Cornell Engineering:
A Tradition of Leadership and Innovation
Dedication

This history of Cornell Engineering is in your hands today thanks to the inspiration, enthusiasm, and support of W. Kent Fuchs, the Joseph Silbert Dean of Engineering at Cornell University from 2002 to 2008. It was his vision to capture the enduring legacy of leadership and innovation in the college from its earliest beginnings to the present time, within the context of both the history of Cornell University and the history of the engineering profession. It seems especially fitting that this project reaches its conclusion in tandem with Dean Fuchs’s tenure as dean. We begin a new epoch at Cornell and the College of Engineering as we welcome Kent Fuchs as the fifteenth provost of Cornell University.
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At the crest of Libe Slope—where the I. M. Pei–designed art museum commands a panoramic view of the town below, the hills around Ithaca, and the crooked finger of Cayuga Lake as it reaches to the north—is the spot where twenty-one-year-old Ezra Cornell paused one April evening in 1826. The carpenter had walked to Ithaca the forty-one miles from his family homestead in DeRuyter, New York.

Born in 1807 in Westchester County and cradled in his mother’s arms as his father’s horse-drawn wagon brought the family to what then was the western frontier, young Ezra had little chance for schooling (about three months each winter) in rural Cortland County. But he did have a knack for building, in wood, stone, and metal, and a precocious aptitude for mathematics, which he called ciphering, filling the handmade paper pages of several notebooks. As a teenager he had replaced the family’s log cabin with a wood-framed house—to the astonishment of experienced builders. Traveling north to Syracuse, he worked building sawmills—until swindlers took his earnings. His father, potter Elijah Cornell, who had seen him off to the Salt City with some fatherly advice (“Mind and behave yourself in a becoming manner. Write often and come home when a convenient opportunity presents.”) again offered counsel when a discouraged son returned home: “Go see what Ithaca has to offer.”

The final leg of the trek to Ithaca had taken Ezra Cornell along the same Fall Creek he would one day harness, using dams and aqueducts, for Col. Jeremiah Beebe’s water-powered mills. He also would come to own the farmland where he stood, but first he had to make a decision.

The valley below looked promising enough. Manufactured goods and commodities were being transferred from wagons to steamboats and barges for the trip up Cayuga
Lake to markets beyond. New homes, factories, commercial establishments, and public buildings were rising everywhere in the thriving village. There was even talk of Ithaca’s first railroad connection.

At last he had come to a place, Cornell decided—before continuing down the hill, taking a boardinghouse room for the night and finding a carpentry job the next morning—where he could make something of himself.

By 1863 Ezra Cornell had reinvented himself several times. The carpenter’s résumé had grown over the previous thirty-seven years to include mechanic, millwright, civil engineer (although he never called himself that), scientific farmer, land speculator, visionary builder of the world’s first telecommunications network, politician, and philanthropist.

Some of his engineering undertakings had turned out as planned. The two blasting crews driving a 200-foot tunnel from opposite ends through solid rock at Ithaca Falls met in perfect alignment right where his calculations had predicted they should.

However, Cornell’s signature engineering project—building the telegraph lines between Baltimore and Washington, D.C., for the May 24, 1844, “What hath God wrought” message by Samuel Morse—was temporarily derailed. The combination trenching plow and cable-laying machine he had designed to bury electric wires underground worked better than expected. The demonstration project was nearing completion when a serious glitch arose. The electrical insulation of the 1840s (cotton yarn and shellac) could not protect Morse’s dots and dashes in their travels through leaky lead-conduit pipes. Galvanometer readings found shorts in the underground telegraph wires, and Cornell knew he had to learn some fundamentals of electrical science in a hurry.

After research at the Library of Congress and the U.S. Patent Office, Cornell devised a practical—if unsightly—alternative. He hung the first telegraph wires from wooden poles, trees, and the sides of buildings and just about anywhere he could fasten the glass insulators that he had modeled

Ezra Cornell outfitted this pottery factory for his father, Elijah Cornell. The 175-year-old building still stands (as apartments) near the base of Ithaca Falls, although the town’s commercial ceramics industry is gone.
after bureau-drawer knobs. When the regional utilities consolidated into the Western Union Telegraph Company, Ezra’s stock holdings made his fortune.

It’s tempting to suspect that when Ezra the philanthropist conducted an 1863 horse-and-buggy tour of Ithaca’s East Hill—and said he intended to found “an institution for poor young men [with] no entrance examination [where] they could study whatever they were inclined to”—he had younger versions of himself in mind.

But it took more than wordsmithing to spin that 1863 declaration into the now-familiar “institution where any person can find instruction in any study.” His dream of doing away with entrance exams did not come true, either. Cornell had connected with the Yale-educated Andrew Dickson White (they met while serving in the New York State Senate), who convinced him that a proper university had to have some academic standards, after all. The day before the October 7, 1868, inauguration, applicants to the startup university were ordered to report for exams. Those who did made up the largest entering class (412) at any American university up to that time. Housing was in short supply, classroom buildings were still under construction, and some of the first faculty members (seventeen professors, four assistant professors, and five instructors) lived, took their meals, and taught in the same building where students bunked, the fortress-like former water-cure spa we call Cascadilla Hall.

As principal benefactor ($500,000 cash and land, at first, with more to come), Ezra Cornell gave an inaugural speech:

I hope we have laid the foundation of an institution which shall combine practical with liberal education, which shall fit the youth of our country for the professions, the farms, the mines, the manufactories, for investigation of science, and for mastering all the practical questions of life with success and honor.
That’s where our story begins. From its founding, Cornell University helped to revolutionize engineering education in America, becoming along the way one of the premier institutions for advanced research and education.

Cornell engineering graduates have stories as well, such as the engineer–entrepreneur who created the Moog music synthesizer and broke the elevator in Clark Hall; the Cornell electrical engineer who invented the implantable cardiac pacemaker and escaped the wrath of animal-rights activists in Varna; and the Cornell mechanical engineer who popularized electric organs and made the first 3-D movie glasses.

These Cornell engineers and others have some things in common with Ezra Cornell. They’re all, in their ways, builders. They created new technologies and discovered ways to make the world a better place. Educators and problem-solvers who went beyond putting off-the-shelf answers together, they asked fundamental questions designed to lead to answers that produce solutions.

