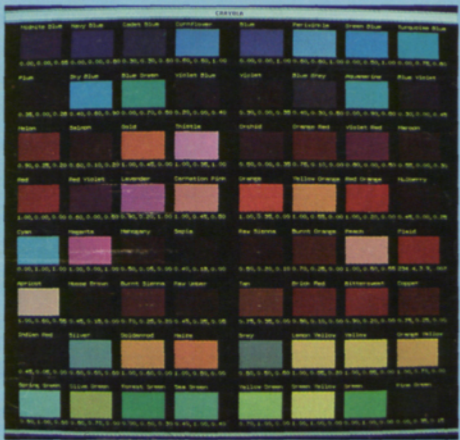
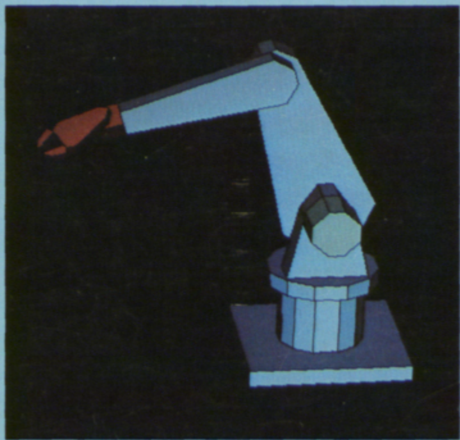
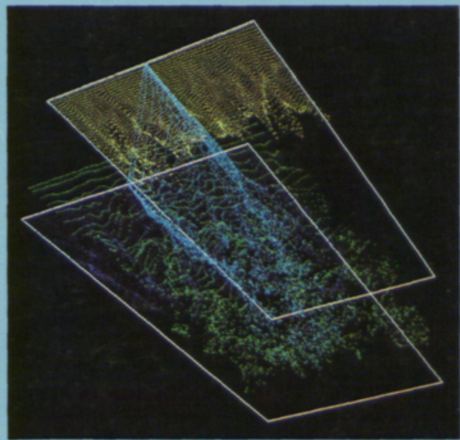
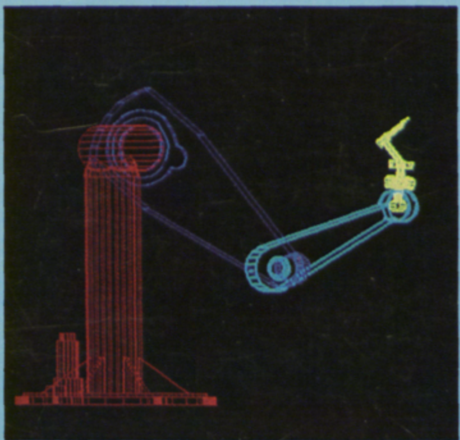
ENGINEERING

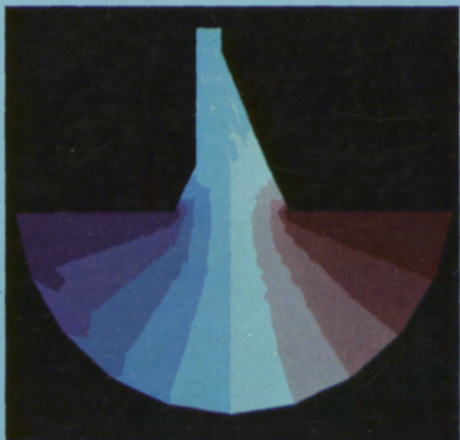
CORNELL QUARTERLY











VOLUME 21
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KEEPING ON TOP IN UNDERGRADUATE EDUCATION

IN THIS ISSUE

ENGINEERING: Cornell Quarterly (ISSN 0013-7871), Vol. 21, No. 2, Winter 1986-87. Published four times a year, in autumn, winter, spring, and summer, by the College of Engineering, Cornell University, Campus Road, Ithaca, New York 14853-2201. Second-class postage paid at Ithaca, New York, and additional offices. Subscription rate: $6.00 per year; $9.00 outside the United States.

Cover illustrations: Images photographed at workstations in the college's instructional computer-graphics facility. Clockwise from top left: a palette of available colors; a robot arm ready for manipulation; a three-dimensional flow diagram, part of a dynamic display; a color plot of stresses in a concrete dam; a welding robot model using the object-oriented language HOOPS.

Opposite: Students in a junior course in systems dynamics evaluate a control system.

TIME FOR AN UPDATE

The Focus on Engineering Education Nationally and at Cornell

In the face of global competition and accelerating technological advances, this country needs engineering graduates who are prepared to deal with modern technology. At the same time, these graduates should have a basic background that enables them to adapt to changes in the profession, or to become scientists or engineering researchers or business leaders. Furthermore, they should be able to communicate well, interact with professionals in various fields, and contribute to an increasingly complex society.

This constitutes quite an order for a four-year undergraduate program. In fact, the situation in engineering education is close to being a crisis, according to a number of recent studies by panels of national leaders in science, technology, and education. At Cornell the College of Engineering has begun a concerted effort, in line with the national mandate, to improve undergraduate education. This includes the introduction of innovative curricular changes and a large-scale project to renovate existing laboratories and establish new ones.

The initiative is not entirely new, of course. All along, the college and its schools and departments have been introducing new course work, programs, and facilities. For example, the Computer-Aided Design Instructional Facility (CADIF) was established six years ago as one of the most advanced laboratories of its kind in the world. Computers have appeared everywhere to support instruction in new techniques. Exposure to industry has been made more available to students through an expanded work-study program and through new programs sponsored by the college or its units. Emerging interdisciplinary fields have been accommodated. Much incentive and capability has been and is provided by the presence of a vigorous program of research and graduate education.

Still, college administrators and faculty members felt that a more concentrated and focused effort was needed to bring the undergraduate facilities up to high modern standards and to promote the improvement of programs.

During the next few years, according to Dean William B. Streett, hundreds of thousands of dollars will be spent to renovate existing undergraduate laboratories and establish new ones in emerging technological areas. The intention, he says, is "to make our undergraduate laboratories the best in the country."

This will be accompanied by an ongoing effort to improve the "software" aspects of the undergraduate program. As Professor Philip L.-F. Liu, who is the associate dean for undergraduate student affairs, points out, maintaining instructional quality and balance in the curriculum is equally as important as keeping facilities up to date.

THE NATIONAL CONTEXT: URGENT RECOMMENDATIONS

The status of engineering education has been the subject of intensive study at the national level in the past few years. Not surprisingly, the same general conclusions have emerged from all of them: there are serious problems in undergraduate programs in engineering (and to a lesser extent in mathematics and the sciences) that must be addressed

"The intention. . .is to make our undergraduate laboratories the best in the country."

Streett

soon by governments, academic institutions, and industry.

A report issued in March 1986 by the National Science Board's Task Committee on Undergraduate Science and Engineering Education under the title *Undergraduate Science, Mathematics and Engineering Education* recommended that the National Science Foundation provide "highly leveraged program support for undergraduate science, mathematics and engineering education in order to meet critical needs that affect the health of the Nation." The committee concluded that the NSF "cannot assume responsibility for the financial health of higher education, even in the sciences and engineering," but should take a leadership role in stimulating change and should provide support for programs undertaken at the educational institutions. In this area of undergraduate education, the report said, there should be additional NSF expenditures of $100 million a year.

The three areas targeted for attention are laboratory instruction (the costs for needed instrumentation alone were estimated at $2–4 billion), faculty development, and courses and curricula (characterized as frequently out-of-date in content and unimaginative, among other deficiencies). The report pointed out that both corporate and government support, though substantial, has been directed primarily to research and graduate education.

A comprehensive and influential report was commissioned by the National Research Council (an arm of the National Academy of Sciences and the National Academy of Engineering). Under the general title *Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future,* the findings of distinguished panels of educators and industrial leaders were published in 1985 and 1986 in a series of volumes. (Two of the participants have Cornell connections: The chairman of the committee that carried out the study is Jerrier A. Haddad, retired IBM executive and emeritus member and former chairman of the Engineering College Council at Cornell. The chairman of the panel on undergraduate engineering education is Edmund T. Cranch, former dean of the College of Engineering; Cranch was president of Worcester Polytechnic Institute at the time of his appointment to the NRC panel and is now president of the Wang Institute of Graduate Studies.)

The recommendations that are directed to educational institutions address problems of *faculty shortages* (positions should be made more attractive in terms of salary, facilities, and teaching loads, and second-career appointees should be considered), *undergraduate programs* (they should be broad and fundamental with postponement of extensive specialization, they should include nontechnical components useful in dealing with foreign markets, and they should provide options for dual-degree programs between, for example, engineering and liberal arts colleges), *facilities* (with help from industry and government, the schools should create programs for developing educational technology such as computer-aided instruction), and *enrollments* (efforts should be made to increase the participation in engineering of women and minority students).

Jerrier A. Haddad, a long-time member of the Engineering College Council at Cornell, headed a National Research Council committee that conducted an extensive study of engineering education and practice in the United States. Haddad, who earned the B.E.E. degree at Cornell in 1945, is now practicing as a consultant after a long career at IBM, most recently as vice president for technical personnel development. The photograph was taken in Carpenter Hall after a meeting of the Engineering College Council. Haddad served as chairman of this advisory board from 1981 to 1985.

Edmund T. Cranch, who was engineering dean at Cornell from 1973 to 1978, was chairman of the National Research Council panel that recently published a report on engineering undergraduate education. Cranch earned three degrees in engineering at Cornell and was a member of the faculty until 1978, when he became president of Worcester Polytechnic Institute. He is now president of the Wang Institute of Graduate Studies. The photograph was taken in his office in Carpenter Hall while he was dean at Cornell.

The report also recommended patterns of government support that would benefit undergraduate as well as graduate education, and matching-grant legislation to facilitate the acquisition of laboratory equipment and buildings. It called for more programs that would strengthen the ties between engineering schools and industry, including the establishment of research centers and the development of more and better work-study programs.

Also published in 1986 was *Quality of Engineering Education*, a report from the American Society for Engineering Education that resulted from a two-year study by four task forces drawn from industry and academia. The study centered on faculty excellence and some key aspects of the academic working environment; included are the recurring matters of the use of educational technology and the undergraduate engineering laboratory.

The National Association of State Universities and Land-Grant Colleges issued a 1986 report, *Quality of Engineering Education II*, which constitutes a reassessment of an earlier study, known as the Kemper Report, that was influential in bringing about changes in engineering institutions. The Kemper Report, published in 1982, pinpointed four conditions that were contributing to a crisis in engineering education: overenrollment in undergraduate classes, faculty shortages, obsolete or insufficient equipment, and insufficient space. The current report concludes in that in general these findings remain valid.

States, too, have been studying their role in improving engineering education. The Legislative Commission on Science and Technology of the State of New York, for example, issued a report in October 1986 that provides background material for legislative hearings. The problems addressed include the recurrent ones of obsolete equipment, faculty shortages, and funding for institutions and programs.

THE CORNELL PLAN: FOUR YEARS PLUS AN M.ENG.

A basic problem for engineering schools that is alluded to in the national reports is the impossibility of making a four-year undergraduate curriculum contain all the necessary and desirable components. The National Research Council committee headed by Cranch defined the goals of an undergraduate engineering education as preparation for practice, for graduate study, and for lifelong learning. Their report pointed out that "the common view is that the balance among science, engineering, design, and the nontechnological component cannot be changed further without seriously damaging at least one of the four. Nevertheless, pressures do exist for substantial change. For example, how will the imperative of computers and the information age find room in the curriculum? Or how will time be found for incorporating the field of biotechnology, which is growing within many engineering disciplines? And how is the third goal of undergraduate engineering—to provide a base for lifelong learning in support of evolving career objectives—to be addressed when engineers encounter several technological revolutions during their careers and when they are further called upon to bridge the gap from technology to society?" Inevitably, this dilemma has generated controversy among faculties, especially in their dealings with industries and groups such as the Accreditation Board for Engineering and Technology (ABET).

Engineering educators at Cornell believe they have developed the best solution to the problem of curricular compression: the combination of a broad four-year Bachelor of Science program and an integrated fifth-year Master of Engineering program. The B.S. curriculum emphasizes the physical sciences, mathematics, engineering science, and computer-based technologies, and includes a strong component of course work in the humanities, liberal arts, and social sciences. The M.Eng. curriculum, in a specific discipline, stresses design.

There are several advantages to this plan. One is the preservation of a four-year undergraduate curriculum, as is generally favored by industry and by students. Lengthening the program to five years would relieve curricular pressures, but would cause other problems: Students would put as much time into getting a baccalaureate degree as others devote to getting a master's, and would incur greater expense, and usually debt, for their first-degree education. Another advantage of the two-degree plan is the greater flexibility it makes possible for the B.S. program, which can serve as excellent preparation not only for engineering, but for a variety of other careers.

Actually, Cornell did have a five-year undergraduate engineering program during the post–World War II years, but it was phased out in the 1960s in favor of the five-year program culminating in the M.Eng. degree. Dean Streett points out that the college is now graduating almost as many Masters of Engineering each year (270 to 280) as it did Bachelors of Science (250 to 300) during the peak years of the five-year undergraduate program. Most of the M.Eng. students are Cornell engineering graduates, continuing in an integrated program. The college is successfully seeking fellowship aid and other support from industry for M.Eng. students.

THE ADVENT AND FUTURE IMPORTANCE OF COMPUTERS

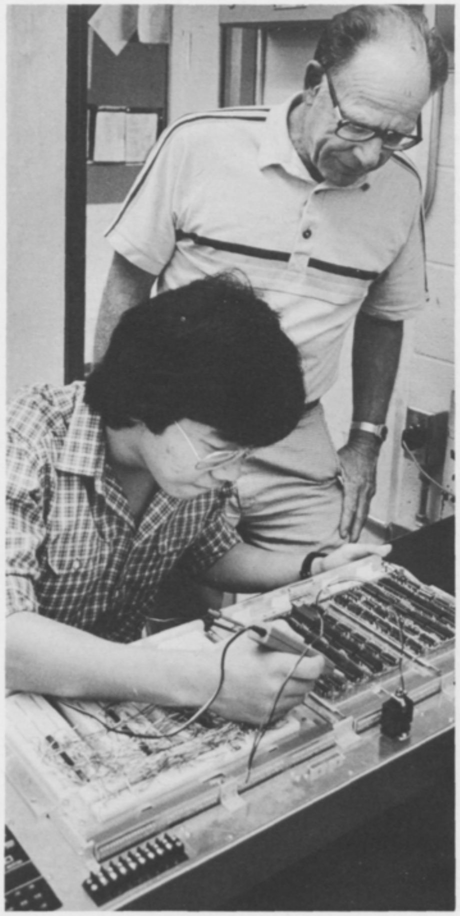
Most noticeable among the changes in undergraduate education that have taken place in recent years is the advent of computers. And as the college's laboratory-improvement program proceeds, computers will become even more integral to the academic program. Because computers are used extensively in real-life engineering, they are essential for student laboratories also—needed for instruction in computer-based operations, as components of experimental systems, and for design.

An example of a successful accomplish-

". . .computers will become even more integral to the academic program."

