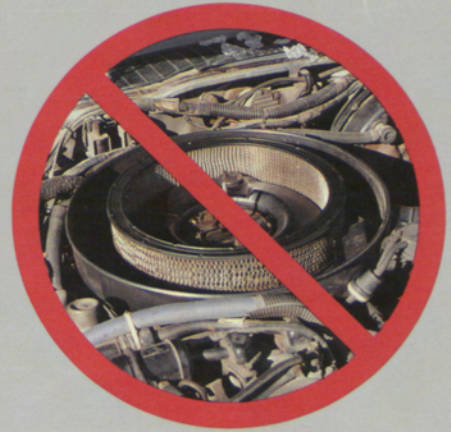
CORNELL ENGINEERING

Q U A R T E R L Y

Winter 1993

Volume 27

Number 2



PUMPS, NOT FILTERS

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Pumps, Not Filters

A commitment to changing the freshman experience is making an engineering education more accessible to nontraditional candidates.



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PUMPS, NOT FILTERS

The passage from high school to college is one of life's more difficult transitions. In college the academic enterprise is organized differently, and students must learn the rules of a whole new game. Living on their own for the first time, they have to take responsibility for the progress of their studies and learn to schedule their time without parents to urge, cajole, or remonstrate. And on top of everything else, the emotional upheavals of adolescence sometimes make it difficult for students to concentrate on academics.

Traditionally, however, neither upper-level students nor faculty members have had much sympathy for freshmen. On some campuses hazing has been the custom, and professors have long used a really tough first exam to shrink uncomfortably large classes. Freshmen have been left to sink or swim, and in demanding programs such as engineering, attrition rates once hovered near 50 percent.

Today, this scenario is changing. Society needs more engineers, and technical schools are looking hard to find good prospects. Once these young people have been recruited, it makes no sense to eliminate a sizeable fraction through criteria that have nothing to do with their ability to become engineers. Good engineers have to be smart, and they need well-honed analytical and design skills. They do not necessarily have to be tough as leather at the age of eighteen.

If the traditional engineering curriculum had a certain resemblance to boot camp, the reason is not far to seek. Engineering, as a profession, grew out of the needs of the military, where rigid discipline, emphasis on uniformity, and intense pressure are customary strategies for "separating the men from the boys." In the lead article in this issue of the *Quarterly*, William B. Streett, dean of the Cornell College of Engineering, shows how military values have influenced engineering education. The Thayer Method, an educational philosophy developed for the United States Military Academy at West Point, spread to other engineering schools founded during the nineteenth century. The heritage of this diffusion is an engineering curriculum that is impersonal and highly competitive, and an engineering profession that has remained, until very recently, the exclusive preserve of white males.

Engineers who work in a civilian context may not have to remain cool and resolute under fire, but they do need a firm grasp on the tools of their trade. Thus, it has long been the custom to weed out students who supposedly lack the potential to become engineers by means of a grueling

program that only the most talented could survive. But a great effort is made to evaluate the potential of students before they are accepted into the engineering curriculum, as described in the article by Richard Hale, director of engineering admissions. If the admissions procedures work, almost all the students who are accepted should be able to complete the program.

To make the study of engineering more inviting, especially for freshmen, the College of Engineering has undertaken a number of initiatives. One, which is described in the article by Robert Thomas, is a new course that introduces students to basic aspects of the profession right at the start of their freshman year. It gives an overview of civil, mechanical, and electrical engineering, showing how all the technological problems that engineers deal with are embedded in a social, political, and economic context.

Women represent a vast resource of engineering talent that has hardly been tapped. But many girls are raised to believe that the male stronghold of engineering is not a legitimate goal for their aspirations. If they manage to breach that stronghold, they may feel less than welcome. In an article that addresses these issues, Michele Fish tells what the College of Engineering is doing to help the pioneering women who are now becoming engineers.

Among the academic hurdles that freshman have to surmount is Mathematics 191, Calculus for Engineers. The material is intrinsically difficult, especially for students with no prior exposure to calculus, and the course has traditionally been taught in large, impersonal lecture sections with nearly two hundred students. In an effort to make the freshman experience less forbidding and give students a better chance to learn the material, the course has been broken up into sixteen small lecture sections instead of two large ones.

In addition, an innovative program has been established to allow students to better assimilate calculus through cooperative learning. Workshops based on this principle have proven highly successful on many campuses across the nation. In an article on the Academic Excellence Workshop, Michael Kelley tells how the program is working at Cornell.

In a word, the Cornell College of Engineering is trying to make sure that the freshman year is an educational experience, not a rite of passage. In particular, the general courses required of all freshmen engineering students are being revitalized so that they will function—in a phrase favored by Dean Streett—as pumps, not filters.

THE MILITARY INFLUENCE ON AMERICAN ENGINEERING EDUCATION

by William B. Streett

The past few decades have seen a substantial effort to recruit women and minorities into science and engineering, but there has been little reflection about how these groups came to be excluded in the first place. The identification of engineering and technology with white males has been taken as a given—something to be overcome, but not explained. It is important, however, to identify the influences that led to the exclusion of women and minorities, and to find out whether these influences continue to slow the pace of assimilation.

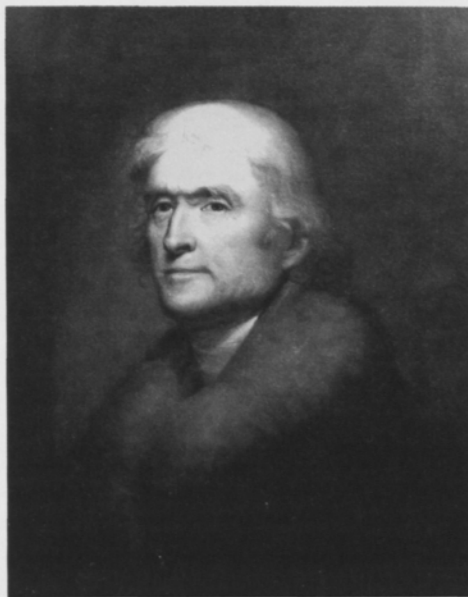
My reading of history suggests that many aspects of the sociology and pedagogy of engineering, including the preponderance of white males, can be traced to the military origins of engineering education in the United States. Recent historical scholarship calls attention to an intriguing bond between the military enterprise, with its emphasis on discipline, loyalty, and uniformity, and other institutions, including science, engineering, government, and education. Sally Hacker, a sociologist who has written extensively on gender and technology, calls military institutions “the central patriarchal institutions of civilized societies.” The military played a key role in America’s rise as an industrial power, and the technological and social implications of this linkage are just beginning to be explored.

Thomas Jefferson and the Founding of West Point

The earliest colleges in England’s American colonies were patterned after Oxford and Cambridge. The curricula of institutions such as Harvard, Yale, and William and Mary were designed to prepare young men for careers as clergymen and lawyers; at their core were ancient languages and moral philosophy. Newtonian science had not yet made a significant impact at the beginning of the nineteenth century.

Washington, Adams, Jefferson, and other leaders of the new republic championed the creation of an institution that would help build a national sentiment and provide a practical education for future public servants. Having observed the effectiveness of the French engineers and officers who helped train the Colonial Army during the American Revolution, they advocated a national university, to be based on the French model. Jefferson, in particular, was in the forefront of the battle to replace classical studies with more practical education. As early as 1779, when independence had not yet been won, he tried—without success—to turn out the professors of divinity and ancient languages at the College of William and Mary and replace them with professors of law, chemistry, modern languages, and natural history.

When he became president, Jefferson sought to create a national institution of higher education based on utilitarian and scientific principles. He concluded that such an institution would be more acceptable to Congress—and to the country—as a military academy,



“It is important . . . to identify the influences that led to the exclusion of women and minorities, and to find out whether these influences continue to slow the pace of assimilation.”

Thomas Jefferson favored a practical education in subjects such as law, chemistry, modern languages, and natural history.

Sylvanus Thayer, superintendent of the U.S. Military Academy from 1817 to 1833, instituted a highly competitive and rigorously disciplined mode of teaching engineering.



rather than a national university. Thus, the United States Military Academy was founded at West Point, New York, in 1802, to educate young men in mathematics, natural philosophy, and the military principles of fortifications and artillery.

The new school enjoyed little success during a chaotic first decade. There was little or no military discipline, only a few textbooks, and no regular program of instruction. Cadets could take examinations for graduation whenever they and their instructors felt they were ready—often less than a year after matriculation.

During the War of 1812, it became apparent that the United States lacked both effective military leadership and technical expertise in military engineering. The fledgling military school at West Point had not developed effective programs to address these needs. Following the war, President James Madison and Secretary of State James Monroe set out to revitalize the Military Academy. They selected for this task a young officer, Major Sylvanus Thayer, who was an early graduate of West Point. They sent him abroad in 1815 to study European systems of military and engineering education. Thayer, then aged thirty, was a native of Braintree, Massachusetts, and a graduate of Dartmouth College, class of 1807. He had completed the course of study at West Point in one year, and was commissioned into the army in 1808.

Sylvanus Thayer and the École Polytechnique

Thayer spent almost a year at the École Polytechnique, the school that had given France its best mathematicians, engineers, military officers, and administrators. In Sally Hacker's analysis, such institutions had arisen to serve the needs of modern nation states.

Early modern Europe saw the growth of ever larger states and armies, inseparable institutions. These, in turn, made trade and commerce possible on a scale before unknown, and stimulated tremendous growth of cities. Engineering served as the technological arm of military institutions. Indeed, engineering was an exclusively military calling until the eighteenth century. . . . Military institutions constructed a kind of masculinity useful for them and [this was] transmitted to young men through engineering education.

Schools such as the École Polytechnique provided education for a largely homogeneous, male-only student body, drawn from the lower nobility and upper middle class. The system of instruction involved a daily routine of academic, athletic, and military training, designed to discipline both mind and body. It combined technical education in science, mathematics, and engineering with socialization into a culture that stressed hierarchy, discipline, loyalty, and self-control. As graduates of these schools became leaders in both the military and in civilian society, they shaped other institutions along military lines.

Thayer acquired experience, methods, some faculty, and a thousand-volume library covering military art, cartography, engineering, and mathematics. (Much of this remarkable collection remains intact at West Point.) On his return in 1817, he was appointed superintendent of West Point by James Monroe, who had become president in the interim, and he set about introducing the reforms that came to be known as the Thayer System—which became the dominant pattern of academic life at the United States Military Academy, and remains so to this day.

Thayer had concluded that rigid discipline, intense academic pressure, and a ruthless weeding out of all those who failed to mea-

sure up were key to the success of the French military system. He imposed a strict military/academic framework on a cadet's every moment at the academy. The curriculum included civil and military architecture, defined as including "elementary parts of buildings and their combination; orders of architecture; construction of buildings and arches; canals; bridges and other public works; machines used in construction; and the drawing of plans, elevations and sections." French was a required subject and was the principal language of instruction, since most of the texts were in French.

The Thayer System has been described as a "novitiate, in which every man suffers equally, and every man is rewarded according to his performance, moving toward a common goal, under an impartial, impersonal command." Classes were divided into small units or sections (as they are to this day) with no more than fifteen or twenty cadets in each one. Graded daily recitations were held in each subject, with students re-assigned monthly to sections according to grade-point average. Attendance at class and preparation of assignments were considered

a military duty, and absence or failure to prepare was a serious dereliction.

Thayer had created the first comprehensive program of scientific and technical instruction in the United States, and over the next half century it exerted a profound influence on the development of both engineering education and American industry. For several decades West Point was the principal producer of engineers with formal training in mathematics and science. Thayer's students were hired by civilian universities, where engineering programs were beginning to take shape, and by industry. They were especially prominent in the development of railroads, where they carried out much of the early surveying and construction, and brought military methods to the organization and management of workers.

Thayer remained as superintendent at West Point until 1833, when he returned to regular military duty. Following his retirement from the army, he endowed and helped to establish the Thayer School of Engineering at Dartmouth College. He died in 1872. He is known at West Point as the father of the Military Academy. It is also fair to say that he is the father of American engineering education.



West Point cadets lined up at the blackboard to work out a problem in civil engineering, about 1944.