It might make you wonder what a reborn Ezra Cornell would study if he were entering the university he founded.
October 1868

The campus was not exactly ready for the sixty-four students of engineering and the mechanic arts who ventured up East Hill to begin the first year of Cornell University. Founder Ezra Cornell acknowledged as much. He said there would be work for skilled and able-bodied students (see “Patent Plows, Electricity, and the Mechanic Arts,” page 8), building with their own hands a university they would be proud to call their own.

Engineering on their application papers meant civil engineering, the civilian side of the military engineering taught initially at West Point. Mechanic arts was the other subject—besides agriculture—that New York’s newly designated land-grant university was obliged to teach. The promise of a science-based engineering education implied laboratory experiments to learn the nature of the forces they would try to harness.

Not until 1869 did the spirit of full disclosure move engineering faculty members to use the word “experiment.” Eli Whitney Blake was the first dean of the College of the Mechanic Arts when the University Register printed the following plan to make engineering students the masters of their art, and to distinguish Cornell engineering schools from shops:

It will easily be understood that the instruction in this College must be at first largely experimental in character. It is not its purpose, however, to teach rudimentary branches—to narrow down its instruction to any single trade or to the ordinary use of simple tools. The schools for this are the myriads of shops scattered throughout the country, and in them this work is done on a much larger
scale, in much more varied ways and in places much nearer the homes of students than the University can ever hope to do it. It would be a misapplication of funds to devote them to adding one or two simple workshops to the thousands on thousands already in existence, and to do at the University what must necessarily be done better elsewhere. The great want of the country in this department is master mechanics who are thoroughly trained. The waste incurred through uninstructed or half-instructed master mechanics would more than suffice to endow splendid institutions for this sort of instruction.

**Shop Culture, Book Learning, and Work–Study**

Cornell University in the first decades became a laboratory where two means of educating engineers—shop culture and book learning—were examined and debated, where even the kind of labor that students performed to earn their keep was thought to affect their education.

**SO THEY SAID**

**PATENT PLOWS, ELECTRICITY, AND THE MECHANIC ARTS**

“A man was needed who knew the laws of science, had the inventor’s brain, and who also had, like Watt of the steam-engine, a decidedly mechanical genius.”

Steel baron and Cornell trustee Andrew Carnegie, recounting Ezra Cornell’s role in building the first telegraph lines, in an address to Cornell University students on April 26, 1907

The start of a revolution in communications, this is one of the two telegraph instruments that carried Samuel F. B. Morse’s “What hath God wrought” message in 1844 through lines built by Ezra Cornell. In 1883, less than forty years later, electrical engineering was taught in Cornell’s Sibley College of the Mechanic Arts—because early electrical technology was electromechanical in nature. Ezra Cornell’s patented trenching tool, shown here, had worked well enough on the telegraph line between Washington, D.C., and Baltimore—until water seeped through conduit pipe and shorted out the wires. A resourceful Cornell recycled the wire, using glass insulators he devised to hang the lines from poles, trees, and even sides of buildings. He never claimed to be an electrical engineer.

Nor was “engineering” in the name of the college established at Cornell University to meet one obligation it had incurred as the newly designated land-grant institution for the state of New York. The federal Morrill Act of 1862 required land-grant institutions to operate “at least one college where the leading object shall be, without excluding other scientific and classical studies, and including military tactics, to teach such branches of learning as are related to agriculture and the mechanic arts . . . to promote the liberal and practical education of the industrial classes in several pursuits and professions of life.” In the early years of Cornell University, the College of the Mechanic Arts helped meet that obligation. Today the School of Mechanical and Aerospace Engineering is part of the College of Engineering, as is the School of Electrical and Computer Engineering. Morrill Hall honors the legislator (U.S. Senator Justin Smith Morrill) who envisioned land-grant colleges. Lincoln Hall—named for the president who signed the Morrill Act into law, and built in 1888 with $66,000 from the sale of land-grant timberland—was the first home of civil engineering at the university.
By the time Sibley College’s annual spring banquet rolled around, students in the college foundry must have worked up an appetite. This keepsake menu from April 24, 1909, is printed on varnished wood and promises six courses, culminating with dessert: vanilla, peach, and pistachio ice cream; “cocoanut” drops; lady fingers; nut bars; or chocolate cake. Or all of the above.

In the foundry, located on the south rim of Fall Creek gorge and now used by sculpture students in the College of Architecture, Art, and Planning, Cornell engineers learned molding, core making, mixing of metals, and operation of a cupola.

Robert Henry Thurston, dean of the Sibley College of the Mechanic Arts from 1885 to 1903, ultimately prevailed over faculty members who favored shop training over book learning. Immersion in shop culture, Thurston said, would keep Cornell’s student engineers from reaching “the front rank of those who do the great work of the profession.” (See “Do the Great Work of the Profession,” page 10.)

But first came work for Ezra’s “poor young men” with bills to pay. Professor Blake offered what is now called work–study financial aid in the 1869 University Register, beginning with a confession:

*The shops which are ultimately to form a part of the College of Mechanics are not yet ready. It is hoped that they will be in operation before another year. When they are in operation, good practical machinists, who have already sound ordinary English education, and who wish to make themselves thoroughly scientific master mechanics, can probably do much toward their own support, and at the same time perfect themselves in their special department, in making models of instruments, machines, and apparatus for the University and other illustrative collections. But this will require skilled labor, the labor of young men already more or less accustomed to the use of tools.*
So engineering students with *previous* training as machinists, for instance, would be paid to build the brass models and other teaching devices. Still, the 1800s work–study program sounded awfully close to shop culture. The division was underscored when steam-powered printing presses moved into the College of the Mechanic Arts’ newly built West Sibley Hall in 1870. Again, engineering students with previously acquired skills were paid to set the type, operate the presses, and bind the books in what is now one of America’s oldest academic publishing houses, Cornell University Press—but only if they had come to Cornell with those skills. The university was not a trade school to teach skills like typesetting, some engineering faculty members insisted. It was permiss-

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**SO THEY SAID**

**DO THE GREAT WORK OF THE PROFESSION**

“The greatest of all arts, that of contriving methods of turning the powers and processes of nature to uses of man.”


The newly appointed dean of Cornell University’s Sibley College, Robert H. Thurston, knew what the “principal special schools” of engineering were—MIT, RPI, and Stevens (the three known for “school culture” education), and Worcester County Free Institute of Industrial Science (the “shop culture” school that would become WPI in 1887). On the way to telling how the university could join (and maybe rise above) the school-culture elites and differentiate itself from Worcester, Thurston staked Cornell engineering’s place in a three-tier “complete scheme of education.” The scheme, he said, encompassed manual training schools for youth, trade schools “for those proposing to fit themselves for . . . industrial pursuits,” and the technical and engineering schools “in which the scientific development of the constructive professions is aimed at.”