Professor Vrana supervises a student in the electrical engineering school's computer-based laboratory. As part of an M.Eng. project on the CORNELL COMPO-BOX, the student is checking the final design and construction of a system that will display on a console any faulty component.

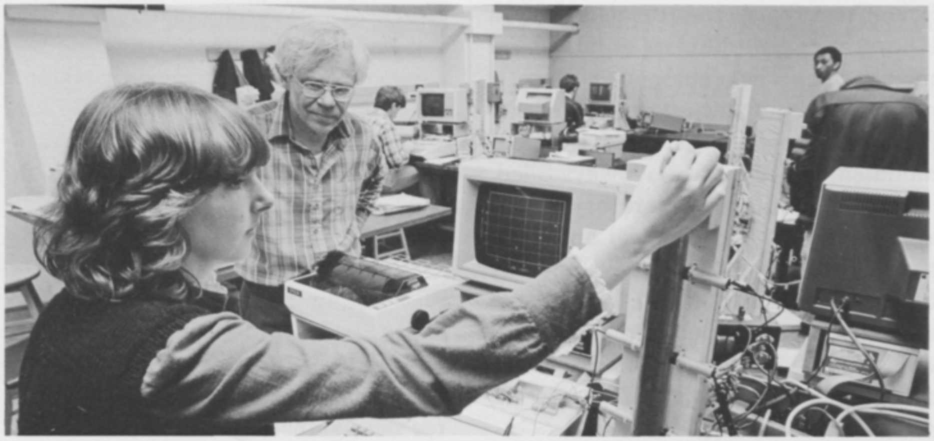
ment is the maintenance, since its establishment fourteen years ago, of an up-to-date computer-based laboratory at the School of Electrical Engineering. It is used for two senior-level courses—Computer Structures, and Microprocessor Systems. According to Professor Norman M. Vrana, who is responsible for the laboratory development, this facility is "probably better than most industrial labs." The equipment, which has been provided over the years by Hewlett-Packard and Intel, allows the students to use modern computers to do design work in complex digital systems. The facility has the capability of integrating software and hardware into the design of systems that may employ any one or more of as many as thirty different microprocessors. Although primarily an undergraduate laboratory, it is used also by graduate students, mostly in the Master of Engineering (Electrical) program. In fact, Vrana says, M.Eng. students working on their design projects have contributed so much to the development of the laboratory that it "probably wouldn't exist without them."



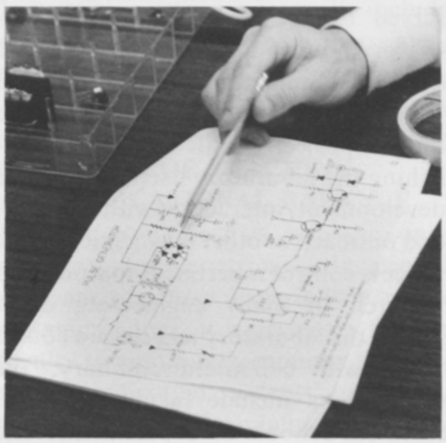
Another example of the use of computers in undergraduate laboratories is the new Macintosh facility that has been set up for the electrical engineering course Introduction to Digital Systems. In this laboratory a simulation package replaces more traditional hands-on equipment—a kind of development that some faculty members feel needs watching. "In my opinion," one of the school's professors remarked, "the jury is still out on how this change to a 'dry lab' affects the laboratory part of our educational process."

In the School of Applied and Engineering Physics a recently established laboratory is used for the course Computerized-Instrumentation Design, which was developed by Professor Arthur Kuckes and Bruce Thompson in 1983. About twenty-five microcomputers, an equal number of oscilloscopes, and other equipment including printers are used by the students to control experiments, collect data, fit the data with theoretical guidelines, plot the graphs, evaluate the important parameters, and process reports. At first the students program the computers using BASIC with theoretical equations, but as the term advances, they find they must program in machine language so that the computers can keep up with the faster experiments.

The upper-level course in instrumentation offered by the Department of Agricultural Engineering provides another example of how computers are used in laboratory instruction. The students use IBM PC-XTs and ATs (Project Ezra equipment) for data acquisition, data reduction and analysis, process control, and simulation. The computer is also used to characterize and calibrate sensors and transducers, and as a digital storage oscilloscope to capture time-varying signals. An example is a set of experiments in which piezoelectric materials are characterized and then a piezoelectric accelerometer, mounted in an apple, is monitored to show the force the apple might experience as it drops onto different types of protective materials. Professor Daniel J. Aneshansley remarked that "the personal computer has provided students and faculty with inexpensive and easy access to computer-based data



Left: Professor Kuckes advises an undergraduate student on a laboratory assignment in the engineering physics course Computerized-Instrumentation Design.



Left: A recently developed "hands-on" engineering physics course is The Laser and Its Applications in Technology, Science, and Medicine. In the popular course the students build two lasers, using a kit designed by Professor Cool.

acquisition and control. For experimentalists, this capability gives the same sense of excitement (and sometimes frustration) as word processing gave to those who compose written material. For our students, it has meant new experimentation and experiences throughout the curriculum."

HANDS-ON EXPERIENCE FOR FUTURE ENGINEERS

Providing students with up-to-date, hands-on laboratory experience requires not only computers, but the continual replacement and addition of other equipment. A *Quarterly* survey of the schools and departments in the Cornell College of Engineering revealed some impressive accomplishments, as well as areas in which improvements are sought.

One of the accomplishments was the development of a laser laboratory at the School of Applied and Engineering Physics. It was begun in the early 1980s by Professors Terrence Cool and Aaron Lewis for a new freshman course, The Laser and Its Applications in Technology, Science, and Medicine. (For this work, Cool and Aaron shared one of the Dean's Prizes for Innovation in Undergraduate Teaching, awarded for the first time last spring.) A major reason for introducing the course, the instructors say, was "to give students hands-on experience in assembling instruments and to convey some of the fun and excitement of contemporary applications of physics." In the laboratory, groups of students use a kit—designed by Cool—to build a nitrogen laser and a tunable dye laser, and then use the instruments for experiments.

"The unique [Process Control Laboratory] entails. . .interaction with industry, and outreach to other universities."

Scientists from industrial research laboratories visit the class to talk about their work. The course is extremely popular—about one-quarter of all the freshmen in the college can be accommodated, and the class is always filled.

The well-equipped laboratory is used also for the course Physical and Integrated Optics, which was developed by Cool and is being offered for the first time this spring term. The equipment was purchased with funds from the college, augmented by gifts from Xerox, AT&T, and Corning.

At the Sibley School of Mechanical and Aerospace Engineering, a major effort has been a quarter-million-dollar upgrading of the basic Mechanical Engineering Laboratory. According to Albert R. George, director of the school, changes were mandated by general obsolescence of the existing apparatus and the need for new kinds of equipment. Also, more experimental units were needed to accommodate the increased number of students who use the laboratory. It had become necessary for instructors to demonstrate certain experiments rather than have students perform them. Funding for the project was spearheaded by an alumnus, Ted Ohart '29, who contributed $100,000. Additional money has come from bequests and from other alumni.

The Department of Materials Science and Engineering is also upgrading its Materials Laboratory, which is used for all the undergraduate laboratory courses. (These include a two-term sequence in Research Involvement.) Modern equipment is replacing the original machines that were installed when Bard Hall was built in the early 1960s; some of those old-timers were World War II surplus material. According to Professor Rishi Raj, who coordinated the effort to decide what should be purchased, an important criterion is that replacement equipment should be useful in a range of applications. So far, with a $30,000 allocation from the college, the department has made two major acquisitions: an electrical-mechanical testing machine and a hardness tester. In addition, the laboratory has new state-of-the-art control equipment and measuring and recording devices for data-gathering.

An interdisciplinary subject will be served by the Process Control Laboratory now under development by the Cornell Manufacturing Engineering and Productivity Program (COMEPP). The unique project entails not only establishing the laboratory itself, but course development, interaction with industry, and outreach to other universities. Since process control is pertinent to study and research in many engineering disciplines, the laboratory and certain course work will be interdisciplinary; the participants include faculty members from six schools or departments. The director is Paulette Clancy, assistant professor of chemical engineering and associate director of COMEPP.

The Process Control Laboratory project will involve instruction at both the B.S. and M.Eng. degree levels. One of the first accomplishments will be to set up an interdisciplinary first course in process control for undergraduates, and the establishment of a sensors laboratory has high priority. Equipment and software worth several hundred thousand dollars is being provided by IBM (through Project Ezra), Alcoa, Prosys Tech, and other companies.

Liu

"We want to encourage the view that teaching is a faculty member's primary function."

Industrial participation will include seminar talks by company personnel, the provision of data for course work, and the sponsorship of M.Eng. interns.

CONCERN FOR TEACHING AND EDUCATIONAL BALANCE

Modern equipment is not the only necessity for a strong educational program, of course. Especially in an era of rapid change, it is necessary for the faculty to continually monitor the content of individual students' programs, taking care to ensure quality instruction and balance in the course work. At the college, the watchdogs of the undergraduate program, along with Associate Dean Liu, are the members of the Common Curriculum Governing Board (CCGB), which comprises faculty representatives of each of the academic fields.

Keeping course offerings and their subject content current is the responsibility of the faculty in each field, and this is well accomplished, Liu said. The overall composition of the four-year curriculum is a more general concern. The faculty as a whole, working largely in terms of CCGB recommendations, must see that students receive a good general education as well as instruction in a specialty field. The requirement for a significant number of courses in the humanities comes under faculty jurisdiction, for example. A specific matter now under consideration is the possibility of incorporating more writing assignments into upperclass technical course work. (The recommendations of a recent college-sponsored study are outlined in the article in this issue on communication skills.)

Cornell engineering educators are in accord with the call at the national level for undergraduate engineers to have more opportunity for hands-on experimental work. The college expects to encourage participation in new National Science Foundation programs designed to foster the preparation for careers in research. One of these programs offers "creativity awards" to individual students who plan to undertake graduate study. The other is the Research Experiences for Undergraduates Program (REU), which provides funding to institutions in two ways—as grants to schools selected as *sites* for research participation by undergraduates, and as supplements to ongoing NSF research awards when one or two undergraduates are included on the project team.

Another concern is the quality of instruction provided by graduate teaching assistants and also by junior professors. As Liu points out, many people confronting their first teaching assignments have had no previous teaching experience or training. To improve the situation, the college is beginning to implement a training program for teaching assistants. Also under discussion is how senior faculty members can be encouraged to help new instructors manage their initial classes. "The rewards to faculty members for success in research are numerous and apparent," Liu remarked. "They include opportunities for consulting, additional salary during the summer, and an advantage in terms of promotion. We want to encourage the view that teaching is a faculty member's primary function." Recognition for excellence in teaching is enhanced, for example, by the annual awards sponsored by the college and by schools and departments.

Because a good instructional program depends on good student-faculty interaction, the CCGB is also attempting to encourage more contact between professors and undergraduates. One aim is enlist more faculty members as academic advisers.

WAYS AND MEANS FOR ACHIEVING THE GOALS

An important factor not apparent in a survey of facilities and course listings is the influence of research activity throughout the college and university. Undergraduates are exposed, at least indirectly, to what is going on in the graduate laboratories and special research centers. Sometimes they become involved in project work, and soon this kind of opportunity will be made more available. In addition to the NSF programs already mentioned, there is now taking shape a project special to Cornell: as a gift in honor of his twenty-fifth reunion, James O. Moore '62 is providing about $250,000 over the next five years to facilitate the participation of undergraduates in research.

The support for undergraduate research projects illustrates the broad base of funding that underlies the overall effort to improve undergraduate education. Equipment and money is coming from government, corporations, foundations, and private donors, as well as from university and college resources. Often the initiative comes from faculty members, who determine what is needed and help secure support.

"The support for undergrduate research projects illustrates the broad base of funding that underlies the overall effort. . ."

Additional help from government is being sought by educational institutions. One effort in which Dean Streett is involved, along with other engineering deans in New York State, is the preparation of a proposal by the Association of Engineering Colleges of New York State for state funding in support of undergraduate education. On the basis of a study of facilities of twenty-one engineering institutions in the state, the association has concluded that an average of $3,600 per graduate per year would raise these schools' laboratories to state-of-the-art conditions and sustain them at that level. (The National Science Board report, referred to above, also recommended that the states provide substantial funding for laboratory instrumentation; the amount suggested is $2,000 per engineering or science graduate per year, as recommended by bodies such as the National Society for Professional Engineers.) An appropriation of the magnitude called for by the New York State association could bring the Cornell College of Engineering as much as $1 to $2 million a year for several years.

The quality, content, and context of engineering education is the overall concern. Evident in the current effort by the College of Engineering is the recognition that at Cornell the experience of learning to become an engineer is not gained exclusively in certain classrooms and laboratories, but extends to the rest of the university enterprise and to the professional world beyond.—GMcC

COMPUTERS, COMPUTERS, COMPUTERS

1. Their Role in the Life of Undergraduate Engineers

The slide rule, once the trademark of the engineering student, was long ago replaced by the pocket calculator. Now future Cornell engineers rely on computer workstations, and not only for routine calculations. Homework requiring computers is assigned in many courses, partly because the computer has become an essential tool of the profession. In fact, the computer has transformed the instructional program at the College of Engineering.

This transformation has kept faculty members, facilities directors, and support staff busy. Since 1984, the college has had an associate dean for computing to coordinate and provide direction for all the activity. Space has been found for small computers all around the campus—for example, the engineering library has computers where there used to be lounge chairs.

Besides keeping course content and laboratory work up to date, the proliferation of computers is having an additional educational impact: it is aiding the learning process itself. Skills in problem-solving, long considered at the heart of engineering education, are sharpened by the rigorous demands of computer programming. Physical processes, such as three-dimensional motion, are understood more easily and quickly with the help of computer graphics. More time can be spent studying basic concepts and principles if the student isn't swamped with the mechanical details of lengthy calculations.

COMPUTING AS AN INTRINSIC PART OF INSTRUCTION

The part of the Common Curriculum that is required for all freshmen in the college includes the course Introduction to Computer Programming. The subject is programming itself, not a particular language, and the emphasis is on concepts and techniques of problem analysis. As the students progress in their education, they encounter computing in regular course work; regardless of their major, they are required to take at least one course with a significant amount of programming and application.

Because of their impression that computers are where the action is, freshmen often come to the college with the idea of majoring in either computer science or electrical engineering, but they soon find that computing is an intrinsic part of all engineering disciplines. In 1986 the Office of Undergraduate Affairs (headed at that time by Professor Richard H. Lance) published a pamphlet, *Computers, Computers, Computers*, for distribution to sophomores about to choose a field program (or major subject). This pamphlet describes how computing is incorporated into the various upperclass curricula, and how students in every field are prepared to use computing techniques in their future professional work. A summary is given in the table.

THE FACILITIES FOR ENGINEERING STUDENTS

Computing equipment is available in university-administered centers, college-wide facilities, and special laboratories run by schools, departments, or programs.