West Point graduate Alexander Dallas Bache was the first president of the National Academy of Sciences, director of the U.S. Coast and Geodetic Survey, director of the Office of Weights and Measures, a founder of the Smithsonian Institution, and an early president of the American Association for the Advancement of Science.

West Point Graduates at Other Institutions

During my years on the faculty at West Point (1961–1978), I became interested in the history of the Military Academy and the contributions of its early graduates to engineering and technology in nineteenth-century America. I was struck not only by the important part played by these men in technical education and industrial development, but also by the fact that their contributions were virtually unknown and largely unrecognized within the academy itself.

The principal reason for this neglect is clear: West Point was created to train officers for military careers, and the academy has found it awkward—even harmful—to publicize the civilian accomplishments of its graduates, unless they distinguished themselves in military service before leaving the army. Throughout its history, the Military Academy has struggled to justify its existence during peacetime. During long intervals between wars, many graduates have resigned from the army to pursue civilian careers, leading to criticism from Congress about public expense for private gain.

The period from the end of the War of 1812 to the beginning of the Civil War in 1861 was such an interval, and during this time many West Point graduates resigned from the army and became professors of mathematics, natural philosophy, and engineering in the new programs of science and engineering that were beginning to take shape in American universities.

- Charles Davies, class of 1815, resigned as professor of mathematics at West Point in 1837 to accept the professorship of mathematics at Trinity College, in Hartford, Connecticut. He became a professor of mathematics and philosophy at the University of New York in 1845, and professor of higher mathematics at Columbia College in New York City, a post he held until his death in 1876. He translated several important French mathematics texts and later wrote his own.

- Horace Webster, class of 1818, resigned in 1825 and was for twenty-three years professor of mathematics at Geneva College, in Geneva, New York. In 1869 he became the first president of the City College of New York.



- Edward Courtenay, class of 1821, resigned in 1834 to become professor of mathematics at the University of Pennsylvania and later at the University of Virginia.

- Alexander Dallas Bache, class of 1825 (a grandson of Benjamin Franklin), resigned in 1829 to become professor of natural philosophy and chemistry at the University of Pennsylvania. He reorganized and expanded the U.S. Coast and Geodetic Survey, which he headed from 1843 to 1867. He was the principal founder of the National Academy of Sciences and served as its first president, from 1863 to 1867. Under his leadership the Franklin Institute in 1830 undertook an investigation of steam boiler explosions, which included construction of the first testing machine for systematic study of the strength of metals.

- William A. Norton, class of 1831, resigned in 1833. After holding professorships at New York University, Delaware College, and Brown University, he became, in 1852, professor of civil engineering at the Sheffield Scientific School of Yale University, a post he held for the next thirty-one years.

- Richard S. Smith, class of 1834, resigned in 1856 to become professor of mathematics, engineering, and drawing at the Brooklyn Collegiate and Polytechnic Institute. In 1859 he became director of the Cooper Union Institute in New York City. He was president of

Girard College in Philadelphia from 1863 to 1867.

- Henry L. Eustis, class of 1842, resigned in 1849 to become professor of engineering in the Lawrence Scientific School of Harvard University. He was dean of the Lawrence School until his death in 1885.

- William G. Peck, class of 1844, resigned in 1855 and served on the faculty of the University of Michigan (where he was a colleague of Andrew Dickson White). Two years later he became professor of mathematics, mechanics, and astronomy at Columbia College—a post he held for thirty-five years.

- William P. Trowbridge, class of 1848, resigned in 1856 to accept an appointment as professor of mathematics at the University of Michigan. In 1870 he was appointed professor of dynamic engineering at the Sheffield School of Yale University, and in 1877, professor of engineering at Columbia University, where he remained until his death in 1892.

West Point graduates spread the Thayer System to all parts of the country. Faculty and graduates of the U.S. Military Academy found themselves welcome at other colleges and universities, not only because of their technical expertise, but also because of their familiarity with Thayer's system and its rigid discipline,

departmentalized study, and intense academic pressure. By 1862, there were about a dozen engineering schools in the United States: West Point, Norwich University, Rensselaer Polytechnic Institute, Union College, the U.S. Naval Academy, the Chandler Scientific School at Dartmouth, the Sheffield Scientific School at Yale, the University of Michigan, the Polytechnic College of the State of Pennsylvania (which offered the first degrees in mining engineering and mechanical engineering before it closed in the 1880s), New York University, the Polytechnic Institute of Brooklyn, and Cooper Union. With the exception of Rensselaer and the Polytechnic College of Pennsylvania, the engineering programs in all these institutions received their early form and direction from West Point graduates.

The Lawrence School at Harvard did not offer a comprehensive program in engineering until about 1865, and MIT, incorporated in 1861, admitted its first students in that year. With the passage of the Morrill Land Grant Act in 1862, engineering education expanded rapidly, and West Point soon lost its preeminence as a provider of engineering and mathematics professors. But by this time, Thayer's system had taken root all over the country as an integral part of engineering education.



West Point cadets study civil engineering, about 1904.

The Persistence of Military Values in Engineering Education

High rates of failure were—and are—a fact of life in engineering education. Failure rates at West Point hovered between 50 and 60 percent in the mid-nineteenth century, as did failure rates at other colleges, including Harvard, Columbia, and Princeton. These institutions viewed themselves, first and foremost, as builders of character and disciplinarians of the mind—and only secondarily as purveyors of knowledge. Mathematics was the principal gate-keeping course, accounting for more than 70 percent of the mid-nineteenth-century failures at West Point. (This was still true in the mid-twentieth century, during my own years at the academy.) Today, mathematics remains as one of the principal gate-keeping subjects in engineering education nationwide.

Military patterns in engineering education were reinforced during each of the two World Wars, when universities, and especially engineering colleges, were closely allied with the military in preparing young men for service. An engineering graduate of the class of 1945 recently recalled the V-12 Program at Cornell during World War II. Students in this program were members of the U.S. Navy, assigned to Cornell to complete their engineering education on an accelerated basis. They rose at 5:50 a.m., had mandatory calisthenics before breakfast, marched to and from meals in mili-

tary formation, and devoted long hours each day to classes, laboratories, and required evening study periods. (Not surprisingly, he did not express the same nostalgia for his undergraduate days at Cornell as other alumni.)

During my years as dean of the College of Engineering, I have been astonished to discover the extent to which traditional military models of education have shaped the curriculum. In the late 1940s, a five-year bachelor's degree program was put in place; it required 180 credit hours for graduation, with few elective courses. The stated purpose for the change to a five-year program was to provide more opportunity for the study of social sciences, humanities, and arts, in order to produce more well-rounded graduates. But this was accomplished with a rigidly defined curriculum that allowed students relatively little freedom to pursue their own interests.

Instead of becoming more humane, the program was imposed with heavy doses of pressure and discipline. Classes were held five and one-half days per week, with mornings and afternoons filled with lectures, and laboratory exercises that often lasted until late in the day. A sink-or-swim atmosphere prevailed. Graduates who were students at that time have vivid memories of their freshman orientation, at which a dean or department chairman stood before them and said, "Look to your left; look to your right; only one of the three of you will



During World War II, students in the U.S. Navy's V-12 program studied engineering at Cornell.



Students in the V-12 program had to roll up their sleeves to work on a diesel engine.

be good enough to graduate." At least one distinguished graduate remembers hearing as the next statement, "And we don't care about the rest of you!" For many students, the pressure was overwhelming, and those who could not keep up were quickly weeded out. (Most simply transferred to another college at Cornell.)

In 1962 the dean of engineering at Cornell, in his annual report to the president of the university, reported that attrition in the College of Engineering was 55 percent—about the same as the national average, and about the same as at West Point a century before.

Reassessing the Assumptions of Engineering Education

While it is clear that military models have contributed much to the success of engineering education, the legacy of early military influence has also left serious problems. On the positive side, military traditions of discipline, hard work, competition, and individual responsibility—traditions that have long characterized engineering education—have encouraged self-confidence and independence, resulting in many generations of graduate engineers who have made important contributions to American life. On the negative side, the rigidity and exclusivity of the military model, typified by the boot-camp mentality of the academic routine, the exclusion of

women and minorities, and the almost ruthless weeding out of all who do not measure up, have denied many capable and qualified students the opportunity to earn an engineering degree. They have also left today's engineering colleges ill-prepared to bring about needed changes in gender and ethnic diversity among both students and faculty.

Some observers—especially feminists—have pointed out how traditional military values have tended to exclude or discourage women and minorities. According to Sally Hacker,

Patriarchal and military values of discipline, their structures of hierarchy and order, pervaded society through both education and industry. They provided a stable structure of gender stratification vis-a-vis technology, during times of rapid change. . . . At each step along the way, technology and craft were re-defined and women and minorities were discouraged or formally excluded.

Currently, attrition at the Cornell College of Engineering is about 28 percent, and the national average is 35 percent. But the failure rates for women and underrepresented minorities in most engineering schools range from 35 percent to as high as 60 percent.

Where will the engineers and leaders of the

*"We must reach out
to students, [and]
welcome them into
engineering. . . ."*



future come from, if we continue to rely mainly on white males to fill the profession of engineering? Women and underrepresented minorities were virtually excluded from engineering education until the 1970s, and even now their presence is far below their proportion of the college-age population. Half of this population consists of women, and by the year 2010, approximately 40 percent of the college-age population will be African American and Hispanic. Nationwide, only about 17 percent of engineering undergraduates are women, and African and Hispanic Americans, who presently account for about 23 percent of the college-age population, are represented in engineering at about half this level.

Many engineering educators still believe that intense academic pressure and weeding out a large fraction of students are the best way to assure that those who survive will have the self-discipline, knowledge, and skills to succeed. But this view is being challenged by those who are aware of the rapidly changing demographics of American society. If we do not bring women and underrepresented minorities into the mainstream of education and into the professions, it is unlikely that our country will have the trained and educated work force needed to carry it forward in the era of global economic competition.

What is needed to change the system? We must change the culture of engineering edu-

cation. The problem is not with students; it is not an external problem. The problem lies within the system, in its traditions of accepting large numbers of well-qualified students, placing them under intense academic and psychological pressure, and letting those who do not thrive in this environment fall by the wayside. We must change engineering education so that it becomes, for all students—and especially for women and minorities—an enlightened, supportive, encouraging system. We must reach out to students, welcome them into engineering, and provide them with the curricula, the advice, and the instruction that will enable them to realize their full potential. We must create an atmosphere in which all students feel that they are part of the system, that there are professors who know their names, know what progress they are making, and are able and willing to give them a hand if they stumble along the way. This is one of our important goals at Cornell.

William B. Streett, the Joseph Silbert Dean of Engineering, is especially well-qualified to write on the effect of the military on engineering education. He earned his bachelor's degree at West Point and served on the faculty there for fifteen years before retiring, in 1978, with the rank of colonel. He came to Cornell and joined the faculty of the School of Chemical Engineering that same year. He has been dean since 1984.

SELECTING ENGINEERING STUDENTS

by Richard Hale

Each year the College of Engineering receives from four thousand to forty-eight hundred applications for admission. These applications come from students throughout the United States and overseas, all of whom hope for a place in a freshman class of about seven hundred students. Of course, many also apply to other top, highly competitive engineering programs such as those at MIT, Stanford, and Princeton. But Cornell's reputation in engineering continues to attract many of the best and brightest high school graduates.

Selecting the Best from Thousands of Applicants

Choosing which students to admit among thousands of applicants is a daunting and time-consuming task that we in the Office of Engineering Admissions undertake each year from November through March. Applications are read with considerable care and attention, sometimes many times over.

What do we look for? The best way to express it, I believe, is that we look for young men and women who can take advantage of all that Cornell offers, in the broadest sense. This means that they can be successful academically and, at the same time, take advantage of the range of opportunities afforded by a comprehensive research university. This could include doing research as an undergraduate and making connections with our distinguished faculty, or playing in the Big Red Marching Band. It could include writing for the *Daily Sun*, or working on the electric-car project. But to do all this takes a certain degree of maturity, independence, and assertiveness.