“In the first, young people are to be taught the use of tools, in the second the arts of carpentry, weaving, blacksmithing, stone-cutting, and other industrial arts, and in the third, the greatest of all arts, that of contriving methods of turning the powers and processes of nature to uses of man, and of inventing and designing all the mechanism, apparatus, and structures needed in work. The highest department of instruction, and that in which the greatest of all institutions included in the system will take part, is the thoroughly scientific training and education of students with a view to preparing them to take advantage of all new discoveries and inventions, to thus keep themselves in the front rank among those who do the great work of the profession; it will also, while giving instruction to the ablest and best students, supply technical schools and colleges of the country, well taught and talented instructors, able investigators and skillful administrators, and will aid by scientific research the development of every industry, and furnish a nucleus about which to gather the great men of the country capable of instructing not only the youth who may come to their lecture-rooms and laboratories, but the legislators and executive officers of the government wherever they may be called upon to deal with any one of the innumerable questions affecting the national weal through its industries.

A mechanical engineering class in thermodynamics led by Thurston in Sibley Hall
sible, however, for students who happened to have a trade to work and to finance their education on the way to becoming masters of the engineering profession and leaders of those who toiled.

The debate over appropriate work for engineering students was recalled, forty-five years later, when a retired A. D. White (1832–1918) told mechanical engineering students how close their college had come to being the “Cornell Chair Factory and Afternoon Trade School.”

_Through the early days of that formative period, various theories appeared as to what the work of the institution should be. So far as the department of Mechanic Arts was concerned, perhaps the most seductive and dangerous idea was that it should become merely a manual labor school of a low grade and nothing else. It was seriously proposed that, with the water power at its disposal in Ithaca, the Board of Trustees should become not only an educational, but a manufacturing corporation: that there should be established buildings for the manufacture of cheap articles, easily made, mainly shoes and chairs, and that the work in these factories in the mornings would enable the students to support themselves, while obtaining the rudiments of an education in the afternoons._

White affirmed that “that was the intention neither of the charter from the United States nor from the state of New York.” The engineering graduates’ work would come soon enough, to “develop and improve the great industries of the country.” Meanwhile, students should “receive an advanced education which would strengthen every branch of industry.” (For some examples of this education, see “Mental Analysis,” page 13.)

While Cornell engineering students never did sweat to make “cheap goods” in university-owned factories, some perspired in the Ithaca outdoors. Before Ezra Cornell died in 1874, students earned cash ($232.40 in 1870s dollars for room, board, lights, and fuel) by quarrying stone for the first buildings and laboring to construct the first roads on campus. President White may not have approved—the road gangs were discontinued when Cornell died—but he must have liked what Ezra Cornell said about science and mechanic arts education in his Inauguration Day address on October 7, 1868:

_Thus in whatever direction we turn, we find ample opportunity for the applications of science in the aid of the toiling millions. May we not hope that we have made the beginning of an institution which will strengthen the arm of the mechanic and multiply his powers of production through the agency of a better cultivated brain? Any person who visits our Patent Office in Washington, and contemplates the long halls stored with rejected models, will realize that our mechanics have great need of this aid._

Perhaps that momentary Patent Office flashback returned Ezra Cornell to the frustrating winter of 1843 when he haunted the Library of Congress and the U.S. Patent Office as he tried to salvage Samuel Morse’s groundwater-plagued telegraph line. Morse’s personal mechanic, Alfred Vail, was in the Library of Congress, too, still pondering the underground line plan. When Cornell emerged to suggest restringing the lines above ground, Morse asked the famous physicist Joseph Henry for a second opinion. The physicist said the unschooled mechanic was right, even if Ezra Cornell could not fathom the science behind his hunch. Crews under the direction of Cornell tore up the
underground lines and hung them from poles and trees, and the telegraph worked well enough. But the need for scientifically educated engineers made a lasting impression on him.

The Next Generation of Ezras

The first engineering and mechanic arts students were among the university’s 412 undergraduates in the fall of 1868. They came from as far as Illinois, Louisiana, and Maine, and as near as Aurora, Scipioville, and Ithaca, New York. One Warren Howard Hayes gave his home address as Italy.

Of the 410 courses offered at Cornell University that first year, 27 were in the mechanic arts and 39 were described as engineering. From the start, the engineering students could range throughout the course catalog, which offered 10 classes in chemistry, 143 in other areas of science, 30 in agriculture, 14 in natural science, 28 in philosophy, and 40 in the arts.

In addition to Professor Blake, who taught physics and industrial mechanics, were William Charles Cleveland, C.E., a professor of civil engineering; Charles Frederick Hartt, A.M., economic and agricultural geology; and John L. Morris, A.B., C.E., director of the machine shops and a professor of practical mechanics. Ziba Hazard Potter, A.M., M.D., taught math in the College of Mathematics and Engineering (which included civil engineering), while mathematician Evan W. Evans, M.A., was the dean of that college. Of the seven “non-resident” professors who were slated to deliver twelve lectures apiece that year, John Stanton Gould was to teach “Mechanics Applied to Agriculture” and James Hall, “General Geology.”

Students of civil engineering, where Professor Cleveland was the director, would spend their first two years learning as much science and mathematics as the science majors (their four-year degree would be a bachelor of science). They had to wait until the third and fourth years to try their hands at engineering, in such courses as “Descriptive Geometry and Its Applications to Shades, Shadows, and Perspective”; “Masonry and Stone-Cutting in the Construction of Arches, Domes, and Staircases”; “Carpentry in the Construction of Bridges and Roofs”; “Surveying and the Use of Instruments”; “Draughting [drafting]”; and “Analytical Mechanics and Its Application to the Principles of Construction.” More coursework in surveying and drafting was expected of engineers who hoped to earn a license certificate.