Cornell Computer Services provides a number of Apple Macintoshes in facilities across the campus; many provide access to the IBM mainframe computers. Also available are stand-alone per-

A SUMMARY OF COMPUTING IN CORNELL UNDERGRADUATE ENGINEERING STUDIES

Agricultural Engineering
Computer analysis is considered important because of the inherently complicated and nonlinear processes that characterize biological systems. Students take two programming courses in their first year, and at the upperclass level use applications programs (developed by faculty members) for various agricultural and biological engineering problems.

Chemical engineering
Laboratories provide "hands on" experience in computerized process control and data acquisition and analysis. In addition, students use the school's instructional computing facility for assignments that require the use of the latest "supermicro" hardware and sophisticated software. They use commercial process simulators, spreadsheets for optimization studies, and high-resolution graphics (useful, for example, in studying three-dimensional phase diagrams or the design of distillation columns, or in visualizing fluid flow).

Civil and Environmental Engineering
Students become experienced in the methods of computer-aided analysis and design, which are applicable to the whole range of civil and environmental engineering concerns: housing, energy, hydraulics, water resources, pollution control, waste management, remote sensing, and land-resource and geotechnical analysis. About half the undergraduate courses entail assignments at the Computer Aided Design Instructional Facility (CADIF). In addition, the school offers an advanced programming course and several analysis courses dealing with finite elements, finite differences, and boundary elements.

Computer Science
A major in this field is for students interested in the computing process itself rather than in specific applications. They are prepared to make use of computing in any of a wide range of occupations. Core courses focus on the theory of computation and the design and analysis of programs, computers, data structures, and algorithms. Programming languages, compilers, operating systems, computer graphics, and databases can be studied in elective courses.

Electrical Engineering
About two hundred students graduate each year with a B.S. degree in electrical engineering, and all of them have some training in computing. A sequence of required laboratory courses emphasizes the interfacing among computers, data acquisition, and the control of experiments. Those who wish to concentrate more fully on computing may specialize in computer engineering or telecommunications, or may take electives involving computerized circuit design.

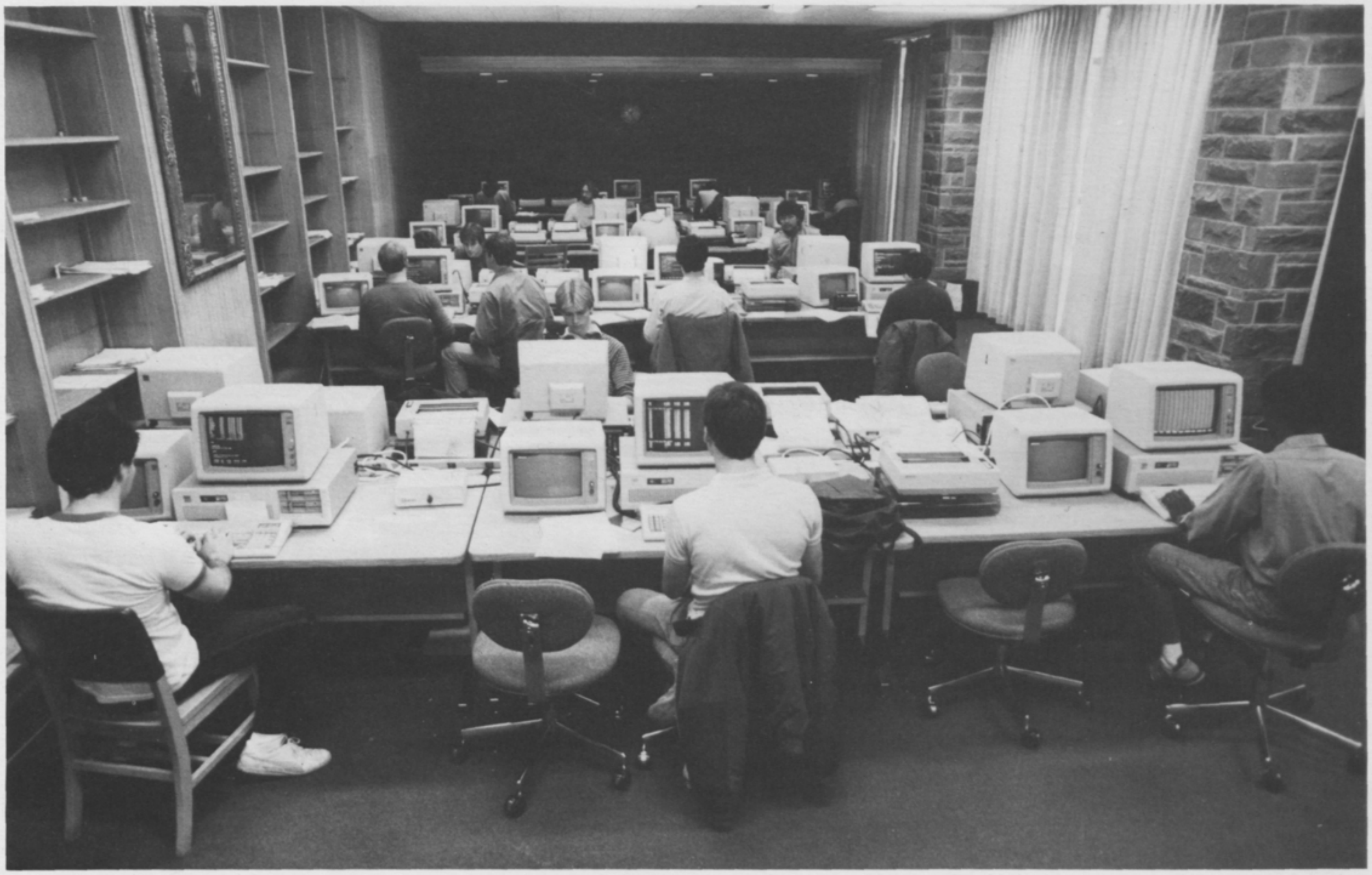
Engineering Physics
Students are encouraged to acquire a sophisticated knowledge of laboratory electronics and computational techniques. Courses offered by the school cover the design of computerized instrumentation, and electronic circuitry, including microprocessors and their integration into systems. Courses in mechanics, electrodynamics, and continuum physics incorporate the use of computers to provide not only the strong theoretical background emphasized in the overall program, but also a better descriptive understanding of the underlying physics.

Geological Sciences
Computing facilities ranging from the many desktop microcomputers to advanced specialized equipment allow researchers and students, including undergraduates, to gain experience with state-of-the-art computing technology. The department has a MEGASEIS—a 32-bit minicomputer system used to handle and enhance large seismic datasets—and a VAX 11/750 minicomputer that is linked to the university communications network and has an array of peripherals including color-graphics equipment for analyzing and manipulating satellite and seismic imagery.

Materials Science and Engineering
Undergraduates may participate in ongoing research projects, most of which use computers to acquire, analyze, and visualize complex data. Computers are used also as teaching aids; for example, computer-generated stereograms allow representations of the three-dimensional structure of large crystals to be displayed and rotated on the screen.

Mechanical Engineering
Computers have assumed crucial importance in industrial operations, with widespread use of CAD/CAM/CAE (computer-aided design, manufacturing, and engineering), as well as computerized data acquisition and analysis. The use of computers is incorporated into all areas of research and instruction. Computer-intensive courses include Computer-Aided Design, Microprocessor Applications, and Mechanical and Aerospace Structures.

Operations Research and Industrial Engineering
This field, concerned with how best to design and operate systems, is fundamentally dependent on computers. Virtually all aspects of the undergraduate program (optimization, probability modeling, applied statistics, simulation, engineering economy, and industrial systems analysis) employ applications software. Emphasis is placed on microcomputers, but some applications use high-resolution graphics workstations.



sonal computers—IBM PC/ATs and Hewlett-Packard Vectras.

Of particular importance is an extensive program, supported by a three-year grant from IBM, that is providing hardware, software, and personnel support to students throughout the university. This is called Project Ezra, in honor of the university's founder, Ezra Cornell. Nineteen institutions were selected by IBM for this program, with the idea that these nineteen will serve as models for other institutions considering the large-scale infusion of computing into instruction. The emphasis is not on creating new tools, but rather on encouraging the innovative application of advanced computer technology to instruction in a wide range of subjects. This is, indeed, happening: in all the schools and colleges there are numbers of faculty members who have already developed software for use in course work.

As part of Project Ezra, clusters of personal computers have been installed at several locations and connected by a local area network. One of the first of these clusters was set up in the engineering library, and the network of twenty-two IBM PCs is now being used for assignments in at least fifteen engineering courses. Special facilities equipped by Project Ezra include an instructional laboratory in integrated mechanical analysis that will open this spring. Initially this laboratory will be

(continued on page 16)

The Project Ezra facility in the Engineering Library provides personal computers for student use.

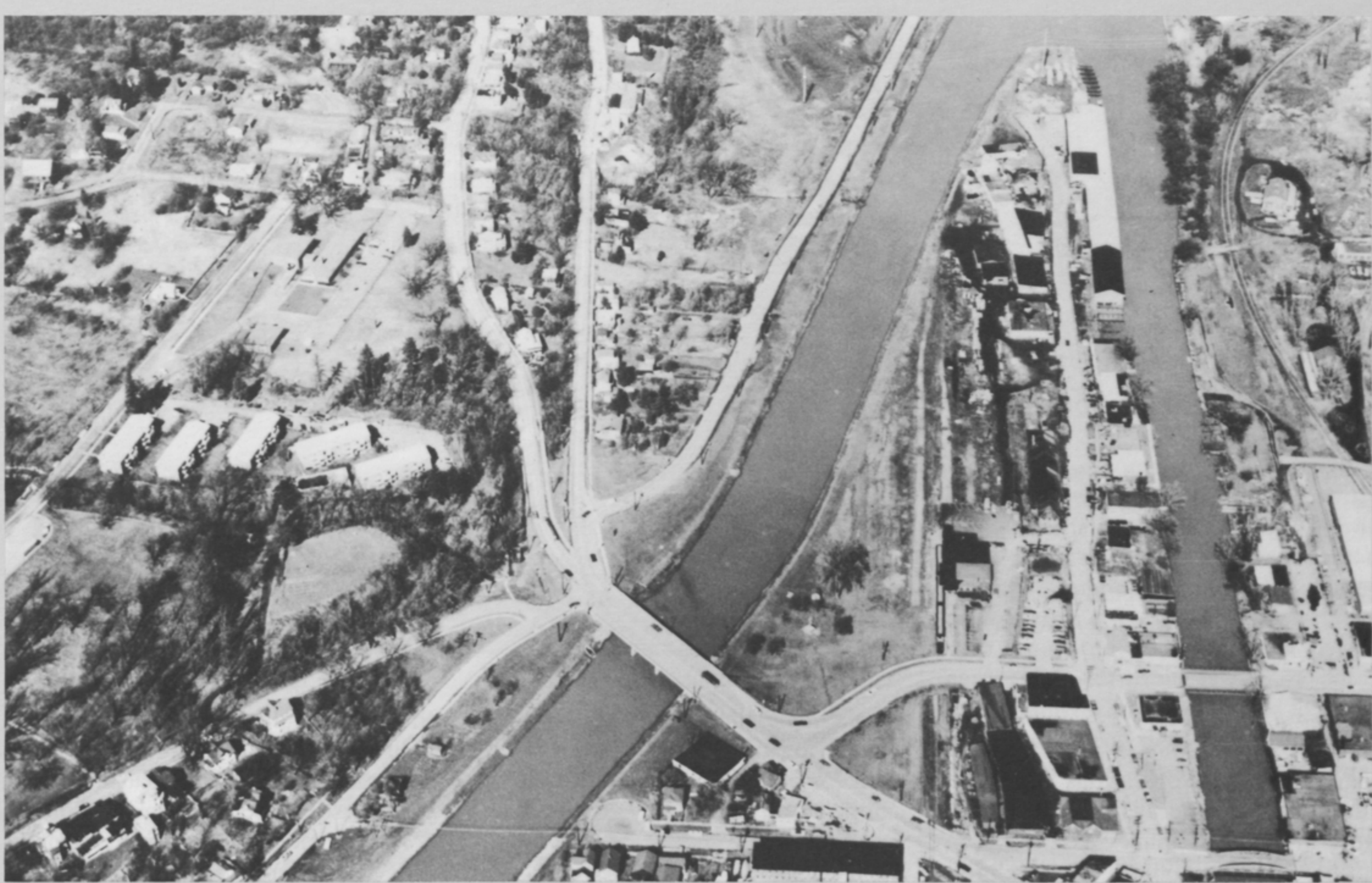
The notorious "Octopus" intersection in Ithaca's West End was a real-life problem tackled by freshmen in the fall-term course Computer-Aided Design in Environmental Systems.

How to improve the traffic situation in that area has been studied by city, town, county, and state officials for some years and the issue has generated much controversy among groups of citizens. Debate concerns such matters as the relief of traffic congestion, the economic impact on downtown businesses of development in the West End, and how to provide better access to the hospital, which is located beyond the West End intersection and across railroad tracks. This spring the New York State Department of Transportation is to propose a solution that the City of Ithaca can accept or reject, and in preparation the city, the Town of Ithaca, and Tompkins County commissioned a study to complement the state's environmental impact analysis. Thomas Niederkorn of a local consulting firm undertook the study and he enlisted Tony Richardson to assist in the analysis of traffic impacts.

Tony Richardson works with a group of his freshman students in the environmental engineering course on computer-aided design. The facility used for the class project is in the Engineering Library in Carpenter Hall. Equipped with IBM PCs, this facility accommodates a number of classes and is open for general student use.

This is where the class project came in. Richardson is a visiting associate professor in the Cornell Department of Environmental Engineering, and he decided to assign the "Octopus" problem as a case-study project in the computer-aided-design course.

In an introductory lecture, Niederkorn outlined the background of the problem and gave the students a feeling for its social, economic, and political aspects. Class lectures by Richardson concerned the use of computer-based models in transportation planning, and the students were given specific assignments related to Ithaca traffic problems. They collected field data on traffic flows and used a computer model to evaluate certain proposed solutions for the "Octopus," particularly the construction



of a second bridge and an overpass over the railroad. As part of that evaluation, some students investigated how the timing of traffic signals at nearby intersections could be adjusted to best relieve traffic congestion. Others studied the effects of creating one-way streets in certain sections. Some considered how constructing the bridge in a different place would affect traffic patterns. Later this year the students may be able to see how their ideas correspond with the plan that is actually adopted.

Basically, the course attempts to show freshmen how computer-aided design may be used in environmental engineering, and is an attempt to provide a context for some of the more technical subjects they will cover as upperclassmen. "Given the large number of science courses taken in the first two years," Richardson commented, "this course serves as a reminder to the students that they are really enrolled in an engineering program in which the purpose is the application of scientific knowledge for the betterment of the community."

The tentacles of Ithaca's "Octopus" constitute segments of four state routes and a number of city streets, including three major arteries. As shown in this 1973 aerial photograph, a single bridge crosses a flood-control channel that was built in 1967. Three older bridges cross the inlet to Cayuga Lake. West of the channel, the road heading straight up in the photograph (Route 96) leads to the hospital.