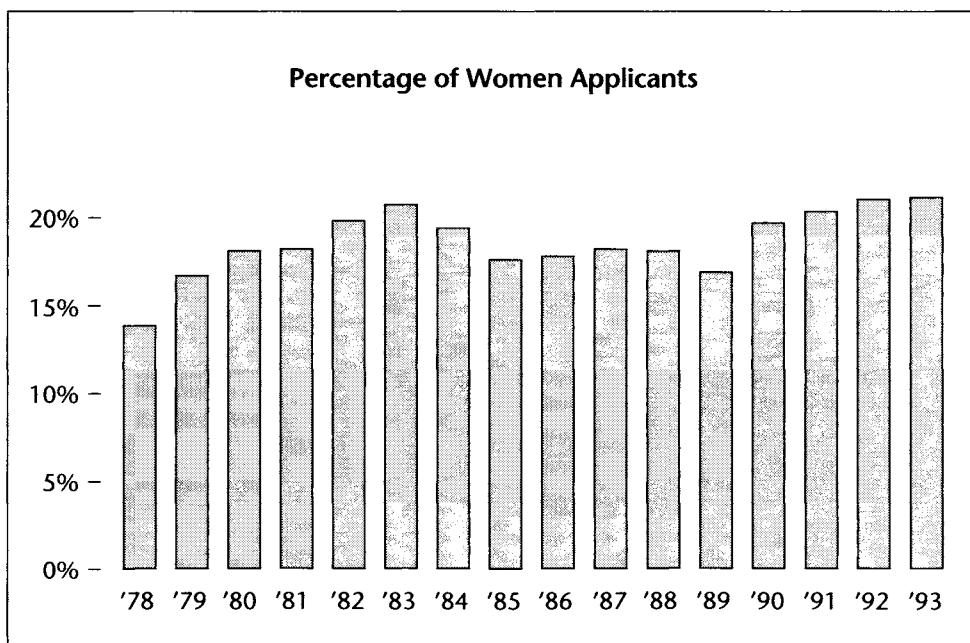
The Cornell College of Engineering is part of a large university, with six other undergraduate schools and colleges. The curriculum allows engineering students to take up to one-third of their courses in nontechnical subjects. We believe that a broad liberal education is an essential in-

"Choosing which students to admit among thousands of applicants is a daunting and time-consuming task. . . ."



Every year the Office of Engineering Admissions evaluates more than four thousand applications.

Over the past sixteen years, the percentage of women applying to the College of Engineering has grown from less than 14 percent to more than 20 percent. While interest in engineering flagged in the late 1980's, the recent increase in applications reflects both a national effort to encourage young women to consider careers in science and technology, and an intensified effort by the College of Engineering to recruit women.



gradient in an engineering education if our graduates are going to become leaders in an increasingly complex, international, and multicultural work environment. So we look for students who also show interest in subjects outside of mathematics and science and who see Cornell as a very special place to receive a liberal education along with technical expertise.

How do we determine which applicants have the qualities we are looking for? Each application includes high school records, college-entrance-exam scores, a review of extracurricular activities, letters of recommendation, and an essay on how and why the student decided to study engineering. This material allows us to evaluate each applicant in two dimensions: academic and personal.

Evaluating Potential: Academic and Personal

In evaluating academic strength we look not only at grades and test scores, but also at the quality and competitiveness of the applicant's high school and the level of the courses taken. Combined with thoughtful letters of recommendation from a guidance counselor or teacher, these elements usually paint a consistent picture of the applicant's academic strength and prepara-

tion for Cornell's rigorous program. In some cases, however, the information is inconclusive or contradictory. That is where experience and judgement come in. We contact teachers and guidance counselors at the applicant's high school and often wait to see midyear senior grades before making our decision.

Although we look at a wide range of factors, most of the students we accept have done well academically and have good test scores. Last year, nine out of ten students offered admission ranked in the top 10 percent of their class. More than nine out of ten scored 650 or higher on the mathematics portion of the Scholastic Aptitude Test (SAT), and three-quarters scored 550 or higher on the verbal portion.

But grades and test scores are not everything. On the personal side, we look at what the applicants write about themselves in the required essays and in describing extracurricular activities. We are not looking for long lists of organizations, but rather, for commitment. We look for evidence of motivation, independence, leadership, and other qualities. What students do in their free time—especially in the summer—often provides significant insights into their character. These glimpses, together with comments from counselors or teachers, give us

a sense of whether applicants have the maturity and motivation to take advantage of the many opportunities at Cornell.

Similarities and Differences among Entering Students

Approximately 40 percent of the students to whom we make offers of admission matriculate at Cornell. Many of the rest choose other top engineering schools. Forty percent is a good yield, considering the competition.

It is all too easy to view entering freshmen as a homogeneous group. In fact, they are remarkably diverse in terms of gender, ethnicity, geographical origin, economic resources, and academic preparedness.

The most obvious differences are in gender and ethnicity. In the fall of 1992, 27 percent of the freshmen were women, and 8 percent were non-Asian minorities. We continue to seek more well-qualified women and underrepresented minority students.

Class members are also diverse geographically. This year we enrolled students from forty-one states and from twenty foreign countries. International students made up 8 percent of the class.

Incoming students represent all economic levels. We select students on an aid-blind basis, without regard for their ability

to pay. As tuition increases each year, financial aid becomes increasingly important, especially in today's uncertain economic environment. More than half of the freshman class receives financial aid of some sort from Cornell. Like other Ivy League schools and MIT, Cornell does not award scholarships for any reason other than need. As a result, Cornell is now losing students to colleges and universities that do award scholarship aid based on merit. Financial aid is now the biggest concern in the admissions community. We desperately want to retain aid-blind admissions, but the cost to the university is growing at an alarming rate, due largely to reduced government support for education. A significant endowment for financial aid will be a key element in continuing Cornell's current aid policy.

Perhaps most significant to academic success are the different levels of academic preparedness. High schools across the country vary enormously in the rigor of their academic programs. One of our new freshmen may be in the top 8 percent of a magnet school in Virginia that requires a competitive entrance examination, while another may be valedictorian at a rural school in Maine, where few graduates go on to college. The student from Virginia may have had up to two years of calculus, as well as a



Admissions staff members Maya Fernández-Llanio (left) and Loni Wheeler-Franklin help decide which applicants show promise.

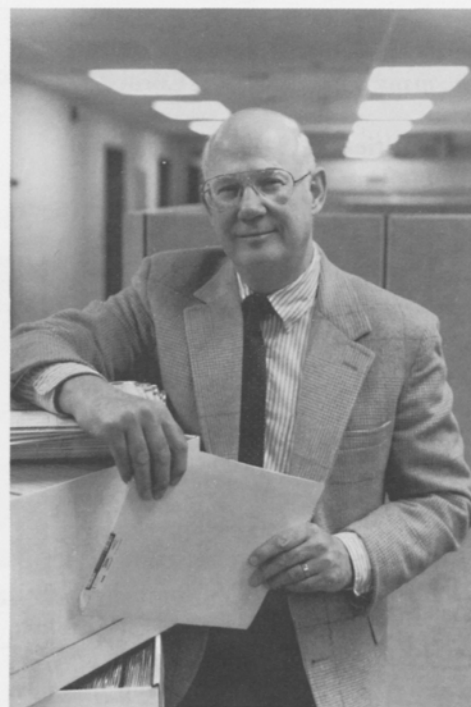
*"Each year . . . we
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year of computer science. The one from Maine may not have had any calculus or computer science. Both can, and probably will, be successful here, but the valedictorian may need some time to adjust to Cornell's competitive environment. The Office of Engineering Admissions has been instrumental in developing a process whereby such a student is advised to take a reduced course load first semester (four courses instead of five) to facilitate this adjustment. Fortunately, the college has a strong advising system which, together with offices for women's programs and minority programs, can facilitate a smooth transition for each student from high school to Cornell.

Assembling a Class That Can Make the Grade

Each year, after all the scores are received, all the letters of recommendation reviewed, and all the offers made, we have assembled a class of about seven hundred of the most talented high school graduates from this country and beyond. Each student is an individual with an individual personality, goals, contributions, and opportunities.

Yet all have much in common—academic track records of the highest caliber, involvement in community or extracurricular activities, and curiosity about the world around them. And each, we believe, has the talent and confidence to succeed in a challenging engineering curriculum and to become a Cornell engineer.



Richard Hale is assistant dean and director of admissions at the College of Engineering. He came to the college in 1984 as assistant director of admissions and served as acting director before being named to the post in 1990.

Hale is a graduate of Antioch College and received a master's degree from the Graduate School of Aeronautical Engineering at Cornell in 1958. He spent six years at United Aircraft Research Laboratories (now United Technologies) and then returned to Ithaca to work at Therm Advanced Research. In 1968 he was a partner in forming Sage Action Inc., a research and development company. (One of the products Hale helped develop is the bubble generator, a tool for visualization of air flow.) He also spent three years as director of management information systems at Tompkins Cortland Community College.

Engineering in Context

by Robert J. Thomas

Freshman engineering students are often disappointed by how little they learn about engineering. They may have been tinkering with old cars or programming computers for years, and they want to begin learning how such skills can be put to use in a paying profession. Instead, they must begin with courses in mathematics, physics, and chemistry that seem like nothing so much as a continuation of high school.

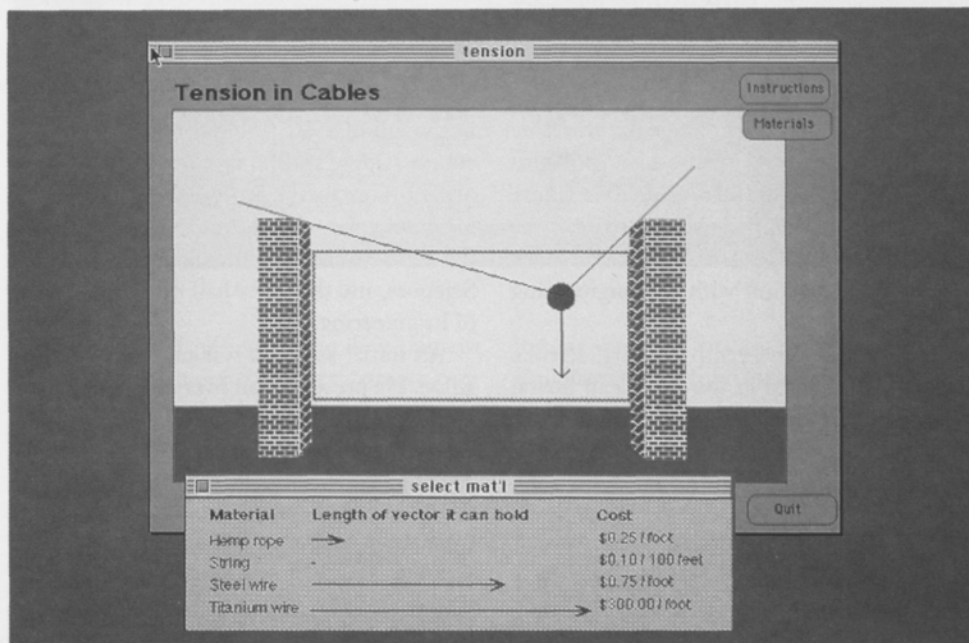
The need for a firm grounding in general subjects means that freshmen may not gain any clear idea of what engineers actually do until they begin taking more specialized courses the following year. Many incoming students do not realize that the essence of engineering is compromise—that an engineer designing a new device cannot just optimize its mechanical characteristics, but must also take into consideration the cost of building it, the safety of the people who will use it, and a host of other factors. Some students think that engineers work by themselves, tinkering in a

room full of equipment until they come out shouting “Eureka!”—when, in fact, today’s engineers often work as teams. Ironically, freshmen are expected to put forth their best scholastic efforts in preparation for a profession that many of them scarcely understand.

Understanding Engineering in Its Real-World Context

To address this problem, I set out, with the collaboration of three colleagues, to design a course that would give freshmen a broad view of the profession. In mid-1991 I got together with Richard H. Lance, of the Department of Theoretical and Applied Mechanics; Geraldine K. Gay, of the Department of Communication in the College of Agriculture and Life Sciences; and Ronald R. Kline, a specialist in the history of technology who is affiliated with the School of Electrical Engineering. Together, we began the arduous process of mapping out a new course, to be called Engineering in Context.