Mechanic arts students knew they weren’t in trade school when they saw the course requirements for their first two years: “English Language, Literature, and Vocal Culture”; “French”; “Linear Draughting”; “Geometry”; “English Literature and Rhetoric”; “Experimental Mechanics”; “German”; “Trigonometry and Mensuration [measurement]”; “Analytical Geometry”; “Chemistry”; “Physics”; and “Strength and Preservation of Materials.” Their third year would bring “Descriptive Geometry”; “Integral Calculus”; “Tools and Processes Employed in the Construction of Machinery”; “Draughting with the Study of Colors”; “Mechanics and the Mechanical Relations of Heat and Building Materials”; “Acoustics and Optics”; “Draughting of Mechanisms”; and “Machinery of Transmission.” There were still more required engineering courses
in the fourth year for would-be masters of the mechanic arts: “Study of the Moving Forces Employed in the Arts with Special Reference to Water Wheels and Steam Engines”; “Machine Draughting”; and “Metallurgy and Study of the Steam Engine.” Four other requirements were intended to produce well-rounded mechanical engineers with a Cornell B.S. after their names: “Architecture”; “Rural Economy”; “Political Economy”; and “Moral Philosophy.”

As tough as those requirements were, a Cornell engineering education had to become even more rigorous if the grand experiment was to be meaningful, and if Cornell was to be distinguished from its peers. The next dean of civil engineering, Estévan Fuertes, insisted that calculus be taught in the first year. He also instituted the summer surveying camp that became a rite of passage for Cornell civil engineers. Working across New York’s Finger Lakes region, Fuertes’ surveying students became so reliably skilled that their measurements were accepted by the U.S. Geological Survey soon after 1879 when cross-country mapping began. (See “Any Further Questions?” page 14.)

The debate over the best way to educate professional engineers—in a science-based “school culture” or the hands-on “shop culture”—was framed by two mechanical engineers, Robert Henry Thurston and John Edson Sweet. Sweet was a “natural mechanic” with little formal education but a string of inventions to his credit when he was appointed director of the machine shops in the Sibley College. Thurston held a doctoral degree and the belief that shop training, while adding a valuable perspective to an engineering education, was not nearly enough. (See “Lathes, Planers, and Milling Machines,” page 16.)

Both men rose to the top of their professional ranks. Sweet could build a steam engine with hand tools and water-powered machines, and he was recognized in his time for introducing advanced methods of shop training at the university level. Thurston emphasized laboratory research and instruction. He wanted engineering students to have

SO THEY SAID

MENTAL ANALYSIS

“Discuss the Flexure of Beams subjected to transverse strain, by means of the Calculus; and show the effects of shearing strain upon the Moment of Flexure.”

Exam essay question in Professor Charles Cleveland’s mechanical engineering class, 1870. Students were not allowed to make any diagrams, but were obliged to make “a mental analysis” and had three hours to complete the essay.

“What is the best arrangement of a battery of 600 cells, when the external resistance is 300 feet of copper wire, resistance of each cell being equal to 18 feet of the same wire?”

Exam question regarding Ohm’s Law from Professor William Anthony’s second-year class in electricity and magnetism, 1874.

“Find the height of swell produced by a weir when it is and when it is not submerged or drowned. Find the amplitude of backwater caused by a weir.”

Exam questions in Professor Estévan Fuertes’ hydraulics class, 1876.
the intellectual tools to design better steam engines, as well as advanced mechanical devices that were yet to come. For that transcending vision Thurston is remembered today.

Cornell students of electrical engineering, the first educational specialty to arise from the campus cohabitation of basic science (physics) and an established engineering field (the mechanic arts), experienced the school culture–shop culture debate firsthand (see “The Rise of Electrical Engineering,” page 15). In the 1880s, when the most rudi-
mentary electrical device was a novelty, Cornell electrical engineering students found themselves at one of the select American institutions to receive state-of-the-art equipment gifts. Electrical equipment worth thousands of dollars was shipped to Ithaca and pried from its wooden crates for the shops and classrooms of Sibley College. Dean Thurston openly solicited the gifts, and the Edisons and Westinghouses gave freely, anticipating that engineering graduates would remember their brands when it came time to buy.

Yet, the early electrical engineering students could only ogle—not touch—the high-tech gear until their fourth year at Cornell. The reward for slogging through three years of basic science and scientific theory was their turn at the university laboratories, and a chance to take field trips to Edison’s Menlo Park and other industrial laboratories to try out even more enticing equipment.

Another practical spin-off from the physical sciences occurred in July 1870 when the university established a professorship in “Chemistry Applied to Manufacturing.” Half a century later, that professor would have been housed in Cornell’s School of Chemical Engineering. But in the 1880s, Cornell chemistry had no place for him, so he taught in the College of the Mechanic Arts.

Soon, more and more engineering specialties were offered: naval architecture and the design of ships’ power plants were taught by the mechanical engineers. Cornell civil engineers taught students how to build the canals and seaports for the ships, and how to design dams on the rivers that ran to the sea. A nation with expanding railway systems needed designers for the locomotives and for the thousands of miles of tracks and switching yards to handle heavy traffic; again, Cornell mechanical engineers and civil engineers, respectively, were there to teach. When World War I
brought aviation to the forefront—and biplanes to Barton Hall—faculty members reinvented themselves to teach aeronautics.

Society expected some assurance that complex works of engineering could be trusted to perform, and that the designers were properly educated professionals. Establishment of organizations like the American Society of Mechanical Engineers (1880) and the American Institute of Electrical Engineers (1884) attempted to address that expectation. It might be less than truthful to claim that Ezra Cornell predicted the rise of the professions. But he had an inkling that technological pioneers ought to be scientifically educated. His vision motivated the first engineering educators at the new university. When society got around to demanding formal, advanced education for its engineering professions, Cornell University was already doing that.
When Barton Hall Was a Hangar

World War I flying “aces” and the aircraft they trained in came from Cornell’s Barton Hall and from a factory on Ithaca’s Brindley Street, respectively. Faculty members in the College of Civil Engineering and the Sibley College of Mechanical Engineering received their orders in late April 1917: report for duty as aeronautic educators.

They were the academic component in one of the first six military aeronautics ground schools hurriedly established by the U.S. Army at university campuses. (Others were at MIT and the state universities of Ohio, Illinois, Texas, and California; two more were later added at Georgia Tech and Princeton.) While the U.S. Army School of Military Aeronautics at Cornell was run by a military commandant, most members of the 140-strong instructional corps were professors and recent engineering graduates. Flight cadets were college athletes recruited from Cornell and other universities.

In eight intensive weeks of drill and training (later extended to twelve), the cadets learned military law and customs, organization of the U.S. Army and the Allies, and the intricacies of Army paperwork. More to the point, the fledgling aviators learned the principles of flight, aircraft nomenclature and materials, rigging, engine adjustment, aerial photography and photo interpretation, map reading and geography of the war zone, and operation of aircraft-mounted machine guns.