All the proposed plans include at least one new bridge over the channel. Other options are a four-lane highway that would become Route 96 north, and additional bridges.

The omnipresence of computers is illustrated by this scene in an agricultural engineering laboratory.

(continued from page 13)
used by undergraduates in mechanical engineering and operations research, but it will also be available for class work in other disciplines.

The College of Engineering has provided facilities in addition to those administered by the university. An early achievement was the establishment in 1981 of the Computer Aided Design Instructional Facility (CADIF). (This is described in the following article by Anthony R. Ingraffea and Catherine Mink.) Throughout the college, computing equipment has been provided through corporate gifts and discounts worth millions of dollars; in addition to IBM, Westinghouse, and Xerox, the donors are Apple, AT&T, Digital Equipment, Hewlett-Packard, and McDonnell Douglas. Alumni have also helped. For example, the 1960 class in chemical engineering gave $85,000 toward equipment for an undergraduate computing laboratory in Olin Hall.

A TOUR OF INSTRUCTIONAL COMPUTING LABORATORIES

When the Engineering College Council met this fall for its semiannual meeting on campus, the members were offered tours of some of the instructional computing facilities in the engineering buildings. Some of the facilities—CADIF and the microcomputer centers in the engineering library and in Hollister Hall—serve students across the college. The others are representative of the computing laboratories that have been set up by schools and departments.

At CADIF the visitors saw a demonstration of a robot simulator, IGRIP, that can display and move complex, realistic robots in real time, detecting potential collisions and near misses. It can be used to help design new robots.

At the School of Chemical Engineering, council members visited the Instructional Computing Facility, recently installed in renovated space. The equipment consists of nine personal computers of various makes, and associated peripherals. The laboratory is open twenty-four hours a day, seven days a week, and offers consultation services from 2 to 10 p.m. every day except Saturday. The emphasis is on the use of computer graphics as an aid to instruction. Teams consisting of a professor and graduate and undergraduate students work together to produce software packages that make course material more comprehensible and offer

". . .computers for undergraduates to use in their course work seem to be everywhere these days."

the opportunity for students to perform "experiments" that broaden and deepen their understanding of topics covered in lectures. Software aids developed so far are in the areas of process control, transport phenomena, and thermodynamics. Commercially available packages in areas such as kinetics and the simulation and design of chemical processes are also used.

The tour also included Phillips Hall, where council members visited the Macintosh facility of the School of Electrical Engineering. This is used by students in the introductory course in digital systems design; self-paced laboratory work is designed to reinforce concepts introduced in class. Using LogicWorks, a digital systems simulator for the Macintosh, students perform a set of five experiments, including two small design projects. The facility includes a network of eleven desktop computers, a hard disk, and a laser writer.

A facility that will be used in teaching computer-aided logistics was demonstrated by the Cornell Manufacturing Engineering and Productivity Program (COMEPP), which has strong ties to the School of Operations Research and Industrial Engineering and the Sibley School of Mechanical and Aerospace Engineering. This laboratory was established for the Integrated Mechanical Analysis Project (IMAP); the Project Ezra facility to open this spring will provide similar resources for undergraduate instruction. Of particular interest is a decision support system called COSMOS (Cornell Simulator of Manufacturing Operations) which, combined with CAD/CAM (computer-aided design and computer-aided manufacturing), will provide a means for systematically reducing design and production lead times and for effectively planning and controlling manufacturing resources and material flow. Also demonstrated was a CAD/CAM software product called CATIA that is being used for instruction as well as research. The software has the ability to perform both surface and solid modeling and to produce machine instructions from the geometric models. The numerical control (NC) code produced in this way can be transferred to the adjacent machine shop and the parts actually cut.

The use of computers in laboratory instruction was illustrated during a visit to the Mechanical Engineering Laboratory. This facility, set up for a senior course, is equipped with HP integral computers outfitted with adapters for data acquisition and control. In a typical experiment, state-of-the-art data-acquisition techniques are used to study compressible flow phenomena. A quartz-crystal pressure transducer, a digital voltmeter, and the computer are used to measure and record the supersonic discharge rate of high-pressure dry nitrogen through a fixed orifice.

Actually, computers for undergraduates to use in their course work seem to be everywhere these days. Even Christopher Pottle, who became the associate dean for computing this summer, says he isn't sure he knows yet where they all are. And since one of the college's priorities, announced by the dean, is an extension of the use of computers, this is just the beginning.

2. Why Cornell Engineers Have Up-to-Date Design Skills

by Anthony R. Ingraffea and Catherine Mink

Cornell pioneered the use of advanced computer graphics in engineering education with the establishment of its Computer Aided Design Instructional Facility (CADIF) in 1980. For the first time, undergraduates could learn in an environment similar to that of a research or top-notch industrial facility.

CADIF was founded by Professor Donald P. Greenberg, the director of the university's Program of Computer Graphics. Effectively, he made the kind of high-powered graphics devices and applications that were being used for research at the program's facility available for engineering instruction at all levels.

When CADIF was set up, a unique, expensive, special-purpose hardware configuration made it possible for many users to write, debug, or run graphics programs sharing a VAX 11/780. Different graphics devices provided static color or dynamic, three-dimensional vector displays. Since that time, the computing industry has undergone a revolution. Today's high-powered graphic workstations are supplying as much computing power as CADIF's original shared machine, plus better and faster graphics, in a package that costs less than a single display device did in 1980.

Now CADIF is being renewed to take advantage of the opportunities and meet the challenges provided by advances in computing and in the various engineering fields. Improvements are being made in many directions:

- new hardware
- local- and wide-area networking
- improved software and program-development tools
- new educational applications
- more programming access for students, and
- the establishment of Project SOCRATES, a permanent program in which the methods and software that have been used with great success here are made available to other engineering schools.

CADIF is now under the jurisdiction of Christopher Pottle, the college's associate dean for computing. As the faculty and staff coordinators, we are directly involved in the day-to-day operations of the facility.

THE NEW EQUIPMENT AND HOW IT IS USED

In the past year eight new graphics workstations, connected through the college-wide Ethernet, have been installed and put to work at CADIF. (Six are Digital Equipment VAXstation GPXs and two are Silicon Graphics IRIS 3020s.) In the very first term they were available these machines were in almost constant operation, both for using existing engineering design and analysis programs and for developing new ones that fully exploit the power of the equipment. A new graphics language, HOOPS, chosen for its power, ease of use, and transportability to a variety of computer systems, has been installed.

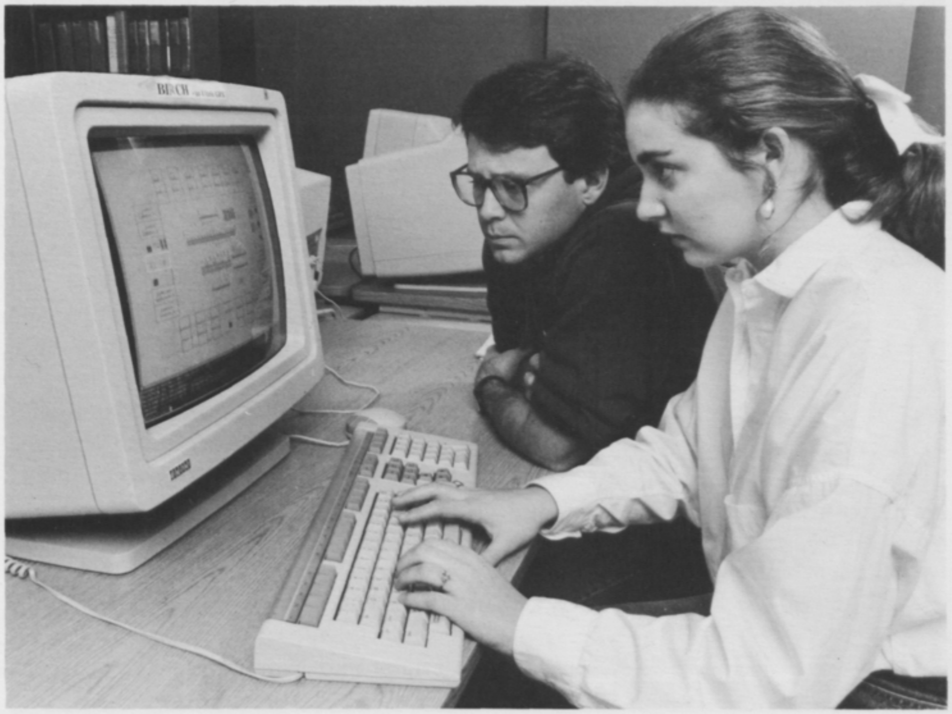
Whereas the original CADIF graphics system was virtually unique in the world, the single-unit workstations we are now providing are fast becoming the standard technology for both research and industrial applications. CADIF has always provided a very effective means, and therefore a strong incentive, for faculty members to channel the results of research efforts directly into teaching,

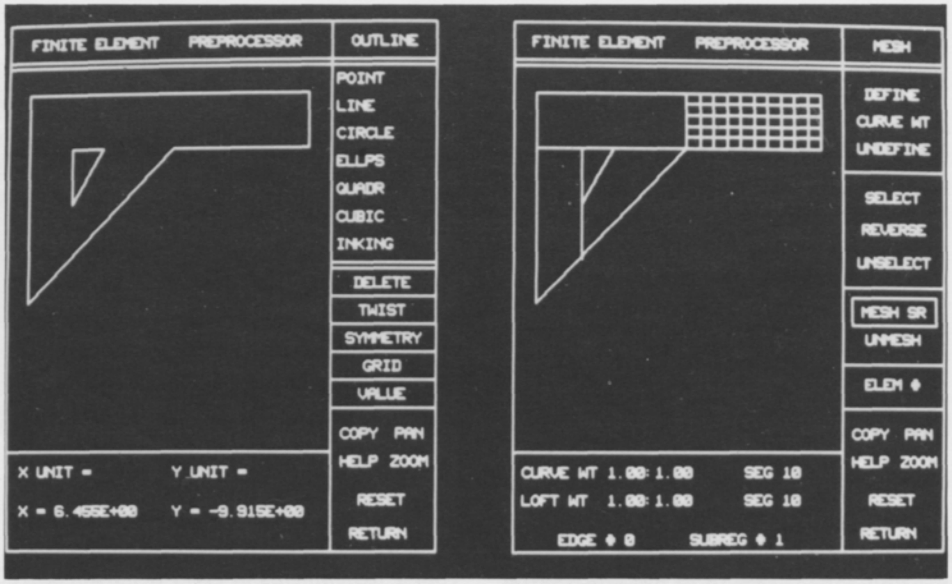
but now it is far easier and faster to do so. Cornell is unique among major research institutions in that the engineering college sees fit to put substantial resources into this link. Partly because of this, the Cornell engineering curriculum is one of the most complete and advanced in the country, and its graduates are highly sought-after.

Even at the undergraduate level, students here have the opportunity for extensive, hands-on design and analysis, developing and using what will be the tools of their trade. Computing and graphics allow them to solve real problems in real time. The drudgery of repetitive calculations is removed and their minds are freed for thinking about the state-of-the-art analytical principles being presented. They can carry comprehensive projects all the way through preliminary design, parameter studies, feasibility studies, optimization, detail design, simulation, and final presentation. For example, in one advanced computer-aided design course in mechanical engineering (489), the students design and simulate 12-meter yachts, which they then race against each other

Above: The Computer-Aided Design Instructional Facility (CADIF) in Hollister Hall provides state-of-the-art equipment for course assignments in every department.

Below: At this CADIF workstation, electrical engineering students are laying out an integrated circuit. Real chips are built according to a computer tape and returned to the class for testing.





The best way to learn real-time interactive design and analysis is to use a computer-graphics program. Here a student has created a structure and a finite-element mesh to use in analyzing it.

". . .you can't understand the limitations of a robot's motion without seeing it move."

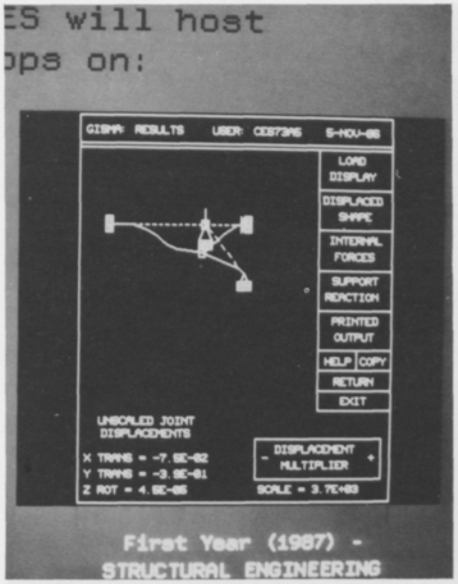
in a REAL-TIME regatta: each group's workstation is used to both control their boat and display the entire field of boats, in full color and 3D, from their viewpoint, using information received from the other stations via a high-speed network.

This is a kind of learning experience that couldn't even have been imagined five years ago. Yet it is only an example, however dramatic, of a fact that has been proven at CADIF a hundred times over: graphics and dynamics are very effective teaching tools, aiding in the visualization of concepts and efficient design, and stimulating the learner's interest. You simply can't lay out a complicated, many-layered integrated circuit without seeing it in color; you can't understand the limitations of a robot's motion without seeing it move.

SHARING CORNELL KNOW-HOW WITH OTHER SCHOOLS

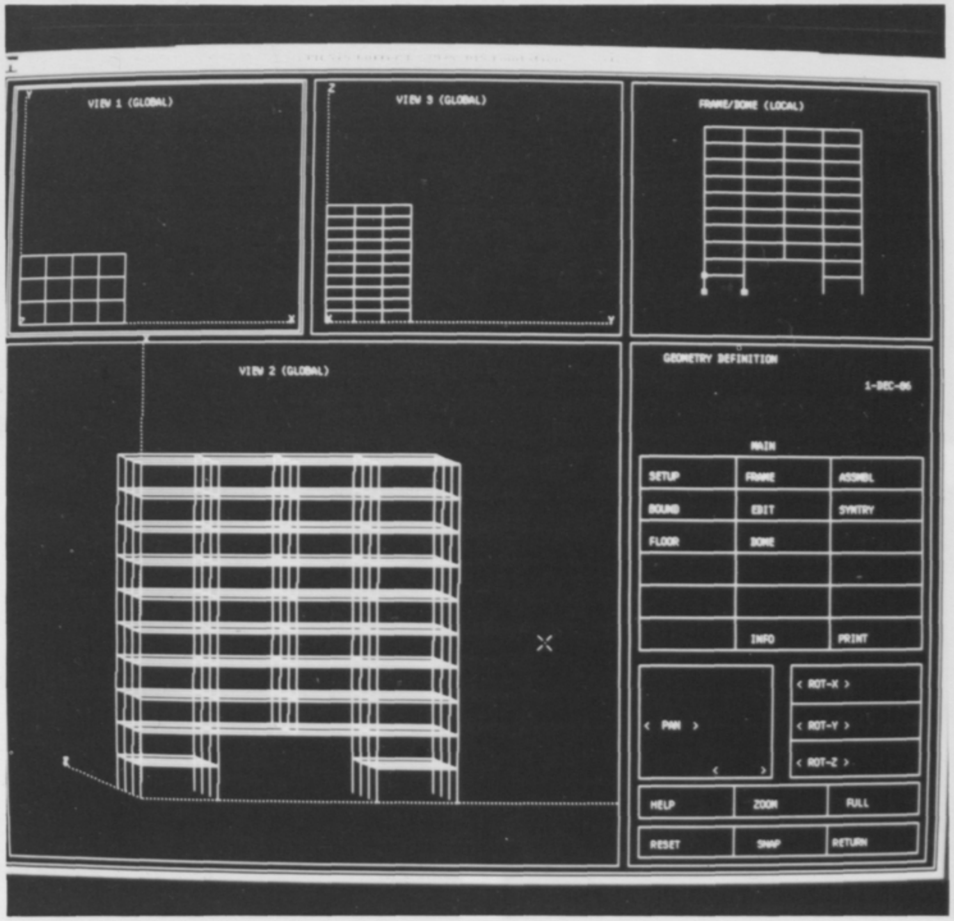
Recently the U.S. Department of Education provided funds that will enable Cornell to share with other institutions the techniques and tools that have worked so well here. A substantial three-year grant will finance Project SOCRATES (Study of Complementary Research and Teaching in Engineering Science).