“The need for a firm grounding in general subjects means that freshmen may not gain any clear idea of what engineers actually do”



A problem involving tension in cables is presented in interactive courseware. Students can slide the weight back and forth, changing the vectors that appear above the brick pillars, and determine an appropriate material in terms of its strength and cost.

We decided to pitch the course at a level that would be accessible to students in other colleges, as well as freshmen in engineering. In particular, we tailored it so that it would be acceptable in the new “science distribution option” in the College of Arts and Sciences and also serve as an “introduction to engineering” course in the engineering curriculum. We wanted a course that would inform students, early in their academic careers, about the fundamental principles that guide practicing engineers in their work. We wanted to explore, with these students, the evolution of engineering and the interdependence between engineering and science.

Everyone in modern society is touched by the products and the technology created by engineers. And engineers have to make technological decisions that have political, social, and economic dimensions. In order to resolve issues involving waste management, nuclear energy, or automobile safety, for example, it is necessary for engineers to have an appreciation of nontechnological issues, and for nonengineers to have a basic engineering literacy. An appreciation for engineering achievements, as well as a sense of their limits and hazards, is needed in order to sort through the welter of technological information relevant to important issues of the day.

Many engineering students are poorly informed about today’s social, political, and economic problems, and fail to see their relevance to engineering. Professors have often shown students how to solve problems with known solutions, while sometimes failing to stimulate their intellects or encourage the creativity they will need to solve open-ended problems that characterize the real world. This failure to make engineering relevant within the human context may be at the root of much student dissatisfaction with the engineering curriculum.

Early in the nineteenth century, science came to be included in the American liberal arts curriculum. Colleges began to expect their students to master natural history, chemistry, and natural philosophy (physics) as part of a standard, “classical,” education. When most colleges adopted an elective system in the second half of the century, they retained these courses as “science requirements.” We have inherited this system largely intact, despite

momentous changes in the role of science and technology in American life. Many educators are beginning to feel that a basic understanding of engineering should become part of a liberal education—among them David P. Billington, the expert on “civil engineering in context” who is currently an A. D. White Professor-at-Large at Cornell.

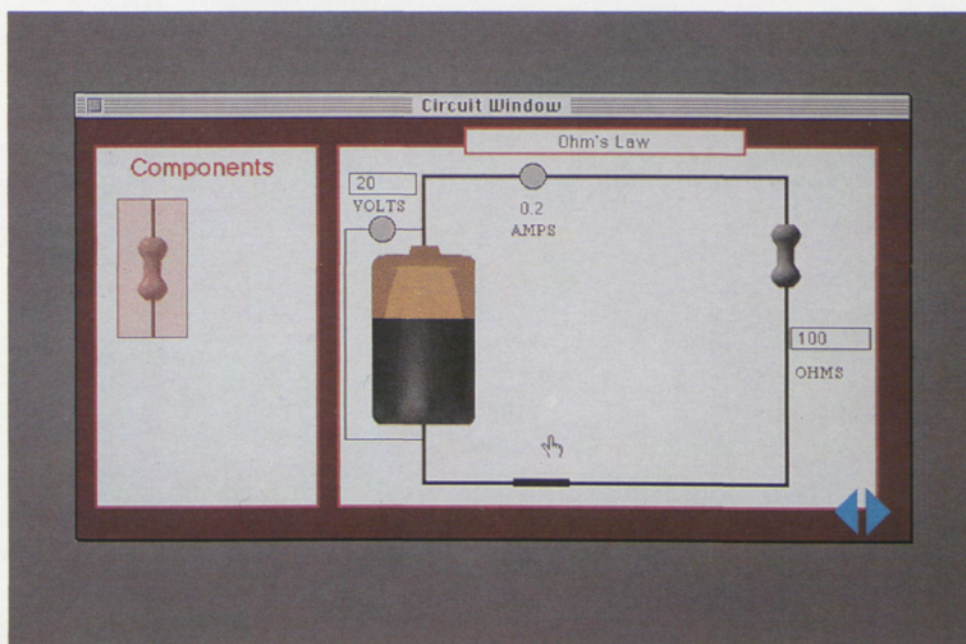
As we worked to develop the new course, we were guided by four general principles. We wanted to focus on ubiquitous technologies that are interesting to practically everyone. We wanted to present and examine fundamental principles that have guided engineering design in the past and will continue to do so in the future. We wanted to examine the social, political, and economic context in which engineering design is embedded. And we wanted to convey this material in an exciting way, making use of the latest and best technology and techniques for classroom presentation.

Our goal, broadly defined, was to give students an appreciation for engineering as a profession, a sense of the integrated design concepts that characterize the different engineering disciplines, and an understanding of the way in which technological know-how is constrained by social, political, and economic factors. We wanted the course to alter the thinking of students in the same way that a course on art appreciation alters the way people look at paintings.

A Broad View of What Engineers Do

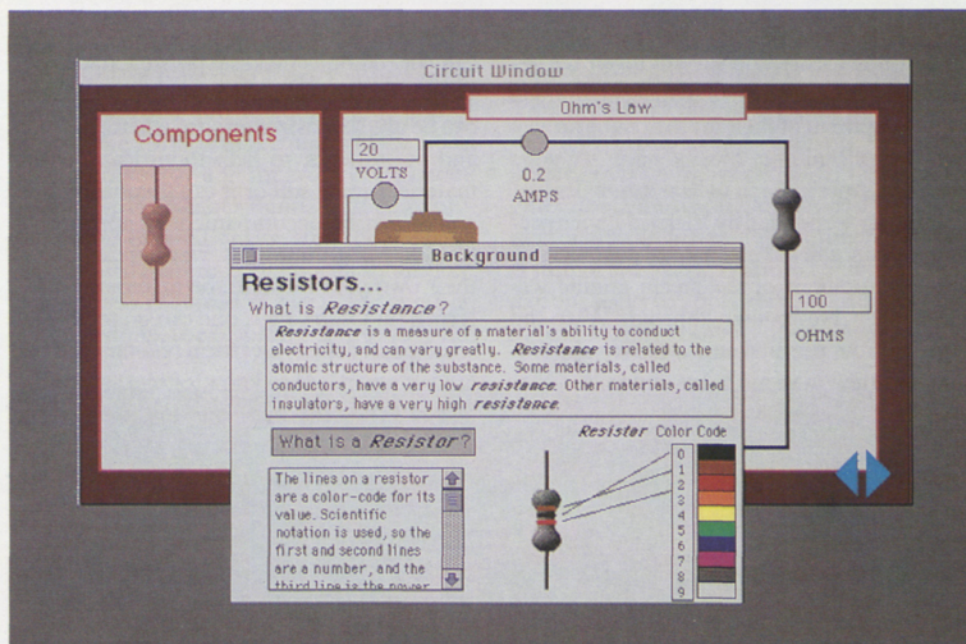
The new course was taught for the first time in the fall of 1992. We did not advertise the course widely and limited the enrollment in order to contain the problems we knew would inevitably arise. Half the students who took the course were from the College of Arts and Sciences, and the other half from the College of Engineering.

An initial segment was taught by Ronald Kline. He presented an overview of the engineering profession from a historical perspective, following the rise of science-based engineering, the transition from the individual inventor to the research-and-development laboratory, and the evolution of the design process. He inquired into the relationships between science, technology, and engineering. He looked at engineering as a kind of social



Interactive courseware lets students go from one screen to another to find out what they want to know. For example, the screen at left is an introduction to Ohm's Law, showing a simple circuit containing a battery, a resistor, an ammeter, and a voltmeter. All quantities may be varied.

Selecting different items on the screen gives access to further information. By choosing the resistor, one can see the screen shown below, which explains resistance and shows the color code used to mark resistors.



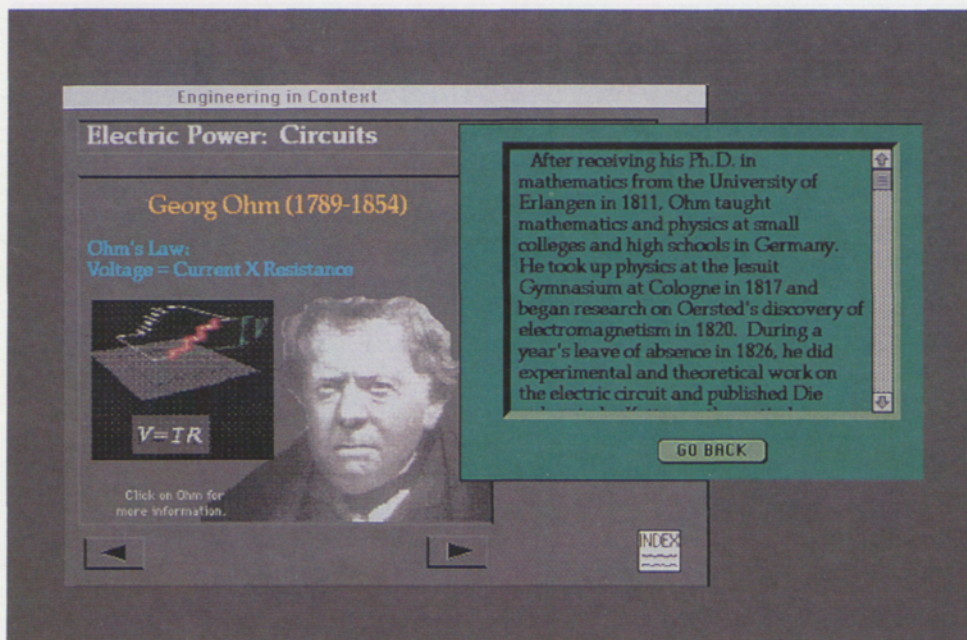
experiment, and presented the development of chemical engineering in the twentieth century as a case study.

Next, Richard Lance presented a section of case studies in civil engineering. He discussed the Brooklyn Bridge as a nineteenth-century icon, as well as other suspension bridges. He described the principles involved in the arch, and showed how they are used in the design of bridges. He also discussed build-

ings as symbols, including the Empire State Building and the John Hancock Tower, as well as dams and their relation to conservation and power, with special reference to the Tennessee Valley Authority and the Hoover Dam.

In a section on communications and the collaborative design process, Geraldine Gay presented a model of communication theory, together with the social commentary of Marshall McLuhan and Charles Horton

This screen gives a picture and a brief biography of Ohm, together with a graphic representation of Ohm's Law.



Cooley. She focused on several inventive geniuses and the circumstances that surrounded the development of their inventions. A project with Lego building blocks gave students hands-on experience in collaborative design.

Another section led by Richard Lance presented case studies in mechanical engineering. The development of the steam engine was traced from Newcomen through Watt and Otto, with its use first in stationary applications and then in steam boats and railroad locomotives. Also explored were the development of flight, from the Wright brothers to Langley; and the rise of the automobile and the construction of the interstate highway system.

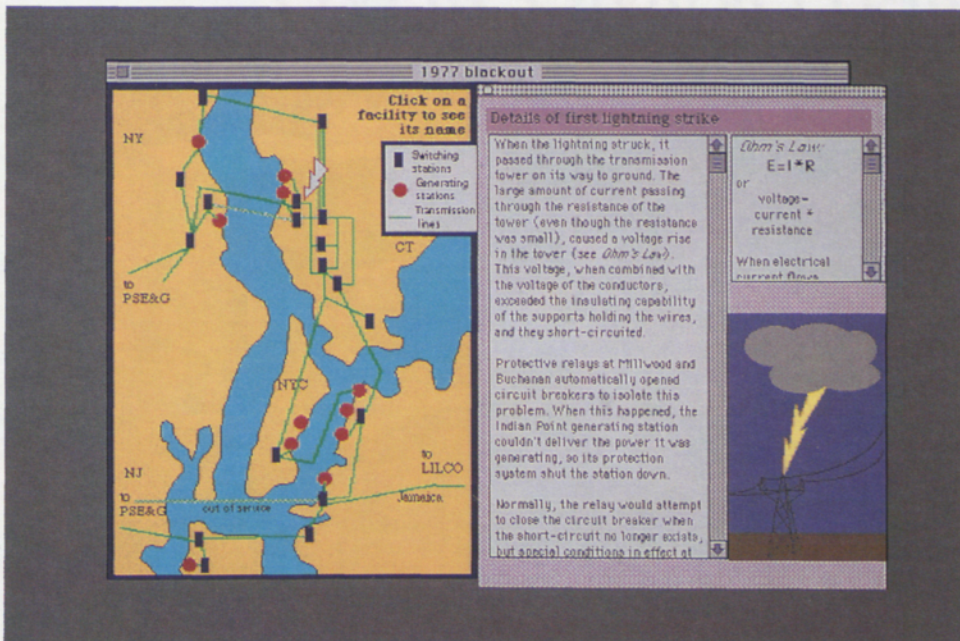
Finally, I presented a section on electrical engineering. The evolution of modern electric power systems, from Edison's Pearl Street station to modern integrated systems, was followed by a discussion of alternative energy sources (fossil fuel, hydroelectric, nuclear, and renewable) and alternative modes of transmission. The famous New York City blackout of 1977 served as a case study.