Wireless communication by voice was not an option in early military aircraft, so fliers were expected to signal with code. A classroom with 300 tables was set up on the balcony in Barton Hall. There Army cadets improved their signaling proficiency (the
For Laurens Hammond, the 1916 Cornell graduate in mechanical engineering who invented the synchronous electric clock and the electric organ that was based on the motor of that “tickless” timepiece, timing was everything. More often than not, his inventions (he held 110 U.S. patents, and his Hammond Organ Company received many more) were in the right place at the right time. But not always.

Probably the first student to apply for a patent before applying to Cornell, Hammond was fourteen and living in Paris when he offered his automatic transmission to the Renault Motor Car Company. Renault wasn’t interested, and neither were customers for Hammond’s one-dollar barometer, patented at age sixteen and so sensitive that it registered the difference in altitude between the floor and the top of a desk.

If many of Hammond’s inventions were inspired, some were farfetched—but almost all of them worked. Consider the “throw-away altimeter,” built for military aircraft during World War II when Hammond Organ converted to wartime production: dropped from a plane, the device emitted a radio signal until it reached the ground or the water. That allowed a crew member to calculate the altitude from the elapsed time, in the days before cockpit gauges simplified the task.

Or the card-shuffling bridge table, of which Hammond built 14,000 to sell at Christmastime for $25 apiece—in the depths of the Great Depression.

Critics and audiences raved at Hammond’s 1922 world premiere, in New York City’s Selwyn Theater, of the first-ever system for 3-D movies (two cameras, two projectors showing overlapping images, and motor-operated revolving shutters in the viewing devices), but the show closed after only thirty days because the movie industry wasn’t ready. Hammond’s 1922 invention of much simpler 3-D glasses (red and green lenses, not motors and shutters) enhanced early “special effects” in Ziegfeld Follies shows; since then millions more have been made in cardboard and plastic for periodic revivals of 3-D movies.

Hammond’s electric organs—built at a fraction of the price and size of pipe organs—were an instant hit. Beginning in 1934, the company made hundreds of thousands, and they sold around the world.

The man who brought organ music to millions could not carry a tune or play an instrument. Most of his Cornell career was spent on the engineering side of the campus, where his timing failed him only once. After studying diligently for a mechanical engineering exam, he found himself in a room full of students who were taking an electrical engineering exam. Hammond took the test anyway—and passed.

graduation requirement was forty characters a minute). Downstairs, on the main floor of what was then called simply the Drill Hall, hundreds of cadets bunked, ate meals, attended classes, and shared their space with some of the dozen biplanes in the Cornell fleet. Other junior officers bunked in Cascadilla Hall, along with enlisted men in the Army Mechanics’ Trade School, while the nearly fifty aircraft engines assigned to the Army’s aeronautics school sputtered to life in a separate engine laboratory. The Army built a sprawling mess hall to serve a thousand men at a sitting. A U.S. Army School of Aerial Photography was established in January 1918, with laboratories in Rockefeller Hall and barracks in Schoellkopf Hall, that graduated more than 700 men.

Those who didn’t wash out from the Army’s aeronautics ground school went on to flight training in the United States and Europe, and some saw combat before the Armistice of November 11, 1918. Five Cornell engineers became “aces,” each shooting down at least one enemy aircraft, including Maj. J. A. Meissner ’20 and Lt. J. O. W. Donaldson ’20.

The old Drill Hall was a hangar, but there is no record of an operational airfield on campus; most of the planes used in class were flightless trainers. Some were Curtiss JN “Jennies” built for the Army by Glenn Curtiss in nearby Hammondsport, New York. After earning their wings in two-seat trainers, flyers graduated to a single-seat trainer, the Ithaca-built Thomas–Morse S.4 “Tommy” Scout, to learn pursuit (fighter) skills and tactics.
Jenny and Tommy trainers prepared student pilots for the more powerful aircraft they would fly in combat (although some Jennies also flew bombing or reconnaissance missions). But for the Tommies of Brindley Street, their dogfight days came after the war. Repainted in the colors of German, French, and British aircraft, the Scouts appeared in Hollywood movies of the 1930s, including *Dawn Patrol* and *Hell’s Angels*.

**Remunerative Engagements, Rapid Promotion**

So the grand educational experiment was working. By 1891 Dean Fuertes could boast:

> No graduates of this college are known to be out of employment. They find, readily, remunerative engagements, generally before graduation, and are promoted rapidly.

That employment—for the first Cornell engineering graduates and those who followed—was to be found in the leadership ranks of industry and in endeavors they would start themselves, in government positions of the greatest responsibility, and on the faculties of other engineering schools.

Word was spreading, too, among potential students. Eighty-five students were enrolled in Sibley College when Thurston arrived at Cornell. By 1905, two years after Thurston’s death, the Sibley College enrollment of 1,065 constituted nearly a third of the university’s entire student body. Mechanical engineering enrollment at Cornell continued to grow, peaking at 1,186 in the 1909–10 academic year, while civil engineering reached 955 a year before.

At the beginning of the twentieth century, long before magazines rated colleges, Cornell was regarded as the top engineering program in the country, attracting students like Willis Carrier of air-conditioning fame; Laurens Hammond, who was a prolific inventor even before he enrolled at Cornell (see “In the Right Place,” page 18); and aircraft innovator Leroy Grumman (see “When Jake and Red Mike Argued,” page 20). Thomas Midgley, a mechanical engineer with two Cornell chemistry courses to his credit, made two of the most influential chemical products of the twentieth century: tetraethyl lead and CFCs. When a special committee of the Society for the Promotion of Engineering Education looked back, in the 1929 W. E. Wickenden report, they called the Thurston years at Cornell “one of the most notable of the recent chapters in the history of American higher education.” Thurston’s influence on the development of curricula and methods of teaching, the report said, “probably exceeded that of any other American educator.”

Ironically, that compliment from engineering educators came at a time when Cornell engineering’s fortunes were waning.
SO THEY SAID

WHEN JAKE AND RED MIKE ARGUED

“The final perfection of the airplane will be one of the greatest triumphs that man has gained over matter.”

Leroy Randle Grumman, Class of 1911 salutatorian, Huntington High School

“That’s one small step for [a] man; one giant leap for mankind.”

Apollo 11 astronaut Neil Armstrong, July 20, 1969

Before “Grumman Hall” appeared on a Cornell engineering building, the name of the 1916 Cornell mechanical engineering graduate went up on an abandoned garage by the tracks of the Long Island Railroad in January 1930: Grumman Aeronautical Engineering Co.