As Ingraffea and Greenberg, the directors of SOCRATES, explain, most engineering schools are not research institutions and therefore their faculties are not in a position to invent techniques or programs for channeling research software into teaching. But they certainly can use what Cornell has to



Left: GISMO is one of the programs available to structural engineering students through Project SOCRATES. Used to study beams, frames, and trusses, it not only lets the student analyze the behavior of the structure under load, but also "animates" and makes visible the mathematical process of using matrices to describe and solve for that behavior.

Below: FRAME3D and its companion programs ANALYZE and INDYNBA are used by both students and researchers to design three-dimensional steel-framed buildings and investigate what they will do under static and earthquake-type loads.



offer: instructional programs that are robust, user-friendly, and well documented. They can also become familiar with how to evaluate, adapt, and improve applications developed at Cornell and elsewhere.

Project SOCRATES will reach engineering institutions through workshops for faculty members. The aims are:

- to show how research software has been and can be adapted for educational use
- to show how instructional computing has been integrated effectively into the undergraduate curriculum and has improved it
- to distribute, free of charge, existing educational applications programs and the tools for developing and adapting new programs
- to provide limited support services for implementing programs at the participants' home institutions.

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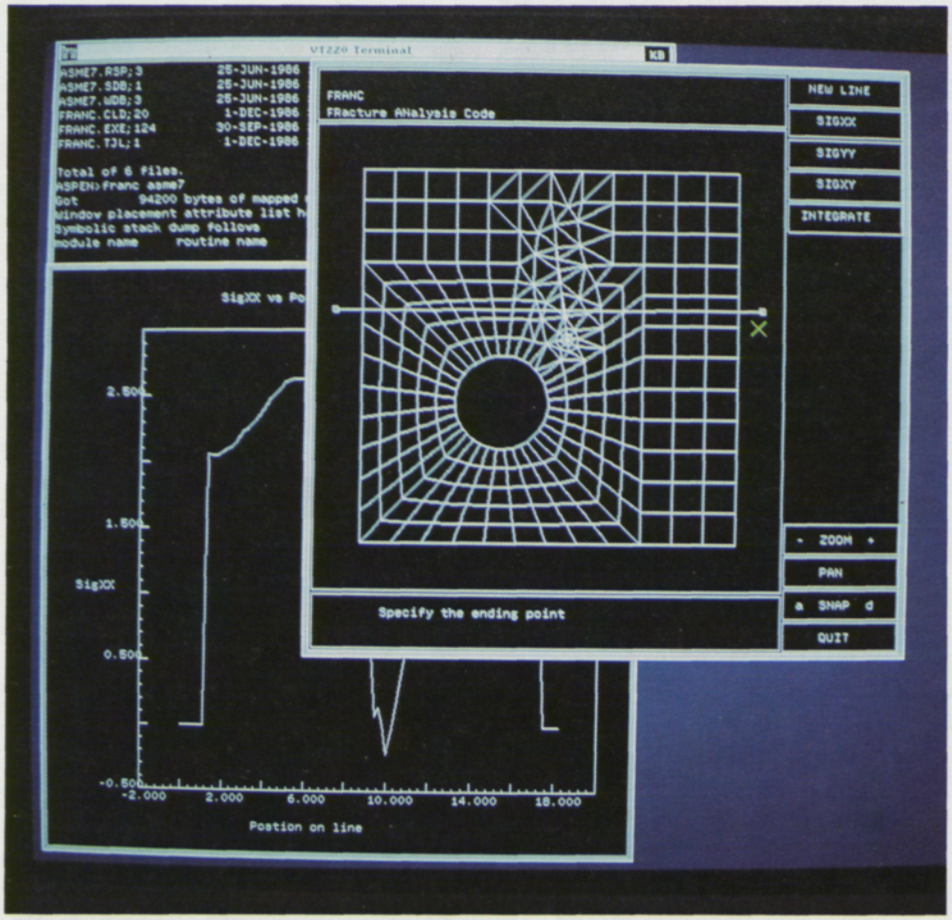

An example of how computer graphics is used in engineering instruction is the FRANC program for finite-element analysis, which is now a basic tool in structural engineering and the study of materials. The images shown here were photographed from the screens of workstations in CADIF.

1–2. Here a plate is being analyzed. In (1) the topmost window shows the plate divided into small subareas (finite elements). FRANC is a particularly advanced program in that it incorporates features of fracture mechanics.

In (2) a graph of a particular structural quantity has been computed and displayed. Any of several quantities (various types of stresses and strains) can be computed and displayed across any line through the object being studied.

The finite-element method would be almost unusably laborious without a computer to do the many repetitious calculations and an interactive, graphic program to streamline the process of defining what is being analyzed and displaying the results.

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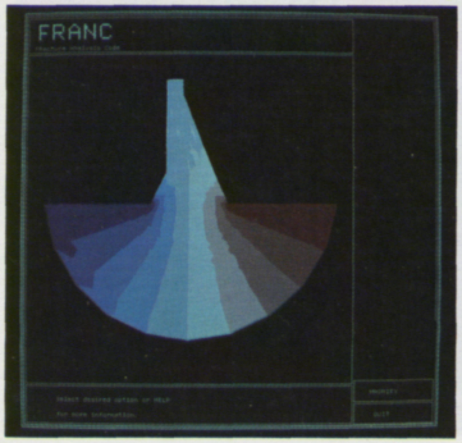

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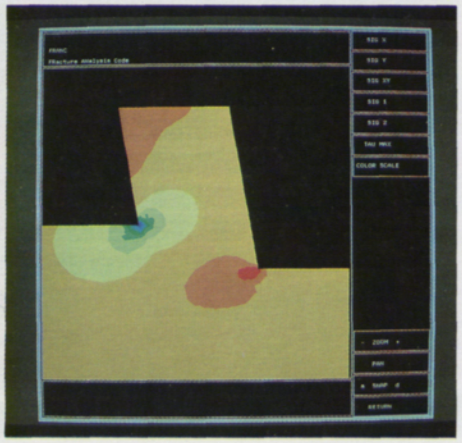

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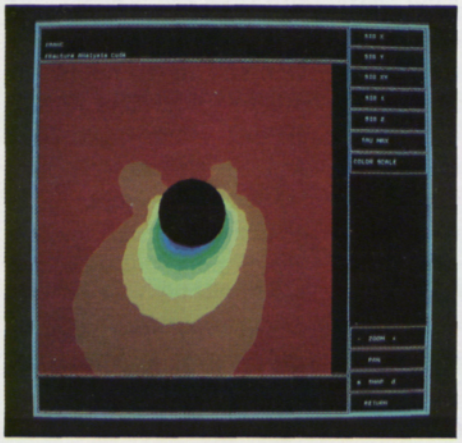

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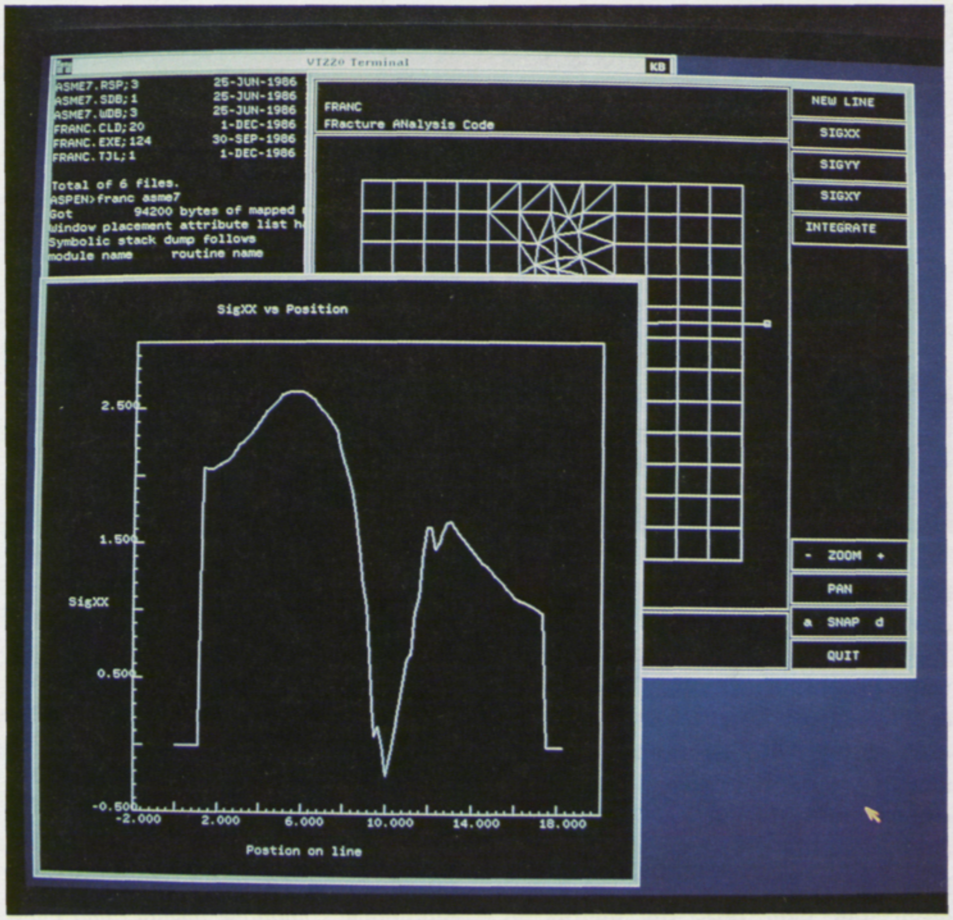

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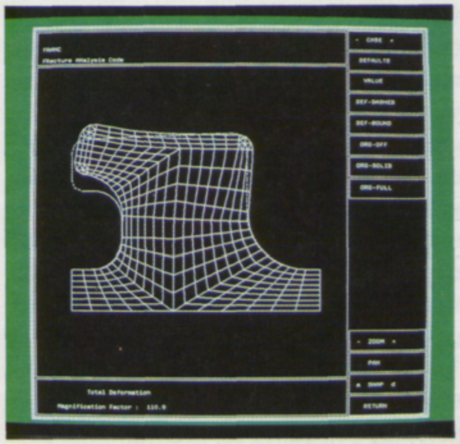

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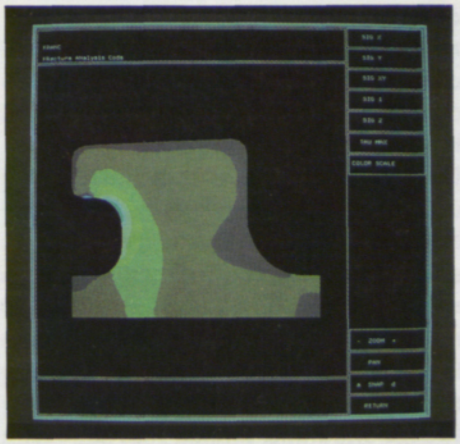


3–5. Values of a given structural quantity can also be computed and displayed in color over the entire object being studied. The analyst can choose among several different color schemes for the best presentation of the data, or to highlight certain features.

Graphics used at CADIF include: (3) a cross section through a concrete "gravity dam" (a dam that derives its strength from its own weight); (4) a detail near the base of an arch dam; and (5) an enlargement of the center of the plate shown in (1). In (4) and (5) contours of the principal stresses are displayed.

6–7. An aircraft door latch is analyzed in a course exercise. In (6) the latch has been partitioned into elements and the student can see the deflections it will undergo when loaded. In (7) the latch has been analyzed and a color stress plot has been displayed—a process that only takes about fifteen seconds.

Computer graphics has removed or greatly reduced the delay between posing a question and seeing the answer; a very complete analysis, exploring many different quantities under different conditions, can be done in very little time.

LOOKING TO A FUTURE OF GROWING SIGNIFICANCE

CADIF provides a capability greatly in demand in engineering education: the means of incorporating into course work the use of high-performance graphics, often in conjunction with extensive computing. The demand has grown steadily and shows every indication of continuing to do so. What do we expect to report in five more years, when we write about CADIF's third generation?

We anticipate continuing improvements in computing power, quality of graphics, and software tools, which will be available, affordably, to users at every level. We expect that problems of now-inconceivable scope and sophistication will be tackled, and that the kind of environment and support our users require will become very different. Computing, especially in interactive design and problem-solving, will become a much more integral part of students' experience, and will open up more opportunities for substantial research work at the undergraduate level. Thanks to high-speed networking, the physical presence of CADIF will be college-wide and tapped into an ever-expanding network of resources throughout and beyond Cornell.

Furthermore, Project SOCRATES will enable a substantial number of engineering colleges in the country to use computer graphics to improve their teaching efficiency and expand their curricula. We hope that communication and a sharing of information among participating schools will foster cooperation and help raise the quality of American engineering education.

Anthony R. Ingraffea, an associate professor of structural engineering, is faculty coordinator of CADIF, and Catherine Mink is the college's educational computing coordinator.

Ingraffea, whose research centers on the fracture mechanics of materials ranging from rocks to composites for aerospace applications, makes extensive use of computer graphics in his own work, as well as in teaching. A member of the Cornell faculty since 1977, he holds the B.S. degree from Notre Dame University, the M.S. from the Polytechnic Institute of New York, and the Ph.D. from the University of Colorado. His experience includes two years with the Grumman Aerospace Corporation as a structural engineer, and he is a registered professional engineer in Colorado. In 1984 he was one of the first recipients of the Presidential Young Investigator Award, sponsored by the National Science Foundation.

Mink describes her duties as "managing the day-to-day operations of the college's educational computing facilities and planning future growth and changes." In addition to CADIF, she supervises computing facilities in Carpenter, Hollister, and Kimball Halls. Mink holds a B.S. degree in electrical (computer) engineering from the Massachusetts Institute of Technology and has done graduate work at Cornell. Before assuming her current position in 1986, she was an applications programmer at CADIF. Previously she was a freelance printed-circuit designer, an instructor in electronic drafting at Tompkins-Cortland Community College (near Cornell), and a programmer at the Raytheon Corporation and at the Smithsonian Astrophysical Observatory in Cambridge, Massachusetts.