Electronic Courseware Really Tells the Story

The course was taught with the aid of custom-made electronic "courseware." The vast amount of digital data that can be stored lo-

cally or remotely makes it possible to develop flexible multimedia information modules that can be used by instructors, to help them teach, and by students, to help them learn. Visual material can be still or it can involve motion, and it can be accompanied by appropriate sounds. Most important, viewers can choose their own path through the material. From a screen on Ohm's Law, one can go to another screen that defines electrical resistance, if that is what one needs to know, or to a screen that gives a brief biography of Ohm and explains how he developed the law that bears his name. One can go in yet another direction, and find out about modern applications of Ohm's Law. Instructors can do this and project the material on a screen that can be seen by the entire class, or students can do it at their own terminals, exploring a concept from all angles until it really makes sense to them.

The author Gail Goodwin has said, "Good teaching is one quarter preparation and three quarters theater." With electronic courseware, the theater part is run with electrical energy, but the preparation part still requires human energy. Courseware for Engineering in Context was prepared with the help of Michael Tolomeo and Scott McCormack of the Engineering Multimedia Research Laboratory (EMRL), which I direct. Some of the material was developed in collaboration with the In-

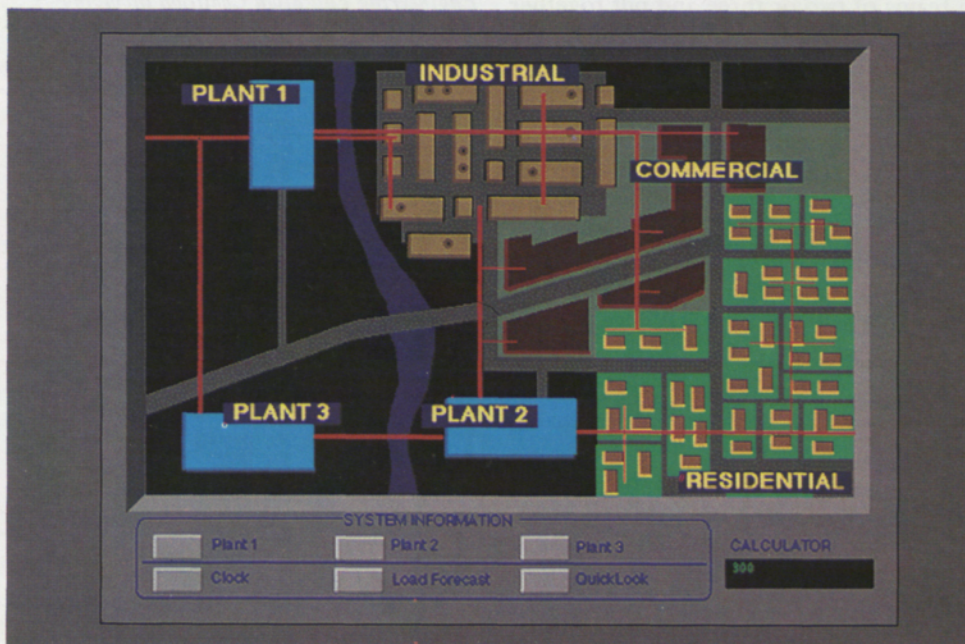


A practical application of Ohm's Law is given in a sequence that explains the great blackout of 1977, when lightning set off a chain of events that plunged New York City into darkness.

teractive Multimedia Group (IMG) directed by Geraldine Gay. The EMRL is housed in the Engineering and Theory Center Building and the IMG is in Kennedy Hall. Costs were defrayed by a grant from the Cornell University President's Fund. All the instructors either created or directed the creation of their own material. An enormous amount of work was required to put it all together, but once done, the resulting courseware has

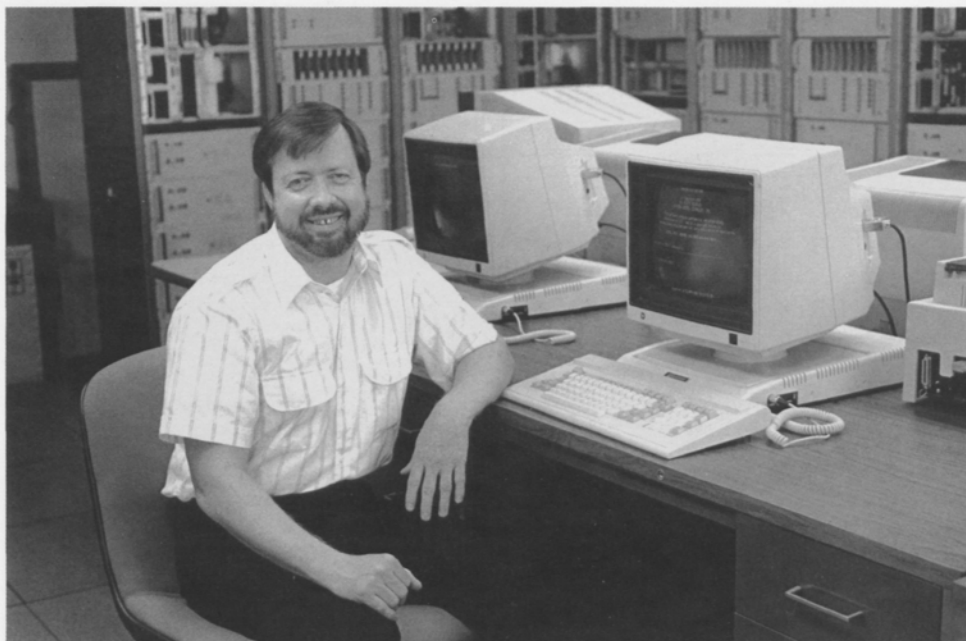
flexibility and broad utility. It can easily be edited and updated, and it can be used for similar courses taught at other institutions.

Indeed, the courseware was developed under the aegis of Synthesis, a National Engineering Education Coalition. This initiative, which involves eight universities and is supported by the National Science Foundation, seeks to apply state-of-the-art techniques to the problems of engineering edu-



A more advanced problem in power-systems engineering asks students to find the most efficient use of multiple power plants to service a complex load.

"we were a new group of instructors collaborating in a new venture, a new teaching style, the integration of a new collection of materials, and a new mix of students."



cation. The Engineering Multimedia Research Laboratory was inspired by Synthesis, and the courseware produced can be used or adapted by other members of the coalition.

An Innovative Course Off to a Good Start

"Term papers" for the course were "written" in the same medium. Students worked in teams of two or three and put together interactive presentations that allow the viewer to explore topics such as the design and use of bicycles or electric-vehicle technology.

Student response to the course was enthusiastic. One student said, "I found the course informative about engineering and it helped me to decide the field I want to study," and another said, "The teaching style was great. I hope more courses will be taught in this manner." We, the instructors, have learned a great deal from this experience. We knew at the outset that we were taking on a host of potential problems; we were a new group of instructors collaborating in a new venture, a new teaching style, the integration of a new collection of materials, and a new mix of students. Before we teach the course again, we will take into account the feedback we received from the students and

from each other. But it seems clear that the students from other colleges who took the course have a much better appreciation for engineering, and the engineering students who took the course now know where they are headed.

Robert J. Thomas represents Cornell on the board of directors of Synthesis, a National Engineering Education Coalition involving eight universities. The coalition, which is sponsored by the National Science Foundation and funded at \$30.6 million over five years, is working to develop and make available innovative courseware and curricular ideas.

Thomas is a professor in the School of Electrical Engineering, where his research focuses on the development of analysis and control techniques applicable to dynamic problems in large-scale power systems. He came to Cornell in 1973, after earning the Ph.D. at Wayne State University. In 1979-80 he spent a sabbatical leave with the Department of Energy's Office of Electric Energy Systems in Washington, as an assistant program manager. He returned to Washington in 1986 for a two-year assignment as a program director in the Division of Electrical Communications and Systems Engineering of the National Science Foundation.

OVERCOMING BARRIERS FOR WOMEN IN ENGINEERING

by Michele D. Fish

When you walk into class for the first time, you feel that everyone is looking at you. You sit down, open your notebook, and wait for the professor to appear. You wonder whether you are in the right class. Ever since you got interested in science and mathematics in the sixth grade, people have thought you were weird. Your high school guidance counsellor had suggested that you work toward a career in accounting. But here you are at one of the best universities in the country, trying to become an engineer.

You look around and see only three other women, in a class of thirty. You feel that you are on display. But when the professor asks a question of the class, he seems to look past you, expecting an answer elsewhere. You wonder if it is worth raising your hand anyway; when the professor does call on you, he sounds patronizing. You got all As and Bs in high school, but when you get a C+ on the first exam, you think that maybe you are just not

smart enough to be here. (The fellow next to you, who also gets a C+, blames it on the professor's "lousy exam.")

You find it hard to form study groups with other students, afraid that they'll react to you more with their glands than their brains. You feel awkward about asking the professor for special help. You begin to think about transferring to some other program, in which women are not regarded as an oddity. If you tough it out for four years, you may still find it hard to get a job. Professors who do not know you as well as your more assertive classmates convey only faint praise when they write your recommendations. Companies may wonder whether a woman can really do the job.

Obstacles in the Path of Prospective Women Engineers

This is what it is like for many women in an engineering curriculum. Engineering is one of the few professions that continue to be dominated by men. Other fields, such as medi-

"Engineering is one of the few professions that continue to be dominated by men."



As part of its effort to recruit more women, the College of Engineering hosts a "Women-in-Red Weekend," which especially promising candidates for admission are invited to attend. Here, Shelley Castro (left) and Jessica LeBlanc listen to a presentation.

A panel of women students tells high school students who have come to campus for the "Women-in-Red Weekend" about the Cornell experience.



cine, law, and business, have opened their doors to women in recent years. But in engineering, women still make up only 8 percent of the work force. Many barriers, both real and perceived, still impede women's access to the engineering profession.

Obstacles that stand in the way of women's success come into play long before they arrive on campus. Girls with an aptitude for engineering may not be encouraged by parents, teachers, or counselors in junior and senior high school. Those who persist and are accepted into engineering programs are stereotyped as unfeminine. Male students are taken more seriously by professors and teaching assistants, and women often feel left out and isolated. Women of color face a double handicap.

Women also have to overcome their own internal barriers. Even though females who enter engineering programs may be as bright and as highly motivated as their male classmates, they often lack self confidence. A recent study of why Cornell students leave engineering showed that males tended to blame failure on external factors, such as the way their professors explained things or the makeup of the exams, while women tended to internalize failure, blaming themselves when their standards and the standards that others had set for them were not met. Women reported feeling

they were "in over their heads" academically, their backgrounds were too weak, and their grades were lower than they expected. This tendency for women to blame themselves often undermines their commitment to engineering. They give up in the first or second year, transferring at a higher rate than their male peers to other majors. To receive higher grades and feel more successful, they sacrifice the challenges and rewards of a career in engineering.