Leroy R. Grumman was the aviation design genius and Leon “Jake” Swirbul, the fellow Cornellian and company co-founder, was the business brain behind the enterprise that invented the first retractable landing gear for military aircraft and the first folding wing for carrier-based planes. Military historians agree that Grumman aircraft—the F6F Hellcat, in particular—helped win the air war in the Pacific theater of World War II.

Grumman had joined the Navy after graduating from Cornell, while Swirbul dropped out in 1917 to join the Marines. They reunited after World War I while working at the same New York City builder of Navy planes, Leoning Aeronautical Engineering Co. The company was sold and moved to Pennsylvania, so Grumman, Swirbul, and another ex-Leoning employee, Bill Schwendler, decided to form their own company. The $64,325 in startup capital included a $16,000 mortgage on Grumman’s house and a $6,000 loan from Swirbul’s mother.

To win its first Navy contract, Grumman Engineering demonstrated that its XFF-I biplane with retractable landing gear could fly 198 miles per hour (the competing prototype from Boeing topped out at 178) and the cash-poor partners breathed a sign of relief. Their insurance policy on the XFF-I expired after one hour, the time they needed for the test flight. Ramping up production for World War II, Grumman Co. built the 330-mph fighter, the F4F Wildcat, for the Allies. At their peak they turned out twenty-seven Hellcats a day. Grumman Hellcats earned 5,156 of the 6,477 Allied victories claimed during the war. Grumman’s production record—more than 12,000 planes between June 1942 and November 1945—is the most ever built in a single aircraft factory.

As the company grew from 700 workers to 25,500, Leroy Grumman worried that the “family-business atmosphere” would be lost; Swirbul focused on morale-raising, launching Ping-Pong and bocce tournaments and establishing more than forty in-plant softball teams. Grumman, Swirbul, and other executives took the field alongside the most junior employees. Fresh poultry was a luxury during wartime rationing, so Swirbul bought thousands of eggs, had them incubated, and every Grumman worker took home the traditional Christmas turkey. Colleagues called Grumman “Red Mike” because of his red-blond hair; but during frequent visits to the assembly lines, he was “Mr. Grumman” to the workers.

Those who overheard loud, harshly worded arguments in the Swirbul–Grumman executive suite say the pair had one inflexible rule: neither would leave the office, which was filled with models of all the military aircraft they had built, until the debate was resolved—until Jake and Red Mike had reached agreement.

The friendship that began on the Cornell campus ended only when Swirbul died of colon cancer in 1960. Leroy Grumman (1895–1982) retired from the company in 1966, three years before American astronauts stepped from the LM-5 Eagle. The engineer who dreamed of the “final perfection of the airplane” had helped move aviation technology from the biplane to the jet age to the space age.
A Dean’s Lament

Student enrollment dropped precipitously from those 1910 peaks, and star faculty members were retiring or were picked off in raids by rival engineering schools that were building campuses and adding costly equipment while Cornell’s building program was virtually dormant. Consolidating all the schools into a single College of Engineering (ordered by university trustees in 1917 and effected in 1921), failed to build momentum. Dexter S. Kimball, the first dean of the consolidated college, tried to rally support and capital when he described the once-grand Sibley Hall:

*The impression of a visitor or respective [sic] patron upon inspecting the low dark rooms and other makeshift shelter which are dignified by the name of laboratory must inevitably be unfavorable. Unless he is quite familiar with the record and inner workings of the College one would naturally be repelled rather than attracted by the general aspect of the plant of Sibley College.*

Dean Kimball’s wants were modest, compared with massive building campaigns at other private and state universities ($150,000 for a new mechanical laboratory and $135,000 for an electrical laboratory), but only Rand Hall (1912) was built. “I cannot believe that one of the greatest, if not the greatest technical school of America, is to be permitted to deteriorate for lack of proper support,” Kimball said. He tried again with a more ambitious plan in 1925. Detailed drawings were prepared and another capital campaign was launched—on the eve of the stock market crash of 1929 and the Great Depression.

Tuition-paying students were nearly as scarce as millionaire donors in the 1930s, and Cornell engineering enrollment suffered. So did job placements for engineering graduates.

It would take another world war to repopulate Cornell engineering classrooms, and to spur the unprecedented growth in research and graduate education that continues to this day.
Although World War II military duty called some Cornell engineering students, undergraduate enrollment actually increased for a while (from 1,239 in 1939; 1,356 in 1940; and 1,517 in 1941 to temporary highs of 1,616 in 1943 and 1,647 in 1944). Then, enrollment declined precipitously in 1945 as more and more Cornellians completed their undergraduate education and went off to war—or simply failed to return for classes.

Besides teaching civilian students during the war, the Cornell engineering faculty was responsible for much of the instruction in the Navy’s V-12 program, which sent some 2,000 sailors and 150 marines to the Ithaca campus over three years, beginning in 1943. The college also trained nearly 2,700 officers in diesel and marine steam-engineering programs on campus. When the engineering faculty fanned out to eighteen training centers around the state, some 30,000 civilians took classes through the Engineering, Science, and Management War Training programs. Cornell was the first among universities throughout the country to set up ESMWT programs under the sponsorship of the U.S. Department of Education.

For many young women, the wartime training was their first exposure to engineering—and a chance to become more than assembly-line workers. Women studying at training centers near their homes took Cornell-taught classes such as “Fundamentals of Radio,” “Introduction to Engineering,” “Airplane Design,” “Tool Engineering,” and “Industrial Safety.” For women with at least two years of college in any subject, defense-related companies, such as the Curtiss–Wright Airplane Division in Buffalo, recruited
“Engineering Cadettes” and sent them to Cornell and other campuses for ten months of all-expenses-paid training—and then put them to work. Over the course of the war, 147 Engineering Cadettes were trained at Cornell before returning to $150-a-month jobs at Curtiss–Wright in aircraft design, stress analysis, experimental testing, and technical analysis. (In retrospect, women’s studies historians now question whether Engineering Cadettes received the high-level jobs and promotions they were promised, but no one doubts the quality of the engineering education they received.)

Engineering faculty members were dispatched to defense plants around the state to provide instruction on such topics as welding metallurgy, engineering-design computation, stress analysis, and aerodynamics. The engineering college was paid for its services, of course, but the Curtiss–Wright relationship continued to pay off with an end-of-war gift to the university—the Buffalo facilities that became the Cornell Aeronautical Laboratory (CAL).