3. The New Math for Cornell Engineers

At Cornell a new way of using computers in the teaching of engineering mathematics is giving students a head start on skills they may need on the job. Computer programs that can handle the symbolic equations of algebra and calculus are used for homework assignments, much as industries are beginning to use these methods in the workplace.

Three professors in the Department of Theoretical and Applied Mechanics—Richard H. Lance, Richard H. Rand, and Francis C. Moon—introduced the innovative teaching method over the past three and one-half years. Cornell is believed to be one of the first universities to introduce computer algebra — which permits traditional algebra and calculus problems to be done more quickly and more accurately than by hand—into both graduate and undergraduate courses.

The first use was by Rand in a graduate course in applied mathematics. (He has since published a text on the use of computer algebra in the context of advanced dynamics and applied mathematics, and has another text in preparation.) Next, sixty-five students in one section of the junior course in engineering analysis were introduced to the new software, getting the chance to work interactively with a computer to perform differentiation or integration of complicated expressions. Since the fall of 1985, all 550 students in the sophomore engineering mathematics course have been taught with the new system, and this year all the students in the junior course. Implementation has depended, of course, on the increasing availability of computers for student use, primarily through a multi-million-dollar gift from IBM.

RECOGNIZING THE POWER OF THE COMPUTER

Behind the experimental teaching method is the awareness by educators, particularly in engineering, that the computer has enormous potential to change the way professionals work and students learn.

Engineering analysts in industry are already using computers to make symbolic computations, the Cornell professors point out. For example, computer programs have been used in the aircraft industry to derive finite-element models for numerical codes, and in manufacturing plants to derive complex equations for robot manipulations. Indications are that in the future, engineering analysis will be accomplished completely on computers, and CAD/CAM will incorporate symbolic methods.

According to Moon, the impact of computer algebra in mathematical and theoretical work is "bound to have as much effect as the orginal introduction of the computer." He remarked that his own master's degree thesis, written in 1964, required six months of extensive algebraic calculation that could now be done in one or two hours using computer algebra.

As for the learning process, computers are already having a strong effect in fields across the university curriculum. This is especially true in engineering subjects. As described elsewhere in this issue, the use of the computer as a learning as well as a professional tool is a component of the program in every engineering department; and the college's Computer Aided

"Computer software that can do more than 'crunch' numbers is now available on the market."

Design Instructional Facility (CADIF) is being used for undergraduate instruction in every field. Extension of the educational use of computer techniques to include the performance of computations involving algebraic and calculus symbols is a logical development.

USING NEW SOFTWARE IN THE MATH COURSES

Computer software that can do more than "crunch" numbers is now available on the market. The programs being used in Cornell's engineering mathematics courses are muMATH, which is put out by The Soft Warehouse, and MACSYMA (MAC's SYmbolic MAnipulation system), which was developed at the Massachusetts Institute of Technology a decade ago and has now been licensed to Symbolic Corporation.

The muMATH program is one of several that are capable of performing symbolic as well as numerical manipulations on personal computers such as the IBM PC-XT. This is the software used in the sophomore course, along with a traditional textbook and the usual syllabus. The course covers partial derivatives, multiple integrals, first- and second-order ordinary differential equations, vector spaces and linear algebra, matrices, eigenvalue problems with applications to systems of linear differential equations, vector calculus, boundary-value problems, and an introduction to Fourier series. Problems of this kind can be so tedious to solve that the point of an assignment may be lost in the details of calculation; with muMath it is the computer that performs the calculations—quickly and without error. The student is able to tackle more difficult problems than would otherwise be feasible to assign, and in the process reinforces and clarifies the underlying principles.

MACSYMA, a comprehensive and much more powerful system that requires a large-scale computer, is used in the upperclass course on differential equations (Engineering Analysis I). The topics covered include analytical and numerical methods, special functions, initial- and boundary-value problems, eigenvalue problems in linear partial differential equations, and an introduction to nonlinear ordinary differential equations. Graduate students are also encouraged to learn MACSYMA so they can use it in their research and advanced courses in analysis.

ASSESSING THE EDUCATIONAL VALUE AND PROMISE

The Cornell professors say they are often asked whether computer-aided algebra and calculus will produce students with fewer mathematical skills. They think not, since one has to know the mathematics in order to ask the computer to perform the operations. A scientific analysis of the effectiveness of the new approach has not yet been made, but in a few years, when the current sophomores undertake advanced engineering courses, their ability to handle mathematics will be tested.

As experienced teachers, the professors believe they have achieved what they set out to do: help students learn better and faster, and train them in the computing techniques they will need as professionals. The time to accustom future engineers to these methods is now.

MANUFACTURING ENGINEERING

A Strong Cornell Program in a Crucial Area

A cadre of engineers able to implement modern manufacturing methods is a crucial need of U.S. manufacturing industries competing in the world market today, and Cornell's College of Engineering is doing something about it. Students can prepare for effective work in manufacturing engineering in an innovative program that was begun four years ago and is rapidly expanding.

This year about a sixth of the graduating seniors in the College of Engineering will have majored in manufacturing-related subjects; about one hundred graduates with Bachelor of Science degrees enter manufacturing positions each year. Also graduating in the spring will be some thirty-five Masters of Engineering who will receive, in addition to their degree, a Dean's Certificate in Manufacturing Systems Engineering.

During the past year, about ten doctoral degrees have been awarded to candidates whose work was concentrated in this new specialty area, and more are coming along. Hand in hand with this educational impetus is, of course, a vigorous program of research.

COMEPP AT THE HUB OF THE ACTIVITY

The center of activity is the Cornell Manufacturing Engineering and Productivity Program (COMEPP), established in 1982 as a cross-disciplinary program to initiate and sustain research, education, and outreach activities in manufacturing systems engineering. Diversity is built in, since manufacturing engineering falls within no single traditional field, but rather encompasses business organization, systems development, and factory management, as well as various engineering disciplines.

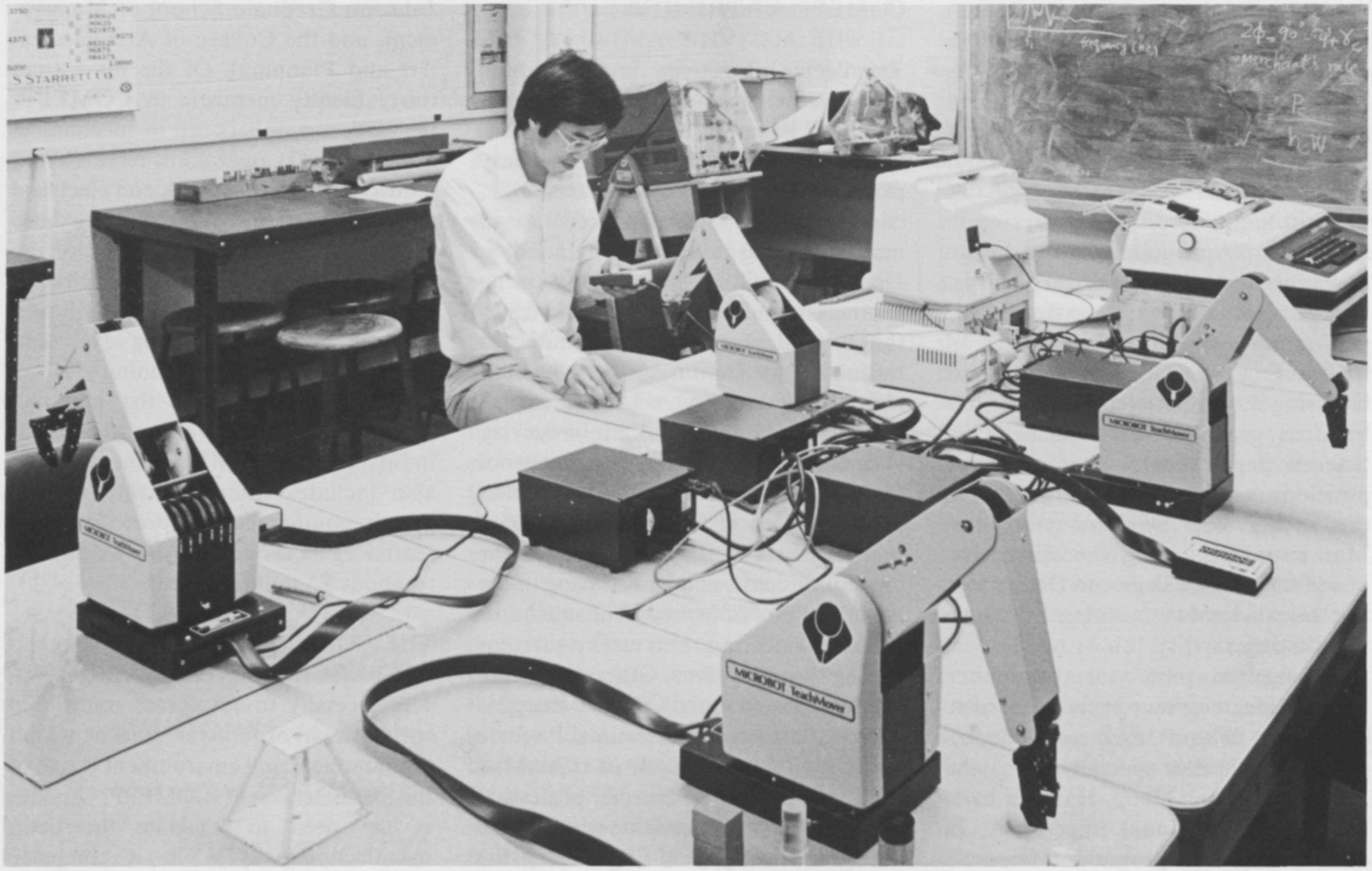
Spearheading the establishment of the program were John A. Muckstadt of the School of Operations Research and Industrial Engineering, who is the current director, and K. K. Wang of the Sibley School of Mechanical and Aerospace Engineering, who was co-director during the early years. Other disciplines are represented in the COMEPP organization: the associate director is Paulette Clancy of the School of Chemical Engineering, and the member professors are from eight departments within three colleges (the College of Engineering, the Johnson Graduate School of Management, and the College of Architecture, Art and Planning). Of the more than thirty faculty members in COMEPP, the largest numbers are in mechanical engineering (7), operations research and industrial engineering (6), and electrical engineering (6), but also represented are management (4), chemical engineering (3), theoretical and applied mechanics (3), computer science (2), civil and environmental engineering (1), and architecture, art, and planning (1).

Since the nature of the program requires especially close ties with industry, the COMEPP membership also includes fifteen actively participating companies. Support from research agencies and industry amounts to about $3 million a year.

THE COMEPP APPROACH: RESEARCH AND EDUCATION

The necessity to cut across traditional specialties in order to create a new kind of manufacturing environment is one of the basic tenets of COMEPP. Another is the need to integrate the entire manufacturing cycle in a computer-

The robotics laboratory supervised by Professor Ming C. Leu is used for the mechanical engineering course Fundamentals of Manufacturing Processes. The student at right is experimenting with an instructional robot to learn the teach-and-playback function of industrial robots.



controlled system. To achieve better quality, productivity, and efficiency, new techniques and procedures must be part of an overall strategy.

Accordingly, the research program has two predominant themes: a fundamental approach to the integration of design and manufacturing techniques, and the extensive use of computers for controlling the manufacturing system from concept to finished product. Specific projects now underway are in the areas of object representation, materials processing, automated manufacture of discrete parts, automated manufacture of integrated circuits, robotics, and production management.

As an educational unit, COMEPP coordinates doctoral study, establishes internships and other educational programs for M.Eng. students, and stimulates the development of concentrations in the established undergraduate field programs. A current goal, for example, is to set up core curricula and laboratory facilities in the rapidly developing areas of process control and nanoelectronics.

All these educational programs reflect the essential cross-disciplinary character of manufacturing engineering. M.Eng. students are enrolled in one of the eleven regular fields in which designated degrees are awarded—the M.Eng. (Mechanical) and the M.Eng. (Operations Research and Industrial Engineering) are prominent choices by students who want to concentrate in manufacturing engineering. Similarly, undergraduates enter field programs in one of ten established disciplines, and a concentration in manufacturing engineering is arranged within the field program.

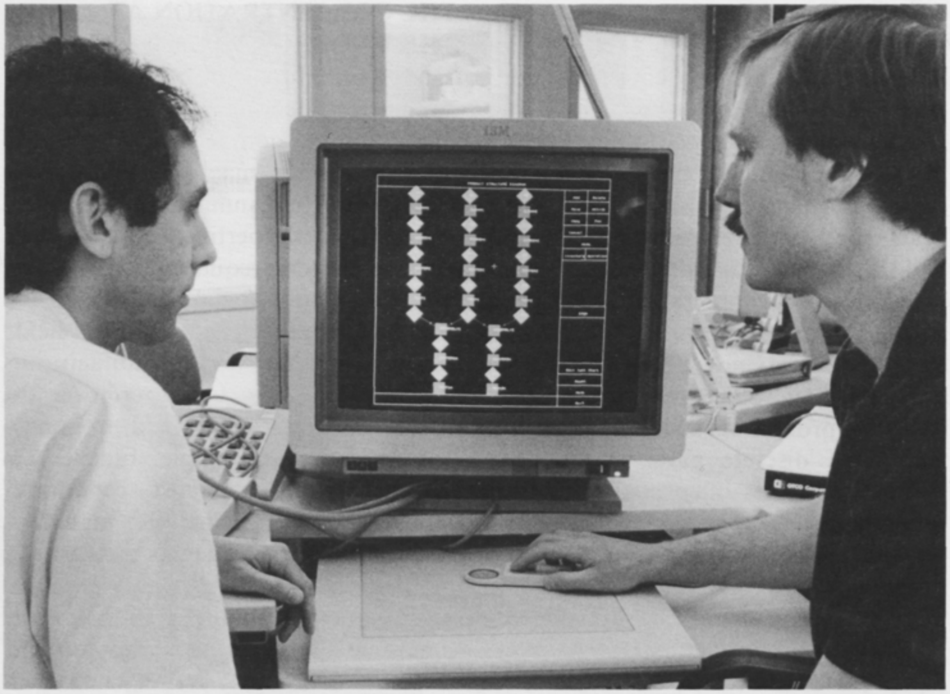
THE CONCENTRATION AT THE UNDERGRADUATE LEVEL

Early exposure to manufacturing systems engineering is provided by an introductory course for freshmen. Undergraduates may further develop their interest in manufacturing engineering by selecting pertinent courses that satisfy degree requirements in the humanities and social sciences. After they have chosen a specialty field, students can arrange a manufacturing systems option by taking appropriate courses as part of their field program.

In OR&IE, for example, students can take such subjects as cost accounting, industrial systems analysis, manufacturing information systems, production planning and control, inventory and logistics control, statistical methods in manufacturing, and factory layout and material-handling systems.