If more women are to become engineers, they need extra support—at least at the start. Women have been excluded from engineering ever since the profession began, and change is not easy. As Lilli Hornig has written, "Most people, male or female, are just not cut out to be pioneers, and the individuals who consistently find themselves chosen last when teams are picked usually go and find some other game to play." But this must not continue. It is not fair to millions of talented women for engineering to be an exclusively male profession. And besides, society needs more engineers. Nationally, the number of full-time undergraduates in engineering programs is falling. This is due, in part, to the shrinking college-age population, which is expected to go on declining through the mid-1990s.

Cornell has been working hard to develop an academic environment that makes it pos-

sible for women to succeed in engineering degree programs. Through equitable recruiting and admissions procedures, more women are entering the engineering curriculum. In their classes they see more people who look like them and are able to find academic and emotional support. And skillful guidance in career planning helps them approach the job market with confidence.

Recruiting More Women into a Friendly Environment

The Office for Women's Programs in Engineering was established July 1, 1991, to promote the recruitment and retention of undergraduate women in engineering. In the spring of 1992, a Student Advisory Board was established to act in an advisory capacity, helping the office tailor programs to meet the needs of female engineering students. There are currently fifteen student members, representing all four classes—freshmen through seniors—who meet monthly throughout the academic year. They have contributed many valuable insights.

The Cornell College of Engineering has made an intensive effort to recruit women, and the effort has paid off. Women now constitute 24 percent of the undergraduate student body, as contrasted with 17 percent for engineering and technical colleges nationwide. As part of

this ongoing effort, the college recently produced a video called "She's the Engineer." This video shows high school girls who are already in the mathematics and science track how they can use their talents to pursue an engineering career. Both college and professional life are discussed in realistic terms, in a format that appeals to the target age group. Brochures about the video are sent to high school girls who might want to pursue engineering degrees, along with information on how they can receive a copy for a nominal fee. The video is also used by thirty-five or forty members of the Society of Women Engineers who return to their high schools each year to discuss their experiences as engineering students.

To help improve the climate for women, the office organized a series of workshops to sensitize the faculty to the long-standing cultural biases that subtly undermine women's success in engineering. The Cornell Interactive Theatre Ensemble performed a scenario depicting a female student talking with her advisor about sexism that she had experienced in one of her classes. The audience of faculty members was then encouraged to ask questions of the characters to get a sense of why the student and advisor behaved as they did. Feelings were also explored, allowing the audience to learn in a nonthreatening manner about the power of sexism and the anguish it



High school seniors Sun Joo Kim and Alison Aubrecht (left and middle) discuss their impressions of Cornell with freshman Carrie Ortiz.

can cause. The faculty members were then able to explore the ways in which they, as instructors and as faculty advisors, can work more effectively with their female students.

To help women feel more connected to the College of Engineering and the women's program, a periodic newsletter, *Women and Engineering News*, is sent to all women students in the college as well as corporate friends and other friends of the university. Through this newsletter students can learn about events in the college, information of importance to women, scholarship and fellowship opportunities, and noteworthy accomplishments of women in engineering at Cornell and elsewhere.

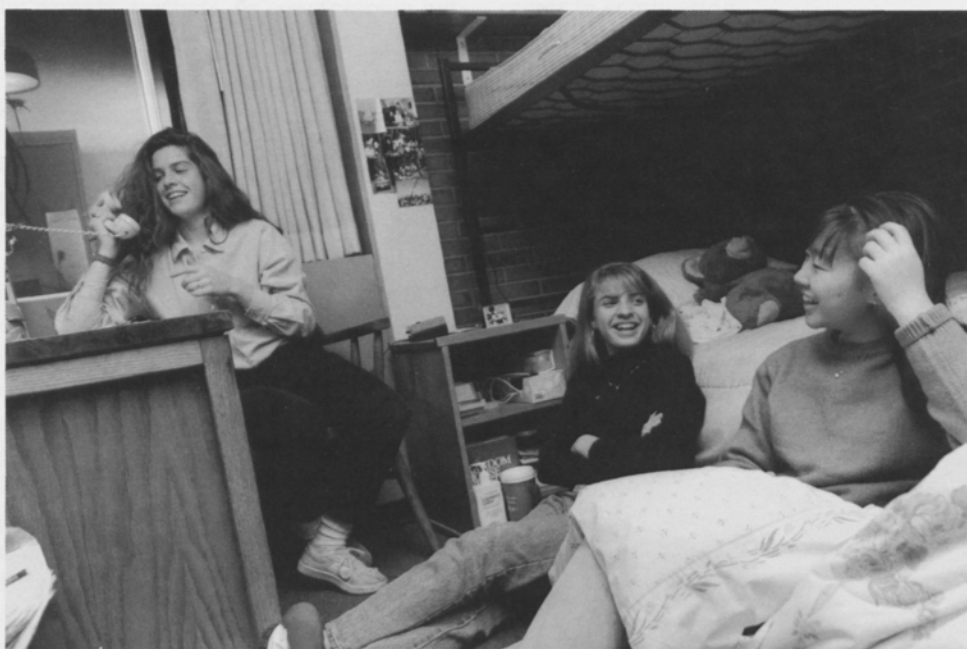
Supporting Women As They Cope with a Challenging Curriculum

Among the college's first institutional efforts on behalf of women was a mentoring program, started in the spring of 1991, before the Women's Program in Engineering was even established. Freshman women were paired with graduate and faculty women in engineering in the hope that students and mentors would develop relationships that would be rewarding and would provide the students with a special resource and role model. Not many relationships developed, but the students felt supported by the mere existence of the pro-

gram. The following year when the mentoring program was offered, junior and senior women were assigned as "big buddies" to freshmen. Some graduate students and faculty women served as second mentors to freshman women, or continued as mentors to upper-level women.

Transition to college can be a challenge for anyone, especially for women who have chosen a nontraditional field of study. To help in this transition, an engineering tutorial section, designed specifically for women, was set up. This provides women in their first semester with an opportunity to meet weekly with their female faculty advisors and form social and academic support networks with other participants. Invited speakers give presentations about various programs in the college, study techniques and time-management skills, and how to deal with stress. Classroom discussions and interaction are encouraged. Upper-level students and professional women engineers, who serve as important role models, talk about their experiences and the challenges and opportunities they have faced.

In the spring 1992 semester, a tutoring program was started, offering freshman and sophomore women tutorial help with basic courses from paid women tutors. This tutoring, which is generally one-on-one but sometimes in a group format, provides needed aca-



To get a sense of campus life, Alison Aubrecht and Sun Joo Kim (middle and right) spend a night in the dormitory with freshman Carrie Ortiz.



High school students brought to Cornell for the "Women-in-Red Weekend" are treated to a variety of demonstrations and hands-on displays. Here, Grace Park tries her hand at designing a bridge in the Computer-Aided Design Instructional Facility.

ademic assistance as well as peer support and encouragement. The fall 1992 semester saw a 25 percent growth in this program, with 60 students being tutored by 13 tutors. The office has received a great deal of positive feedback from tutors and those being tutored, suggesting that this is a most important service.

In the fall of 1992, a Women's Resource Room was opened in the Engineering Library to provide informational materials targeted to the issues women encounter in a male-dominated field. The materials cover career planning, techniques for boosting self-esteem, team management, sexism, sexual harassment, and women as role models in mathematics, science, and engineering. The room also provides a place where all members of the community, including faculty, staff, and students, can find information that may be used to help create a more positive environment for all. The Engineering Library and Women's Programs in Engineering are working together to purchase and gather materials for the collection. A book endowment has been established to receive funds designated for this purpose.

Planning for a Career and Joining a Women's Network

A "Women-in-Engineering Career-Planning Seminar" was begun in the spring of 1992 to help junior and senior women make impor-

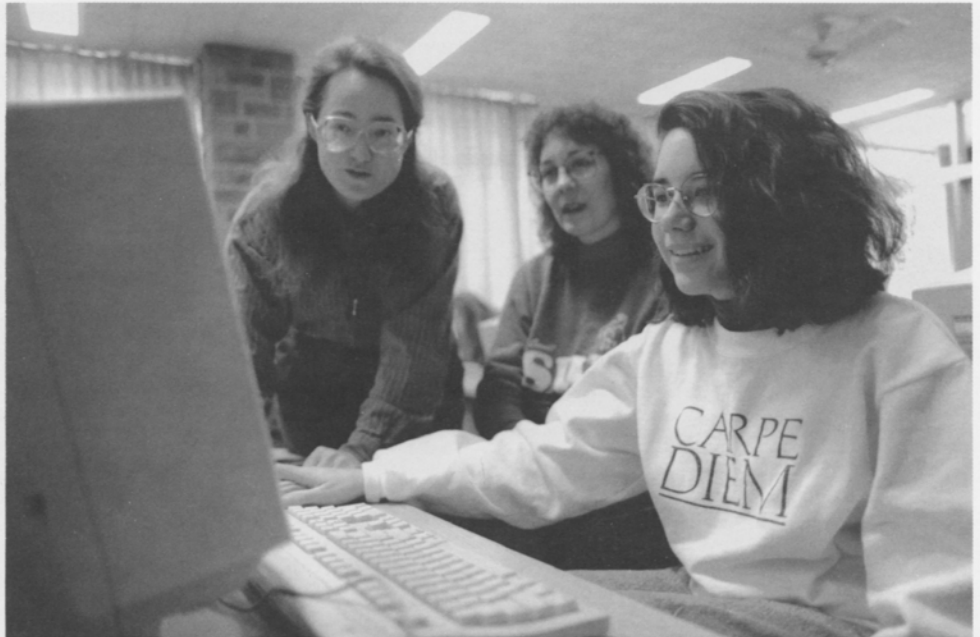
tant career decisions and assist in the transition from college to the workplace. The course covers career planning, graduate-study options, aspects of transition to the engineering profession, sexism in the workplace, and related issues of special interest to women. Corporate professionals and Cornell faculty and staff members participate in classroom discussions. One student said, "Enrolling in this course has truly allowed me to realize what I want for my professional career and the rest of my life. The course has taught me to make affirmative decisions about my future and select the most desired and effective path to achieve my goals, as well as look for alternate paths in case my ideal path is not possible."

The Cornell Student Chapter of the Society of Women Engineers has been active for many years. It is an important organization that encourages social and professional support and provides leadership opportunities for women. The chapter has been named the best student section in its region for the last three years in a row. Activities for members include monthly general meetings with talks by engineering professionals or faculty members, study sessions, and social events. The Professional Networks Dinner, which is held twice a year, allows members to dine at a local restaurant with engineering professionals, faculty members, and spouses. It provides an oppor-

"Some freshmen must take a heavy load of required courses, then find experience of college is a daily round of large classes."

Richard David Kelly and Len Kohnen make a local restaurant to begin planning the 1993 edition of Mathematics 191

Kathleen Remington, a high school senior eager to "seize the day," develops an animated figure as Catherine Mink and Michele Fish (center) look on. Mink is educational computing coordinator of the Computer-Aided Design Instructional Facility.



tunity to talk, in an informal setting, about what it's like to be an engineer in industry or academia while coping with families and other responsibilities. Students also learn the importance of networking for a successful career.

It is still too early to tell if the activities undertaken in the last year have contributed to the retention of women students in engineering. Attrition can only be viewed in retrospect. But the Office for Women's Programs in Engineering is committed to continually assessing the reasons why students leave and working to build an environment where they feel accepted and supported. Hopefully, a day will come when there will no longer be a need for such an office. Until then, efforts to help women find their place in the engineering profession will continue.

Michele D. Fish is director of the Office of Women's Programs in the College of Engineering. The office was established in 1991 to focus attention on the recruitment and retention of undergraduate women in engineering.

Fish, who holds a bachelor's degree in human service studies from Cornell's College of Human Ecology, has worked in various administrative positions in the College of Engineering since 1980. She initially assisted the director of undergraduate programs, the graduate field representative, and the chairman of faculty recruiting in the Department of Computer Science, where she later became the assistant director of undergraduate programs.

In January 1989, Fish became the assistant director of advising for the College of Engineering. In that capacity, she was responsible for counseling and advising students and developing and coordinating faculty-student advising programs. Concurrently, as part of her degree requirements in human ecology, she served as a social-work intern in the Office of Undergraduate Programs in engineering, where she compiled and analyzed several years of data to determine attrition rates for student subgroups in engineering. Fish was named first director of the Office of Women's Programs in July 1991.