Some V-12 visitors stayed on at Cornell to complete engineering degrees after the war, thanks to educational provisions of the GI Bill of Rights (more formally, the Servicemen’s Readjustment Act of 1944). One such student was Edmund T. Cranch, who went on to earn a Cornell Ph.D., join the faculty, and become dean of engineering.

Another was Robert McKinless, a marine who was sent from Camp Lejeune to Cornell in November 1944 (wartime sixteen-week trimesters started in July, November, and March) and graduated with a bachelor’s degree in civil engineering in 1948. “College life [as a V-12 student] was hardly what it had been, or would be later,” McKinless recalled. “We studied in the dorms each evening and lights went out at 10,” he added, noting that Cornell marines were billeted at Telluride and the Delta Upsilon fraternity house. “There were many formal inspections—and we marched in formation to all meals—but it wasn’t all work. Fraternity life had disappeared, but Ithaca’s restaurants and bars were full of students unwinding on the weekends—the drinking age being 18 then.”

The GI Bill and its benefits (up to $500 a year for tuition and fees plus subsistence pay) repopulated Cornell engineering’s classrooms; it also put a strain on faculty members’ time and resources. Postwar enrollment in Cornell engineering swelled to 2,401 undergraduates in 1946 and 2,465 in 1947. Housing for GI Bill veterans was in particularly short supply. Some engineering students slept in Olin Hall, which had been designed for chemical engineering laboratories and classrooms, not as barracks.

Appreciation of Change

Navy veteran Wilson Greatbatch, an electrical engineering student who would go on to design the first commercially successful implantable cardiac pacemaker, found no space on campus for his growing family. Determined to attend Cornell, he bought a farm-house in Danby, New York, six miles from campus, and commuted to class and part-time jobs in a battered used car. After wartime service on the crew of a dive-bomber, Greatbatch recalled later, the move to the quiet Cornell campus suited him fine: “Maybe you have to come straight down two miles with the ack-ack-ack of gunfire bursting all around you to appreciate the change.”

The rise in undergraduate enrollment fueled by the GI Bill enabled the university to revive tabled initiatives and test the waters with new endeavors. Solomon Cady
Hollister, the dean since 1937, resumed his efforts to build an entirely new engineering campus—and to fill the buildings that would rise north of Cascadilla Creek gorge with state-of-the-art facilities for research. By the time Hollister retired as dean in 1959, Cornell engineering had most of its new campus. The “insurance value” of engineering college buildings rose from $459,277 in 1937, when the college was located on what is now the Arts Quad, to $11,936,845 in 1959 in its almost-completed quarters. Usable floor space grew from 227,433 to 593,723 square feet in the same period of construction. Undergraduate enrollment rose from 1,009 in 1937 to 1,961 in 1959. Graduate enrollment more than tripled, from 63 to 222. The roster of full-time engineering faculty members increased from 84 to 125. The average starting salary of a Cornell engineering bachelor’s degree graduate in 1937 had been $120 a month; in 1959 Cornell engineering graduates started at about $510 a month. Some 370 companies interviewed on campus that year, compared with 51 in 1937.

Resurrecting Research and Morale

At the start of his twenty-two-year tenure as dean, Hollister reported that research in the college was limited to three minor projects: hydraulics laboratory studies for the Army Corps of Engineers in connection with Southern Tier flood-control programs; tests of welded joints sponsored by the American Welding Society; and inquiries into the properties of light-gauge structural members for the American Iron and Steel Institute. Cornell engineering’s tradition of research innovation—with the likes of William Frederick Durand, the professor of marine engineering (1891–1904) who advanced design of ships’ propellers, and Harris Joseph Ryan, the 1887 electrical engineering graduate who headed that department (1889–1904) while pioneering high-voltage generation and long-distance power transmission—had languished, according to Dean Hollister. (In fact, both Durand and Ryan joined the Stanford engineering faculty after their stints at Cornell.) It was time to reprioritize for research and advanced study, and to experiment with what Hollister called “public relations.” (See “Public Relations to the Rescue,” page 26.)

Library resources were limited as well when Hollister took over as dean. There were small holdings for civil engineering in Lincoln Hall and for electrical engineering in Franklin Hall; mechanical engineering materials were kept in the offices of department chairs, and were seldom available to students. Hollister targeted successful Cornell engineering alumni in requests for building funds and made an extra appeal for libraries. Today’s approximately 400,000-volume Engineering Library, which was outfitted with additional support from Walter S. Carpenter Jr., was the result, becoming one of the leading scientific and technical libraries in the country.

The dean, with ambitious plans to improve Cornell engineering facilities, faced a skeptical faculty. While some showed flickers of interest, Hollister acknowledged, “they nevertheless felt that since building programs had been prepared on previous occasions with no result, they would withhold their enthusiasm until something more tangible appeared to justify it.” Spirits of the chemical engineering faculty, at least, should have been raised with the opening of Olin Hall in 1942.
Within a year after the war, other engineering disciplines had something to celebrate. Mechanical engineers with their eyes on the sky finally got a formal program when the Graduate School of Aeronautical Engineering was established in 1946. As discussed earlier, the subject that became known as aeronautical engineering—and later aerospace engineering—had been taught by Cornell engineers as early as World War I. (See “When Barton Hall Was a Hangar,” page 17.) Cornell’s School of Engineering Physics—now Applied and Engineering Physics—also began in 1946 (although the university had physicist-engineers almost from the start).

Ever the visionary, Hollister wanted to direct university resources to “the new and rapidly changing field” of biological engineering, seeing increasing opportunities for
biochemical engineers “in a group of industries concerned with food preparation and preservation, manufacturing of antibiotics, and production of chemical products using biochemical methods.”

Dawn of the Jet Age

Propellers were passé and the Jet Age was dawning when Cornell aeronautical engineers broached a new set of fundamental questions, both at a small laboratory on the edge of the Ithaca campus and at the Cornell Aeronautical Laboratory in Buffalo, where massive wind tunnels and advanced instrumentation were available. An emphasis on the theoretical, scientific, and mathematical foundations of aeronautical engineering prompted research on gas dynamics, magnetohydrodynamics, aero-elastic problems, and boundary-layer theory.