A key senior-level OR&IE course is Economic Analysis of Engineering Systems, which was offered for the first time this year. In scope and focus, it is broader than traditional courses in engineering economy. While topics such as the economic evaluation of alternatives, the impact of depreciation and taxes, and the cost of capital are covered, the course also includes discussion of financial, economic, and logistics issues in the design of manufacturing systems. These include cash-flow analysis, the economics of multinational production, the application of optimization techniques, system simulation, database design for manufacturing systems, production planning and scheduling, and inventory control. Some of these subjects are treated in greater detail in other courses; the emphasis here is on integrating them

"To achieve better quality, productivity, and efficiency, new techniques and procedures must be part of an overall strategy."



The CAD/CAM laboratory established for the Integrated Mechanical Analysis Project (IMAP) is used for instruction as well as research. This spring a similar facility will be set up especially for the teaching program.

into a design experience. The major innovation is the use of microcomputers in case studies set up by faculty members.

Mechanical engineering majors who wished to concentrate on manufacturing engineering might take courses in manufacturing processes, design for manufacture, computer-aided design, numerical control, mechanical reliability, and robotics. Courses planned or recently introduced by other schools and departments cover microprocessor applications, nanoelectronic manufacturing, sensors, finite-element methods, computer graphics, simulation, and materials handling. Some of these came about as a result of consultation with people in industry.

Two facilities that are important to the educational program coordinated by COMEPP are the Computer Aided Design Instructional Facility (CADIF), which is described elsewhere in this issue, and a CAD/CAM laboratory that was set up for the Integrated Mechanical Analysis Project (IMAP). Under development is the Process Control Laboratory, which will help coordinate the teaching in this area throughout the College of Engineering; this laboratory will be operated with the support of twelve faculty members from six schools or departments. COMEPP also helps support teaching and research laboratories for robotics, stereophenomenology (the representation of solid objects), and injection molding.

MEETING THE NEED FOR TECHNOLOGIES AND PEOPLE

The aim of university programs like COMEPP is not only to help develop innovative manufacturing approaches and technologies, but to aid in the transfer of the new information and experience.

In the Cornell program this is done by sponsoring conferences for industrial personnel, organizing other kinds of meetings and consultations, distributing reports and articles, and participating in cooperative research projects. Companies reciprocate by providing general program funding, giving or lending equipment, supporting projects, and sponsoring M.Eng. internships. (This optional internship adds up to fifteen months of paid industrial work to the regular M.Eng. program.)

The greatest impact of the program may well be the education of practitioners. Graduates who have been exposed to the technologies and methodologies of modern manufacturing engineering will have the broad-based knowledge that is so necessary for increased productivity and competitiveness in manufacturing industries.

COMMUNICATION SKILLS

Are They a Missing Ingredient in Engineering Education?

The ability to communicate well is among the tools needed by an engineer, and schools and colleges should do a better job of equipping their graduates with verbal skills.

Increasing signals from employers, professors, and recent graduates suggested to administrators at the Cornell College of Engineering that this assessment is valid, and last fall they decided to begin to do something about it. Recommendations drawn up for faculty approval call for the incorporation of writing assignments in technical courses at all levels and the introduction of a variety of support services.

The recommendations are based on a thorough study initiated by Dean William B. Streett and Professor Richard H. Lance, then the associate dean for undergraduate student affairs. It was conducted during 1985-86 by Steven Youra, a Cornell Ph.D. in English who has taught in, developed, and directed a number of university writing programs and workshops, and who was back on campus as a visiting professor, on leave from the University of Maine. Funding for the project was provided by David Ahl, a 1961 graduate of the college whose career has centered on publishing and writing.

CONSENSUS ON THE NEED FOR COMMUNICATION SKILLS

Included in the report are the results of a survey of faculty, students, and alumni about the importance of writing to the engineering profession, and the extent to which Cornell is and should be training undergraduates in this area. Professors were also asked their opinions on how such instruction should be provided.

Tables I and II present some of the information obtained. Faculty respondents rated various assertions on a scale of 5 to 1, with 5 representing strong agreement and 1 representing strong disagreement; similarly, a small number of active alumni were asked to rate their responses on a scale of 1 (minimum) to 5 (maximum). The professors who responded (about one-third of the total number of faculty members in the college) were nearly unanimous in the opinion that good writing skills are important to engineering (92 percent gave this a rating of 5). Of the alumni, almost all agreed (with ratings of 5 or 4) that written and oral communication skills are important in their professional work, and 88 percent indicated (again with ratings of 5 or 4) that writing skills are important in their hiring and promotion decisions.

This attitude is consistent with the findings of national studies. In a 1982 survey, for example, Spretnak (see the list of further readings) found that engineers spend about two-thirds of their time writing, editing, reading, and presenting material orally. Engineering has always involved communication with others—team members, industrial people, local government officials, clients and other nonspecialists—and such interaction is increasing as society becomes more complex.

In his Cornell report, Youra concludes that engineering teachers and practitioners are increasingly recognizing the importance of communication skills, particularly writing, to the engineering profession. "Ironically," he says, "this acknowledgment has emerged precisely while student writing skills in

Table I. FACULTY EVALUATION OF WRITING IN THE CURRICULUM
Cornell University College of Engineering, Spring 1986

Ratings are on a scale of 1 to 5, from 1 = strongly disagree to 5 = strongly agree. A total of 72 faculty members responded to the survey questions.

	5	4	3	2	1	?
Good writing skills are important to engineers:	92%	7%	0%	0%	1%	-
—to the engineering curriculum:	61	24	8	3	1	3
Students in the college are skillful writers:	0	0	37	38	25	-
The writing component/requirement of the Cornell curriculum needs to be strengthened (assuming this can be done without weakening current offerings or requirements):	50	30	10	1	3	6
What is your response to the following possible options to improve undergraduate writing instruction?						
(a) Incorporation of writing into selected engineering courses:	37	32	18	7	6	-
(b) Development of new composition courses geared to engineers:	15	15	25	15	23	7
(c) Increased use of existing courses/facilities outside of the college:	15	23	21	15	7	19
The development of *oral* presentation skills is an important part of engineering education:	69	23	6	1	1	-

Tables I and II present the results of surveys of faculty members and a sampling of alumni.

In both surveys, the respondents were invited to make comments or recommendations—responses that could not be given in tabular form.

Specific questions asked of the faculty are: How much writing (if any) do you assign in courses you teach? What kind(s)? Would you integrate (more) writing into your courses if you could rely on the assistance of support staff? What suggestions do you have for improving student writing / communications? Do you know what other institutions are doing to address this matter?

The alumni were asked to describe the kinds of writing they do, and to make suggestions.

all fields have significantly declined." Actually, a connection between these two developments—the decline in writing facility and a heightened awareness of its value—seems likely.

How well is Cornell's engineering college preparing students for this aspect of an professional career? The assessment by the faculty of their students' writing skill (Table I) is not encouraging, and neither is the rating given by alumni (Table II) to the adequacy of Cornell engineering education in this regard. Not many students were surveyed, but Youra reports that most of those who were indicated that they would like more help in improving their writing. Comments by students returning to campus from co-op jobs in industry provide another indication of how students feel about this aspect of their education: frequently they observe that their jobs entailed a considerable amount of writing, for which they felt inadequately prepared.

Of course, as Youra points out, some engineering students are very able communicators: some excel in forensic competition and others produce the outstanding magazine, *Cornell Engineer*. Still, like their peers in other disciplines, typical engineering students have difficulty with verbal expression.

WRITING IN THE CURRENT ENGINEERING CURRICULUM

During the freshman year, every student in the College of Engineering takes two seminar courses that are writing-intensive and limited to a maximum of seventeen students. These seminars are selected from a large number offered by faculty members in various departments of the College of Arts and Sciences, and the writing assignments have the benefit of being focused on a particular subject area that is presumably of interest to the student. According to Youra, engineering faculty members are generally satisfied with the freshman seminar program, since it provides "writing-intensive instruction early in the aca-

Table II. ALUMNI SURVEY ON WRITING IN THE CURRICULUM
Cornell University College of Engineering, Spring 1986

Ratings are on a scale of 1 to 5, from 1 = minimum to 5 = maximum. The total number of respondents is 32.

	5	4	3	2	1	?
How important are written and oral communications to you as an engineer?	81%	16%	0%	0%	0%	3%
How well did Cornell prepare you for these aspects of your work?	6	10	45	31	6	6
From your experience, rate the need (if any) to improve Cornell undergraduate engineering instruction in writing:	34	41	10	3	6	6
In your capacity as manager or administrator, to what extent do you consider writing skills in hiring or promotion decisions?	38	50	9	3	0	0

demic career, while exposing students to liberal arts perspectives, methodologies, and values."

After the first year, however, very few engineering students do much if any writing. This is partly because the students tend to choose courses that won't require much writing; they often perceive writing assignments as time-consuming and onerous, and probably are not yet aware of how essential communication skills are to engineering. Besides, even if elective courses entail written work, they usually provide little instruction in writing.

The fact is that very few courses currently offered on campus meet the specific writing needs of engineering undergraduates. The Department of Communication Arts offers one class in scientific/engineering communications and a large many-sectioned course in oral communications, but few engineers take them. A rather recently introduced support service is the walk-in Writing Workshop, which some engineering students do use—about 15 percent of the walk-in clientele are from the engineering college. (Most of these are freshmen, presumably seeking help with freshman-seminar assignments.)

In the College of Engineering, about one-third of the faculty members require a minimal amount of writing, usually in the form of literature reviews, short essays, problem analyses, lab writeups, or technical reports. In general, though, there is little written work and oral presentations are even more rare. Some of the senior laboratory courses require writing, but there are big variations in what and how much is assigned and in how carefully the work is reviewed and corrected.

Half the surveyed faculty members include virtually no writing in their courses, and they offered various explanations for this. A chief reason is the pressure on both student and teacher to cover a large amount of material. Some professors find it difficult to see how their subject matter would lend itself to writing assignments. And some feel that their expertise lies elsewhere or that they should not spend a great deal of time and energy correcting writing mistakes.

SURVEYING THE OPTIONS FOR ENGINEERING SCHOOLS

Many solutions have been proposed and tried at institutions around the country, and Youra's report describes some of them. They include the introduction of special courses in technical writing, the provision of support services such as walk-in writing clinics or tutorials, or—the broadest solution—the integration of written and oral communication into existing courses.

A traditional approach is to depend on departments outside the field to teach communications. In his research Youra found, for example, that all engineers at Princeton must take one literature or philosophy course that requires essay writing. At the University of Illinois at Urbana-Champaign, freshman engineers must take a course in rhetoric taught by the English department. At some institutions, such as the University of Wisconsin at Madison, entire departments staffed by technical communications specialists have been formed; a senior-level course, for example, covers the writing of application letters and resumes, proposals, and technical reports, and experience in oral presentation.

Writing clinics exist in a wide range of modes. Some dispense verbal first-aid, some go beyond emergency service to the organization of credit courses, *"Writing. . .is not a separable skill which—once mastered—can be applied to particular situations."*

Youra

some offer workshops, and some provide services to supplement regular classes. At North Carolina State University, for example, writing specialists accept invitations to give lectures in engineering classes, and are available to advise faculty members on the design and evaluation of writing assignments. A well-run peer tutoring program can be effective, since fellow students understand the educational context of writing problems and have a ready rapport with those seeking help.

Coordination of instruction in technical writing with the regular engineering courses has been tried in various ways. At the University of Washington, for instance, the Program in Scientific and Technical Communications is located within the engineering college, and undergraduates can take a technical writing course that is taught in close conjunction with upper-level engineering courses.

An advantage of including writing as an intrinsic part of engineering education is that verbal communication is established as one of the basic tools of engineers, not a bothersome "extra." It is even possible to assign students communications problems that come directly from industrial practice, much as engineering design assignments are increasingly drawn from "real life" industrial problems.

Writing practiced in the context of technical learning has a more fundamental educational value as well, for it helps develop the analytical and organizational skills needed in engineering design and all other aspects of scientific and technical endeavor. It actually helps the student learn technical subject matter and the "engineering approach" to problems. As Youra remarked, "writing (or more precisely, 'writing/revising') is not a static *product,* but an active *process* of composing and reformulating. It is not a separable skill which—once mastered—can be 'applied' to particular situations. Writers fully immerse themselves in a subject, as verbalization requires them to clarify ideas, to arrange, explore and reshape concepts—in short, to *understand."*

A practical advantage is that when instruction and practice in writing is incorporated directly into the structure of the technical courses, students do not have to make room in their programs for special courses in writing, passing up technical courses they would like to take, or substituting for liberal arts or social science electives.

Perhaps the biggest benefit of all is that students write about the subjects they are most interested in, and can perceive the relevance of the writing assignment to their future professional activity. When it comes to improving skill in writing—or in anything else, for that matter—motivation is a powerful factor.

WHAT STEPS SHOULD THE COLLEGE TAKE?

The recommendations set forth in Youra's report are:

• *Incorporate writing in various technical courses at all levels.* To do this without shifting away from the subject material or draining professors' time, different approaches are needed at different levels.

At the underclass level, each engineering field could earmark certain courses as "communications intensive," and require each student to take one of them. New faculty and staff members who are specialists in engineering communications could provide support services and help in needed course revision. Assignments could include, for example, written and oral presentations by student R&D teams. The idea would be to teach students to *use* communications skills in solving engineering problems.

At the upperclass level, a required course, Workshop in Professional Communications, is recommended. Sections would be taught by communications staff members in conjunction with a "paired" senior laboratory or other advanced course. Individuals and teams would prepare written and oral communications (such as memos, analyses, proposals, and reports) that drew upon the technical course material. The workshop would also teach basic visual presentation techniques.

Inclusion of modest writing and speaking exercises would be encouraged in other courses, even those that are not fundamentally "verbal." Students could be required, for example, to outline readings, write out questions, keep course journals, or write answers to questions posed by the instructor.

• *Provide a variety of support services and resources.* These could include tutorials, instructional handouts, newsletters, and colloquia, possibly handled through the university's Writing Workshop program. Also, a program to train engineering students as tutors could be instituted; such a program might carry academic credit and help not only those being tutored, but the tutors themselves, who might consider careers in technical writing and editing.

FURTHER READING

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Mathes, J. C., and D. W. Stevenson. 1976. Technical writing: The engineering educator's responsibility. *Engineering Education* 69(4):331–34.

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Communications faculty members could also assist the Engineering Cooperative Program and the Engineering Placement Office personnel in their ongoing efforts to help students learn to write better resumes and letters of application and to present themselves well in job interviews.

A further possibility would be to look into the feasibility of using text-evaluation software to guide students in their writing assignments.

• *Establish a small communications staff headed by a director of communications instruction with faculty standing.* In addition to developing, managing, and monitoring the overall program, the director would head a faculty committee on communications instruction.

FACULTY SUPPORT: THE CRUCIAL ELEMENT

A "small but important caveat" included in the report to the college is that engineering teachers themselves must value good writing if any measures designed to improve students' communications skills are to be successful. As one faculty member commented, "The faculty must set good standards and then let the students know that good communications skills are important. If everything is expressed in mathematical language or in 'computerese,' good written and oral communications skills go down the drain." Also needed is clear recognition, by the college and by colleagues, that communications instruction is an important faculty endeavor.