To get a sense of campus life, Alison Aubrecht and Susan Kim (middle and right) spend a night in the dormitory with freshman Carrie Ortiz.

CHANGING A FILTER

The Reorganization of Mathematics 191

Anyone who has ever sat in a large lecture hall knows what it's like. Two hundred students in ascending tiers of adjoining chairs look down on a professor who walks back and forth, talks, and occasionally writes on a blackboard with a piece of chalk. As theater, it's not very interesting. As a relationship, it fails completely: The professor must cover a preordained amount of material with a lecture carefully pitched to the average student, and questions, which interrupt the flow, must be answered briefly. The professor does not know students' names, and students feel sufficiently anonymous to owe the professor little respect. One student eats lunch. Another covertly reads a magazine. People cough. Papers rustle. Minds wander.

Required courses invariably have big classes because so many people have to take them. Since freshmen must take a heavy load of required courses, their first experience of college is a daily round of large classes. Freshman engineering students take required

courses in mathematics, physics, chemistry, and computer science. Traditionally, all meet in large lecture sections—even though they also involve smaller recitation sections, led by teaching assistants. But this is neither a hospitable way to welcome students to the university nor an environment that is conducive to learning.

One of the tightest gauntlets that engineering students have to run is Mathematics 191, Calculus for Engineers. The amount of material that must be covered in just a few weeks makes the course extremely demanding. Integration, for example, is basically taught in one lecture—although it took Newton years to develop the concept. With about 180 students in each of two sections, individual attention has been all but impossible. Professors have had to give generic lectures, pitched at an intermediate level. They could neither pause to help students who found the material difficult, nor go into more detail to maintain the interest of those who found it easy.

"Since freshmen must take a heavy load of required courses, their first experience of college is a daily round of large classes."



Richard Rand (left) and Lars Wahlbin met in a local restaurant to begin planning the reorganization of Mathematics 191.

Faculty members from several different fields taught sections of Mathematics 191.

Participating Faculty			
<i>Name</i>	<i>Rank</i>	<i>Department</i>	<i>Number of Sections</i>
Kenneth S. Brown	Professor	Mathematics	2
K. Bingham Cady	Professor	Nuclear Science and Engineering	1
J. Robert Cooke	Professor	Agricultural and Biological Engineering	1
John M. Guckenheimer	Professor	Mathematics	1
Philip J. Holmes	Professor	Theoretical and Applied Mechanics	1
C. Y. Hui	Associate Professor	Theoretical and Applied Mechanics	1
Michael C. Kelley	Professor	Electrical Engineering	1
Richard H. Rand	Professor	Theoretical and Applied Mechanics	1
Charles E. Seyler, Jr.	Associate Professor	Electrical Engineering	1
Michael Stillman	Associate Professor	Mathematics	3
Éva Tardos	Associate Professor	Operations Research and Industrial Engineering	1
Lars B. Wahlbin	Professor	Mathematics	2

Rethinking the Way Calculus Is Taught

To improve the quality of life for freshmen and give them a better chance to learn calculus, the College of Engineering has undertaken a complete reorganization of this course. The initiative came from William B. Streett, dean of the College of Engineering, and Don M. Randel, dean of the College of Arts and Sciences. The details were worked out by a team from both colleges, led by Richard Rand, of the Department of Theoretical and Applied Mechanics, and Lars Wahlbin, of the Department of Mathematics. Their first meeting took place in a local restaurant, where they began figuring out how to break the class into many small sections while maintaining overall uniformity. Rand says, "My criterion for a good design was to have it all planned out in advance—exactly who was going to do what."

In the fall of 1992, Mathematics 191 was taught in sixteen small lecture sections with an average class size of twenty-three students. This involved twelve professors—eight from the College of Engineering and four from the Department of Mathematics. Students attended three weekly lecture sections led by a professor as well as two weekly recitation sec-

tions led by a teaching assistant. The professors and teaching assistants met for periodic "town meetings" to make sure that they were all covering the same material, and at the same rate. Three preliminary exams and a final exam were each written by a different team of faculty members. Ninety percent of the grade was based on these exams, and 10 percent on the evaluation of the professors who taught the individual sections. Wahlbin says, "The teachers were free to do whatever they wanted as long as they kept up with the exam schedule."

Small Lecture Sections: Easier on Both Professors and Students

The faculty member best able to appreciate the change of format is C. Y. Hui, of the Department of Theoretical and Applied Mechanics. He taught Mathematics 191 in large sections for three years, and then taught one of the small sections last fall. "From a lecturer's perspective," he says, "it's easier to teach a small class than a big one." In a big class, a special effort must be made to hold the students' attention. "If you lose 5 percent of the students, you don't really have a good lecture. The lecture hall starts getting noisy and pretty soon some of the students stop coming because

they've decided, 'This is not interesting.' So even though you have to give a generic lecture, you have to say something interesting. Every fifteen minutes, you have to get their attention back."

A particular difference that Hui has noticed is in what happens when the professor makes a mistake, as sometimes happens during a complicated, multistep explanation. "In a large class," he says, "any little thing you do that is wrong gets amplified. You have to prepare very carefully, because if you make a mistake, you lose the students' attention. But in a small class, where students get to know you personally, they overlook your limitations. You just correct the mistake and go on."

Many of the engineering professors responsible for sections of Mathematics 191 had not previously taught calculus. Representative of this group is K. Bingham Cady, of the Program in Nuclear Science and Engineering. He says, "I'm familiar with all the math in this course, but I still learned interesting things myself." He found the students in his section enthusiastic and hard-working and he enjoyed teaching them. "Whenever I found that I was losing the class," he says, "I would stop trying to cover a lot of ground and try, instead, to *uncover* just a little." On exams, most of the section performed at or above the mean. One student had trouble assimilating the material,

and Cady spent many hours giving individual help.

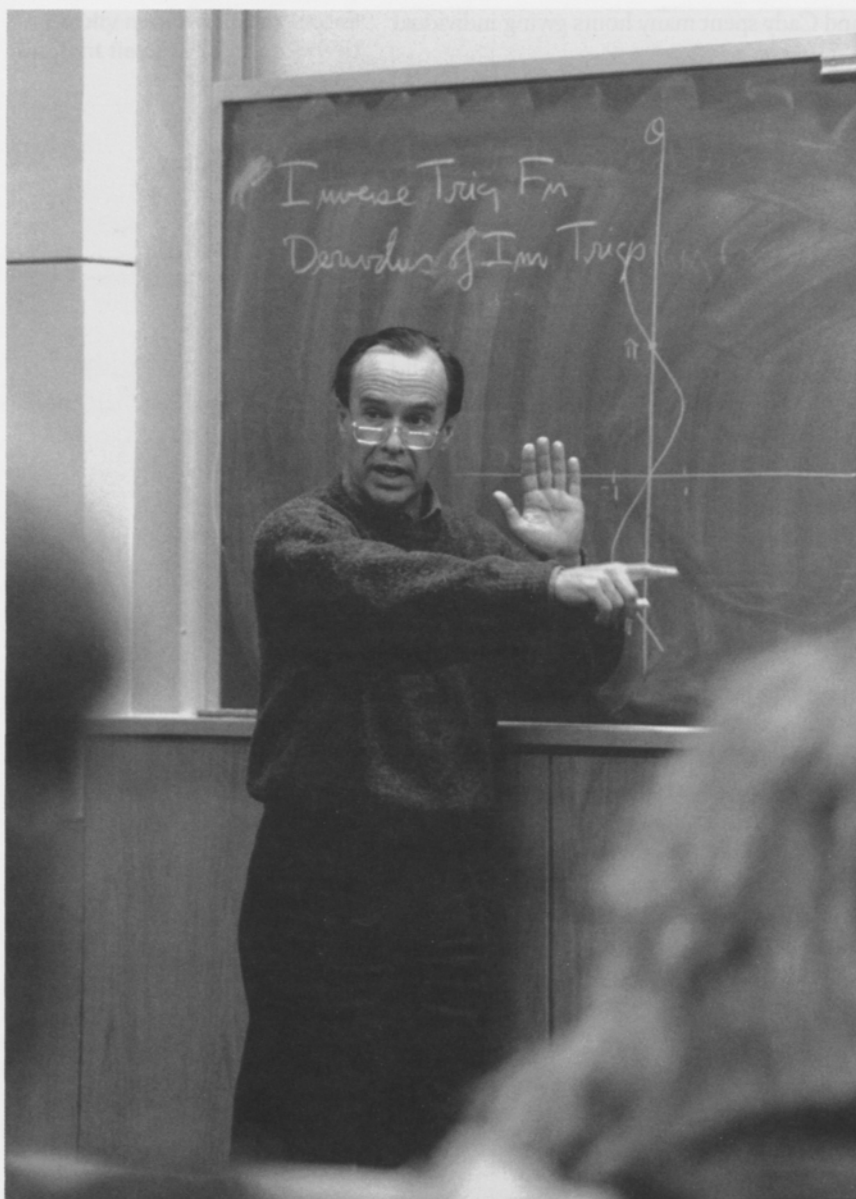
An unexpected outcome of the change to multiple sections was a marked increase in rapport among mathematicians in different parts of the university, who now had reason to meet frequently and something concrete to discuss. But the success of the effort was most notable in student reactions. The following statements are typical of the favorable comments written on course-evaluation forms. "Small classes are a tremendous advantage. I feel like I am really there and I can listen attentively, unlike most other classes where there seems to be a wall between the teacher and me." "I liked the small size of the classes. It allowed me to ask questions in order to fully comprehend the material." "The small lectures made it easier to understand the material. If there was a larger lecture, I don't think the majority of the students would keep up." "It was very personable in a small class. The professor really made calculus interesting, fun, and something to look forward to."

The faculty members were so sure that the students had learned more in small sections that they raised the grading curve. In previous years the mode had been adjusted to a B-, but now they moved it up to a straight B. This brought up the tail of the curve, so that fewer students received Ds or failed the course.



C. Y. Hui has taught Mathematics 191 in both large and small lecture sections. He says it is possible to teach well in both settings, but easier when the class size is small.

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K. Bingham Cady, a specialist in nuclear engineering, enjoyed teaching calculus to freshmen. Students were pleased with his ability to describe real-world applications of mathematical theorems.

Further Improvement Next Time Around

But student comments called attention to a problem with Mathematics 191 that has yet to be addressed. Those who had learned at least a little calculus in high school were far better prepared to handle the course than those who had not. One student wrote, "I took calculus in high school but I didn't feel that I really understood the material. I only learned how to plug numbers into equations and formulas and didn't know how those formulas were derived. Now I feel I really understand the material because the professor goes into the deri-

vations of theorems and formulas. I am able to appreciate the course and enjoy learning the material. I also like the way the professor relates the material to modern applications in engineering." But for another student, "The professor often goes too fast. Sometimes he works out an algebraic equation step by step, but skips steps when calculating derivatives or integrals—the topics we are supposed to be learning. Because I never had calculus before, skipping steps lost me."

Faculty members who taught the sections are also aware of this problem. Rand says, "I tried to pitch the material at a very elementary level so that everybody could get it, and occasionally I would throw in some more advanced stuff to show where we were headed. I knew I was trying the patience of the slower students, but I could see that I was opening the eyes of the others." Of the twenty-two students in his section, five had not had calculus before. "Keeping up with the rest of the class," Rand says, "was no easy matter for them."

One student came up with the idea of teaching Mathematics 191 strictly on a pass/fail basis. Under this regime, students who already have a good command of calculus would not take it just to get an easy A, and students with no previous knowledge of calculus would not feel that there was unfair competition for grades. This approach has not been accepted because many students who have studied some calculus in high school still have much to learn, and depriving them of the ability to earn a letter grade would make the course less challenging. But the next time Mathematics 191 is taught, there will be separate sections for students who have never before studied calculus and those who already have a running start.

Everything can be improved, and yet other ways may be found to improve Mathematics 191 as well as other freshman courses. (Introductory computer science has already been broken into small sections, with neophytes separated from experienced "hackers.") Nothing will make all students get As, as interest, ability, and motivation are bound to differ. But the transition from high school to college is one of the most exciting and challenging times in a person's life, when expectations run high, and the College of Engineering is working to make sure that freshman courses measure up to these expectations.—DP

THE ACADEMIC EXCELLENCE WORKSHOP

by Michael C. Kelley

To look at the students grouped around tables on the second floor of Upson Hall on Sunday nights last fall, one might think that they were playing *Trivial Pursuit*. But there was nothing trivial about what they were doing. They were learning calculus.

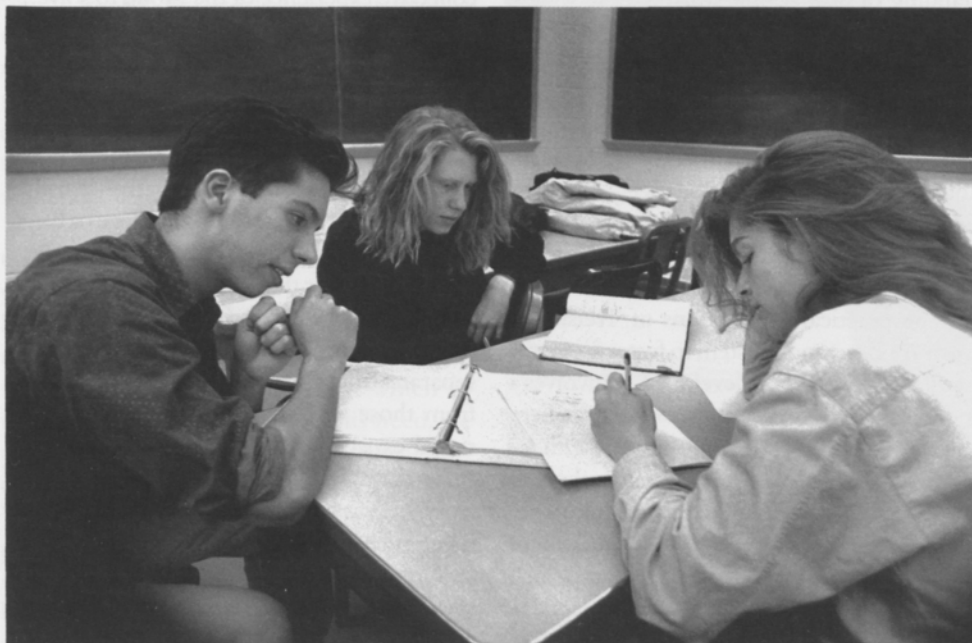
None of the students had to be there. They would not get course credit for their participation. The calculus problems that they were solving were not even part of the homework for Mathematics 191, which they were taking concurrently. Nor was this a remedial program. Students volunteered for it at the beginning of the semester, before there was anything to remedy.

No doubt many of the students who signed up were worried about their ability to survive the calculus course. Many of them had not studied calculus in high school and knew they would have to start from scratch. But the Academic Excellence Workshop was not about calculus so much as it was about a particular way of learning.

Cooperative Learning: Development of the Approach

Several years ago, at the Berkeley campus of the University of California, Philip Treisman began inquiring into why some students performed better than others. He immersed himself in the lives of freshmen with diametrically opposed rates of academic success. He found that the single most important factor distinguishing between these two classes was the propensity of successful students to study in groups. They had formed what Treisman calls "study gangs," which gathered to attack homework with a cooperative exchange of ideas and knowledge. These study gangs often concentrated on "killer problems," which presented the greatest challenge to their skills. They had formed for a variety of different reasons, but their members tended to be academically successful regardless of socioeconomic background, SAT scores, familial support, or a number of other factors often thought to have an effect on achievement.

"study gangs often concentrated on 'killer problems,' which presented the greatest challenge to their skills."



Students learn best by working with others who are trying to understand the same material.

Specially trained facilitators help raise the important questions.



Would it be possible to create a cooperative learning environment for students who do not naturally come together to study in groups? Treisman tried it. He brought together a number of students who had previously studied by themselves, and provided them with work that was not remedial, but genuinely challenging. Their learning improved markedly.

Treisman's work led to a changed understanding of how people learn. In the widely held view sometimes called the "American model," ability is thought to lead naturally to development. A student either "has it" or does not "have it." In contrast, the "cooperative learning model" holds that skills develop when ability is coupled with confidence—and confidence is built through the experience of problem solving among students at the same stage of development.

The practical implications of Treisman's work are clear, and a system to foster cooperative learning was soon developed. It involves a series of carefully structured workshops, where students meet in groups of four to six with facilitators who have, ideally, been members of such groups themselves. These facilitators receive special training before the beginning of the program and are paid for their work, which they are expected to approach as professionals. In the sessions, the emphasis is on the top

end of the curriculum. There is not the slightest hint that the work is remedial. In fact, doing—or even discussing—homework assignments is out of line, although the students are expected to have completed the homework, or at least to have tried each of the problems, before coming to the session. The facilitators provide a set of problems that are tackled with a group approach. The problems are meant to be challenging and to perhaps require the collective experience of the group to solve.

Bringing Cooperative Learning to Cornell: Goals and Objectives

As part of the broad-based effort to help engineering students get through their tough freshman courses, a pilot cooperative-learning workshop was initiated. The College of Engineering may want the freshman year to serve as a pump rather than a filter, but the students seldom see it that way. In particular, they see the mathematics sequence as a trial by fire that separates those who will become engineers from those who must readjust their professional expectations. This should not be so, since all students admitted to the College of Engineering have an aptitude for mathematics, as revealed by their SAT scores.

One initiative to remedy this situation is the decision to teach Mathematics 191 in several small sections, as discussed elsewhere in

this issue. Everyone agrees that the learning environment this provides is nearly ideal, and students' success in mastering calculus is bound to improve. But a commitment to many small sections instead of two or three large ones involves a substantial increase in faculty time, and the college cannot afford to extend this experiment beyond the first semester. In Mathematics 192, students find themselves back in large classes.

A major goal of the Academic Excellence Workshop is to solidify some of the gains made by students in the small Mathematics 191 sections. We who are conducting the workshop hope it will provide further evidence that the college really does care about student success. We also want to provide strategies for success that may not be obvious to students when they arrive on campus. And we want to provide continuity throughout the freshman year, regardless of the size of the classes.

We have begun by targeting those students who are statistically most prone to drop out of the engineering program—women and underrepresented minorities. In the light of Treisman's findings, the reason why these students are at risk is quite clear. When they walk into an engineering classroom and look around, they see that they really are in the minority. There are precious few students whom they would feel comfortable about approaching to form a "study gang." But workshops that involve these students in cooperative learning dramatically change their prospects. All across the nation, programs of this general type are being hailed as a major breakthrough in the retention and education of minority students.

Getting Started with the New Program

Since a cooperative learning workshop had never before been given at Cornell, there was no experienced cadre from which to recruit facilitators. To supply this need, we contacted junior and senior engineering students who might be able to play this role. We were pleased to find that the program practically recruited for itself. Once we described the basic ideas, prospective team leaders invariably asked how soon they could start.

The facilitators were eager to participate because they quickly understood the value of this kind of program—and wished it had been available when they were freshmen. The makeup of the facilitating group was impressive. Of the initial group of six men and six women, two were graduate students in engineering, four were seniors, five were juniors, and one was a sophomore. One facilitator was a Merrill Presidential Scholar. Three were officers in the National Society of Black Engineers, three belonged to the Society of Women Engineers, and one was

**Working in small groups,
students solve problems
together.**



a member of the Society of Hispanic Professional Engineers. Other professional affiliations included the Institute of Electrical and Electronics Engineers, the American Institute of Aeronautics and Astronautics, the American Society of Mechanical Engineers, and the Materials Research Society. Several were involved in undergraduate research projects with faculty members in the College of Engineering.

We were fortunate to have the help of Jonathan Swanepoel, a graduate student who is studying mathematical education. A native of South Africa, Swanepoel has had many years of experience conducting cooperative learning programs among high school students in his home country.

Once the facilitators had been recruited, we hired a consultant, Kay Hudspeth, who coordinates a highly successful program at the California State Polytechnic University at Pomona. She came to Ithaca during the week before classes started and spent two and a half days training the facilitators. She was accompanied by Jeanne Barela, who had served as a facilitator at Pomona, and was able to provide considerable insight into the organizational factors that make a workshop successful.

We launched the new program on the third day of the fall semester. The partici-

pants were self selected, having responded to a letter of invitation sent to all incoming engineering students identified as women or members of underrepresented minorities. We had stressed the fact that this was a voluntary program, that it would carry no academic credit, and that it would involve a considerable time commitment. There was a surprisingly large number of positive responses, but the extensive time commitment, the single time slot allotted, and the lack of academic credit for the effort resulted in rapid early attrition. Nevertheless, the steady contingent that was meeting every Sunday night by the middle of the semester represented nearly 10 percent of the students enrolled in Mathematics 191.

As the term progressed, we had to make a few changes. The student body and campus life at Cornell are very different from those at a commuter school such as the California State Polytechnic University at Pomona. We had to make sure that the pace of the workshop matched that of Mathematics 191, which moved along much faster than students expected, based on their high school experience. There is simply no time to waste in the life of a Cornell engineering freshman. We also found that the Sunday-evening time slot was too restrictive, keeping many students from attending regularly.



Students learn general principles by taking up the challenge of solving particular problems.

Looking Forward and Expanding the Program

Students who persevered all semester received an average grade of 3.1 for the course. This compares to a mean grade of 3.00 for the entire class and 2.39 for students who participated in Mathematics 091, the traditional supplemental course for Mathematics 191.

We hope to bring the methodology to more students in the spring of 1993. In conjunction with Mathematics 192, we are offering a one-credit course called A First Course in Cooperative Learning. Two-hour sessions are scheduled on four different days of the week so that students will be able to attend at times that are convenient for them. Problems that are at the leading edge of the course material in Mathematics 192 will be solved cooperatively. Group members selected at random will explain the answers to the staff and the other groups in the session, and grades will depend on group performance as manifested in these oral presentations.

Mathematics 191 is also being offered in the spring semester, to attend to the needs of students who did not earn a satisfactory grade in the fall. This has not been done before, and we volunteered to conduct the recitation section to help make sure that these students receive a grounding in mathematics that will enable them to catch up with their peers.

The success of cooperative learning in helping students understand mathematics has generated a spin-off in physics. The Department of Physics has set aside two of the twenty-three recitation sections that accompany the lectures in Physics 112, Mechanics and Heat. These will be staffed by faculty members who are interested in the Academic Excellence Workshop approach, and will be open to any students who want to try cooperative learning.

We were especially pleased to find that the facilitators as well as the students benefit from the Academic Excellence Workshops. Educators know that one learns material best when teaching it, and hopefully some of these young people will be encouraged to go on and become educators themselves.



"We were especially pleased to find that the facilitators as well as the students benefit. . . ."

Michael C. Kelley has received teaching awards from both the College of Engineering and the School of Electrical Engineering, where he is a professor. His enthusiasm for the Academic Excellence Workshop played a large part in the program's early success.

Kelley's research interest in the earth's upper atmosphere and its electrical field involves the use of both rockets and ground-based radar. After receiving the Ph.D. in physics from the University of California at Berkeley in 1970, Kelley stayed on for four years as a research physicist, developing his expertise in rocket instrumentation. Then, following a year as an Alexander von Humboldt fellow at the Max Planck Institute in Germany, he joined the Cornell faculty. He was drawn to Cornell because of the radio-radar observatory in Arecibo, Puerto Rico, which is operated by Cornell personnel. He has been involved in a number of international projects and led the NASA campaign to launch sounding rockets from Peru, Greenland, and Puerto Rico.

Kelley is currently chairman of the National Science Foundation's Upper Atmosphere Global Change Program, and is a consultant to federal, university, and industrial laboratories in the areas of geophysics, space science, and aerospace technology. He is a fellow of the American Geophysical Union, and in 1979 he won that organization's James B. Macelwane Award.

Current research activities in the Cornell College of Engineering are represented by the following publications and conference papers that appeared or were presented during the three-month period July through September 1992. (Earlier entries omitted from previous Quarterly listings are included here with the year of publication in parentheses.) The names of Cornell personnel are in italics.

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