If verbal skills become a clear educational priority, the report claimed, students' abilities in this area will improve substantially. The goal is to make the ability to communicate well an intrinsic aspect of the excellence of Cornell engineers.

COMMENTARY

A Decline in Innovation Among Engineers: Possible Causes and Solutions

by Michael W. Strausser and Pamela G. Strausser

Many United States companies have a problem with declining innovation on the part of their research, design, and development (R,D&D) engineers, a decline that may be partly to blame for the firms' decreasing share of global markets. The concern of business leaders is evident in the seminars and literature addressing the problem. Often companies seek outside assistance when actually, solutions may be better found by looking within.

What is causing this decline in innovation? Two basic reasons are suggested by research into the problem: the migration of engineering professionals into the ranks of management, and organizational structures that fail to make the best use of engineers.

SHOULD ENGINEERS BECOME COMPANY MANAGERS?

In today's technological society organizations truly need technically literate managers. These are actively recruited from the ranks of high-performing R,D&D engineers by rewarding excellent performance in a technical role with promotion into management.

In many companies, this migration is further stimulated by the reward system. Experienced engineers are often paid little more than those at entry level, which sends a clear signal to engineers that experience in a technical role is not highly valued by the organization. Managers, on the other hand, do not experience wage compression to the same extent and are generally paid significantly more than engineers. The inequity extends to nonmonetary areas as well. Frequently the status of engineers—represented by such things as titles, desirable office space, and quality and availability of support staff—is lower than that of managers.

An obvious drawback of this type of reward system is the adverse effect it can have on a company's strength in engineering. If the company values its R,D&D engineers, then rewards, both compensation and perquisites, should confirm that valuation. Given the possibility of attaining equal rewards and status as either a manager or a technically contributing engineer, the individual may be more likely to follow the career path that best suits him or her.

AVOIDING THE TECHNICAL OBSOLESCENCE OF ENGINEERS

During the 1960s, industrial organizations began to discuss what impact the rapid introduction of new technologies would have on engineers. It was widely believed that an engineer was "state of the art" upon graduation but began to lose the ability to make a technical contribution as time passed. This loss of ability was referred to as *technical obsolescence* and researchers even began to quantify it: the period after which an engineer would be half as technically astute as at graduation was termed the *half-life*. Various half-life figures ranging from four to fifteen years were prevalent throughout the 1960s and 1970s.

Central to the belief in obsolescence is its inevitability. Fear of becoming obsolete may be one cause for the migration of R,D&D engineers into management, because while technical accomplishments are very measurable and decreased technical ability would be quickly recognized, technical skills are rarely the basis upon which managers are evaluated.

It should be obvious, however, that a

"[A basic reason] is the migration of engineering professionals into the ranks of management."

reputable engineering curriculum does more than arm the engineer with a set of facts. It provides a foundation for understanding a problem and a methodology for approaching a solution that are applicable regardless of the current state of technology. This process does not become obsolete. Rather, the range of possible solutions expands or changes. There is no proof that technical obsolescence is inevitable or inherent in the profession. Research indicates that when it does occur, it may be the result of job assignments that do not keep the individual abreast of the latest technologies.

CONSIDERING PERSONALITY TRAITS OF ENGINEERS

The tendency of people in the same occupation to have similar personalities has been shown in research. Among the traits that have been identified as common to R,D&D engineers are the following: the desire to develop further technical expertise; commitment to the profession more than to the organization; less interest in social interaction than is shown by people in various other occupations; motivation by technical challenge rather than managerial issues; and a desire to be recognized for expertise rather than for leadership or power. Some research suggests that such tendencies guide career decisions and influence long-term goals.

Although a company cannot control or modify the personalities of its R,D&D engineers, it can be sensitive to their inclinations and motivations and establish an open dialogue. This may have two positive results. It may help the company decide which engineers are suited to the role of manager and which should be encouraged to further develop their skills as technical contributors. And it may help the company identify organizational factors that are inhibiting innovation.

DIFFERING PERCEPTIONS OF THE ENGINEER'S ROLE

Innovation may be inhibited if the engineers' concept of what they are supposed to do differs greatly from that of the company. Many engineers view themselves as scientists who fulfill creative, scientific needs. The organization, on the other hand, may view the engineer as a multi-talented technical resource, responsible not only for product concept and design, but also for the myriad details necessary and inherent in production. It is for these details that engineers are often not particularly well suited or motivated.

Differences in expectations may be downplayed during the hiring process. In their wish to employ engineers with the best qualifications, organizations are apt to stress those aspects of a job that conform to what the applicant hopes to find. Many engineers expect to spend a large percentage of their time on technically challenging projects, and reality may be very disappointing. If R,D&D engineers are relieved of routine duties, they will have more time to be creative in designing new and innovative products. Such a policy might even help prevent obsolescence.

WHAT COMPANIES CAN DO TO FOSTER INNOVATION

Organizations that value managers more than technical contributors naturally spend more time and energy developing managerial resources than developing technical ones. Mentorship, for example, is a development tool that has been given a great deal of attention in business and academic literature. A mentor helps promising young people develop more rapidly and more completely than they would otherwise. But while companies encourage mentorship for managerial candidates, there appears to be no such system to foster the development of technical innovators.

Interaction with other professionals is another benefit that companies are apt to provide for managers but not for engineers. Companies would do well to recognize that engineers may need to consult with fellow professionals, and not only with those working on the same project. Brainstorming can be a significant part of the creative process; without frequent interaction among the technical staff members, opportunities for developing good ideas may be lost.

Another way to help make technical careers as attractive as those in management is to have a technical career ladder that is equivalent to the managerial ladder in opportunity, status, and pay. The tendency to place a higher value on managerial skills creates not only a financial liability for engineers, but a perceived stigma. The engineering side of the house may even serve as a dumping ground for failed managers whom the company wants to isolate from business decisions.

The low visibility of top jobs on the technical side, as compared to the managerial side, is a further deterrent. People have been conditioned to associate status with scope of authority; top technical personnel, however, tend to concentrate their efforts. The company can improve this situation through better communication—the R,D&D engineers should be given a clear indication of potential career paths and the status of technical positions. Of course, there must be top positions available for the most esteemed engineers.

The point we wish to make is that many of the factors contributing to decline in innovation can be influenced by the organization. If companies are serious about correcting this problem, they must recognize that they may have inadvertently contributed to it and that as a result, they hold a key to its solution.

Michael W. Strausser, a Cornell electrical engineering graduate, is a partner in Hugh Keegan and Associates, an advertising agency in Cortland, New York. Previously, he worked in various engineering and technical management capacities for E. I. du Pont de Nemours and Company, SCM Corporation, and, most recently, Welch Allyn, Inc. He earned the B.S. degree in 1975 and the M.Eng. (Electrical) in 1976.

Pamela G. Strausser is a compensation and benefits specialist for Welch Allyn, Inc. She has also held a variety of managerial and human-resource positions. She received her B.A. degree from Harvard University in 1975 and the M.S. in human resource management from Cornell in 1986.

The authors commented that this article "is based upon research, observation, and in part on a study of Cornell electrical engineers who received B.S. degrees between 1970 and 1980." The study constituted Pamela Strausser's M.S. thesis.

REGISTER

Hillman

■ The eighteenth College of Engineering professor to receive a Presidential Young Investigator Award is *Lloyd Hillman,* who joined the electrical engineering faculty last fall. His research is in laser dynamics and nonlinear interactions between light and matter.

Two hundred PYI awards are granted annually by the National Science Foundation. They provide research support for five years: A direct grant from NSF is supplemented by matching funds for any industrial support, up to a total of as much as $100,000 a year.

Hillman studied for the Ph.D. at the University of Rochester's Institute of Optics. Before coming to Cornell, he worked for two years at the Kodak Research Laboratories.

■ Awards from professional societies were received recently by five college faculty members.

Keith E. Gubbins and *Michael L. Shuler* of the chemical engineering faculty were honored for their research contributions. Gubbins won the Chi Sigma Award of the American Institute of Chemical Engineers and Shuler received the Marvin J. Johnson Award in Microbial and Biochemical Technology from the American Chemical Society.

The computer science faculty also had two honorees. *David Gries* received the Education Award from the American Federation of Information Processing Societies. *John E. Hopcroft*, together with Robert E. Tarjan (a former graduate student who is now on the Princeton University faculty), received the Turing Award of the Association for Computing Machinery for their contributions to the development of theoretical computer science.

Daniel P. Loucks received the Julian Hinds Award of the American Society of Civil Engineers for research in water resources engineering.

■ Recognition for outstanding professional papers has been given to two faculty members at the college.

Arthur H. Nilson, professor of structural engineering, received the Wason Medal from the American Concrete Institute for his paper, "Design Implications of Current Research on High-Strength Concrete." It was selected from about 250 papers published in 1985 by the institute. Nilson has the added distinction of being the first person to receive the award twice in a row; the last winning paper was by Nilson, colleague Floyd O. Slate, and Salvador Martinez.

Robert W. Kay, associate professor of geological sciences, was an author of a paper selected as a Citation Classic (a publication with a high number of citations in the professional literature). The paper, "Chemical Characterizations and Origin of Oceanic Ridge Volcanic Rocks," was written with J. Hubbard and P. Gast and published in the *Journal of Geophysical Research* in 1970.

■ Leadership positions in professional societies are being assumed by *Gerald Salton*, professor of computer science, and *Francis C. Moon,* professor of theoretical and applied mechanics. Salton was elected director-at-large of the American Society for Information Sciences. Moon is vice president and president-elect of the Society of Engineering Science.

■ Goeffrey S. S. Ludford, professor of applied mathematics in the Department of Theoretical and Applied Mechanics since 1961, died at the age of fifty-eight on December 11, 1986.

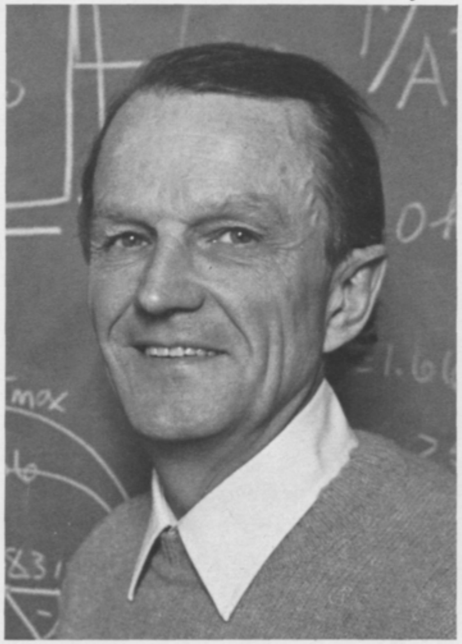
At Cornell he was also the first director of the recently established Mathematical Sciences Institute. He was instrumental in organizing the effort to win the major federal grant that brought the institute to Cornell. Ludford was a member of the graduate Field of Applied Mathematics and recently was elected a professor in the Department of Mathematics.

Ludford was born in London, England, and received bachelor's, master's, and doctoral degrees at Cambridge University. While at Cambridge he was a member of the crew that won the Grand Challenge Cup at Henley and the Oxford-Cambridge Boat Race.

Before beginning graduate study, Ludford spent two years at Harvard University as a research assistant. Before joining the Cornell faculty, he held professorships in mathematics and in aeronautical engineering at the Institute for Fluid Dynamics and Appled Mathematics at the University of Maryland. He had also been a visiting professor in applied mathematics at Brown University.

Ludford specialized in the application of mathematics to fluid phenomema including magnetohydrodynamics and combustion. He was an author of four books, including *Theory of Laminar Flames* and *Lectures on Mathematical Combustion,* both written with his former student J. D. Buckmaster and published in 1982 and 1983, respectively. He also published more than one hundred sixty research papers.

Ludford



At Cornell he established a number of courses in applied mathematics that have been basic to the education of hundreds of graduate students, and he supervised the thesis work of more than twenty doctoral candidates.

He was a recipient of a Guggenheim fellowship, a National Science Foundation senior postdoctoral fellowship, and a von Humboldt Foundation award. He was also a Fulbright-Hays scholar and a United Kingdom Science Research Council senior visiting fellow at Cambridge. He was a fellow of the Cambridge Philosophical Society and a member of numerous professional societies.

Ludford is survived by his wife, Pamela, who is an associate professor of vegetable crops at Cornell, and by two daughters, five grandchildren, and a brother.

■ Several deaths occurred recently among emeritus professors.

Arthur J. McNair of the civil and environmental engineering faculty died October 31 at the age of seventy-two. A specialist in surveying and photogrammetry, he came to Cornell in 1949 and retired in 1979.

John R. Moynihan, professor emeritus of theoretical and applied mechanics, died December 15. He was educated at Cornell and was on the faculty from 1929 to 1971, at one time serving as chairman of the Department of Materials. He was eighty years old.

Byron Saunders, a faculty member from 1947 to 1979, died January 4, 1987, at the age of seventy-two. He served as first director of the School of Industrial Engineering and Operations Research, and subsequently, until his retirement, he was dean of the university faculty.

FACULTY PUBLICATIONS

Current research activities at the Cornell University College of Engineering are represented by the following publications and conference papers that appeared or were presented during the four-month period April through July, 1986. (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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LETTERS

Chaos and Physical Systems

Professor Philip J. Holmes:
Congratulations! The issue on chaos composed by you and your colleagues provides an excellent, extremely well-written introduction to this complex topic. I plan to use your magazine to provide additional fuel for the small fire I have been building under the Georgia Tech administration. I have at least the slight hope of making their asbestos suits warm.

The articles in your magazine provide a rather complete picture of chaos as evolution. As a point of perhaps minor interest, I enclose a recent review of mine which presents arguments for chaos as revolution. This was published in *Chaotic Dynamics and Fractals* (Academic Press, 1965). A companion review is to be published in *The New Physics* (Cambridge University Press, 1987).
Joseph Ford, Regents' Professor
Georgia Institute of Technology

Editor:
The *Quarterly* on chaos was beautiful, well-written, informative, and thoroughly provocative. It was much better than anything like that I've ever seen. I would have paid big money for it in a bookstore. I have a lot of friends who say they are doing chaos, and not a one has ever been able to explain it to me as well as that issue. Bravo!
Thomas McMahon, Cornell B.S. '65
Professor, Applied Mechanics and Biology
Harvard University

Looking Toward the East

Professor Richard N. White:
Your article on "Seven Weeks in China" in the current issue of *Engineering: Cornell Quarterly* is most interesting. Thanks for an excellent report as well as the outstanding photos.

This magazine should have more coverage such as you have presented.
Clifford T. Argue
Alaska Airlines, Seattle, WA

Professor Richard N. White:
I enjoyed your wonderful article, "Seven Weeks in China," in the *Quarterly*. Your photographs are stunningly beautiful and really seem to capture the essence of China and its people. I was also very touched by the letter written by the Cornell Civil Engineering alumni. I think Cornell is remembered as a special place in the hearts of all its former students. Thank you for a great article.
Mary Sansalone, Cornell Ph.D. '86
Gaithersburg, MD

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