CAL became an incubator for high-tech industry in western New York, spinning off at least thirty startup companies, but some Cornell engineers did not need to travel that far. Even before electrical engineering left Franklin Hall for Phillips Hall, faculty researchers were conducting studies in the General Electric Advanced Electronic Center, located first in a converted aeronautical engineering building at the then–Cornell Airport (the East Hill site of Ithaca’s commercial-aviation airport after Cornell sold land to the county in 1956). After General Electric built Langmuir Laboratory at the corporate-academic research center, some of the 300 GE scientists held adjunct professorial appointments and taught electrical engineering classes on campus. Besides Cornell electrical engineers and graduate students working at the GE facility, the university sent two physicists, three mathematicians, one chemist, and one psychologist.

The year 1948 also saw the start, with construction of antennas and equipment buildings at the airport, of the Microwave Astronomy Project—the electrical engineers’ foot-in-the-door effort that would eventually produce the giant Arecibo Observatory in Puerto Rico. Some research in radio astronomy had been under way at Cornell as early as 1946, under contract with the Office of Naval Research. The electrical engineers’ radar instruments and 204-inch reflector had been designed to study variation of the Sun’s solar radio-noise in the 200 megacycles range, as well as the concentration and distribution of emitters at that frequency in our galaxy. At the same time (1948), Cornell engineers built and installed equipment for a rival in the business—the Harvard radio observatory at Sacramento Peak, New Mexico—for observation of the Sun in the optical frequency range.

Cornell’s educational program in nuclear technology was one of the first to stem from the new School of Engineering Physics. Members of other departments engaged in applied-physics research, such as investigations of surface phenomena of metals. Metallurgical engineering at Cornell also traces its origins to 1946. The curriculum included courses such as “Metals at High Temperatures,” “Nuclear Materials,” and “Powder Metallurgy.” A new unit, the Department of Engineering Mechanics and Materials, was formed to consolidate instruction in all divisions of the college.

Just three years after the war’s end, the dean could boast of research in a much wider range of studies: besides microwave astronomy, Cornell engineers were examin-
ing longitudinal stress in reinforced concrete, propagation of expansion and compression waves, and supercritical flow around airfoil profiles. While there still was welding research (testing for fatigue in ship welds), there also was research into the dynamic elastic properties of matter, beach accessibility and trafficability, soil solidification and improved aggregates for highway pavement, and aerial-photography studies of soil patterns.

The aerial photo work would soon take Cornell civil engineers around the world—first in a research-and-education program to teach Burmese engineers to interpret aerial photographs for transportation systems, mineral resources, and agriculture. Their next assignment took them over the central plateau of Brazil to help choose a site for the relocation of the capital that became Brasilia. Eighty-five years earlier, Cornellians conducting the first geological surveys of the Brazilian Amazon (see page 150) had returned with a half-million specimens to fill the university’s new Museum of Geology and Mineralogy; this time (1954) Cornell engineers just took pictures.

Four Years Is Not Enough

As Hollister prepared to retire, he knew his legacy would be the new campus he had built—and the start he had made toward bolstering research and graduate education in engineering. He preferred to be remembered as the father of the five-year bachelor’s degree in engineering. Chemical engineering instituted the five-year degree in 1938; it was phased in as a college-wide requirement for freshmen arriving in 1946.

The new program provided five full years for “an increasing amount of training in basic science and engineering” but also for “a broader basic background of training in liberal subjects.” With remarkable foresight, Hollister understood that engineers pressed to learn a considerable body of technical knowledge in only four years would have little time left for the grounding in social sciences and humanities they needed in a sound and socially responsible engineering practice. The Cornell plan was adopted almost immediately by other engineering schools, including Ohio State University and the University of Minnesota.

The program also fulfilled the recommendations of the Engineers’ Council for Professional Development and the American Society for Engineering Education: to address the critical manpower shortfall in engineering by bringing young men and women “to a position of superior technical competence.” In the 1940s and ’50s, Cornell engineers graduating with a five-year bachelor’s degree earned starting salaries equal to those of many master’s degree holders from other institutions, and they rose rapidly through the profession.

Retiring in 1959, Hollister called the five-year curriculum the “crowning achievement” of his administration and expressed his hope that the college would always maintain a fundamental emphasis on teaching. Eventually the five-year requirement became a competitive disadvantage. Students in four-year programs at other universities could enter the job market in 80 percent of the time and at 80 percent of the cost. But the fundamental emphasis on teaching endures. Today’s equivalent of the five-year program is the Master of Engineering degree: a four-year undergraduate program that provides a
Twenty-five years after Dean S. C. Hollister’s Engineering at Cornell booklet enticed high schoolers, the 1960 version, from the administration of Dean Dale R. Corson—during another period of fluctuating enrollments—asked the question: “What is engineering?” The answer was meant to inspire applicants of both genders, although the pronouns were predominantly masculine: “The engineer is builder of modern technological society. transforms the discoveries of science into the tools of civilization, such as nuclear power plants, automated factories, highways, satellites, petroleum refineries, and radar systems. Taking ideas and principles as raw materials, the engineer converts them into products, processes, and services. In doing so he must strive for the best balance between the practical and the ideal, and help to resolve the problems of human adjustments arising from technical progress.”

Cornell undergraduate engineering enrollments during the early 1960s hovered around 1,900. The classes were heavily dominated by men; women comprised 1 percent or less. By 2008, the enrollment picture had changed markedly. Of the 2,926 undergraduates enrolled, more than 28 percent were women. The College of Engineering enjoys a remarkable track record for retention of undergraduates. About 80 percent of the students in each incoming class graduate four years later with an engineering degree.

basic technical education as well as exposure to humanities and social sciences, plus a one-year graduate program for specialized study in preparation for professional practice.

Paying the Fare to the Endless Frontier

Dale R. Corson had been chair of Cornell’s Department of Physics, and his appointment as dean of the College of Engineering in 1959 was a surprise to both the faculty and the physicist himself. Corson had the briefest tenure in the engineering dean’s office (with the exception of Herman Diederichs, a civil engineer who died after a year as dean, in 1937) before becoming provost in 1963, and then president during the turbulent years of student unrest in the late 1960s and early ’70s.
Corson wasted no time in stating “the most important aspect of my work” was the development of high-quality interdisciplinary graduate programs, while urging undergraduates to “strive for the best balance between the practical and ideal.” (See “Calling All Men . . . and Women,” page 29.) He pointed to two examples of interdisciplinary science-and-engineering programs that were attracting substantial government funding: construction of the Arecibo Observatory with $6 million in federal support to Cornell’s new Radio-physics and Space Center and another $6.1 million over four years to materials science, a collaboration of engineers with scientists in the College of Arts and Sciences.

After World War II, the federal government began to build permanent funding mechanisms to support university-based research. Vannevar Bush, director of the U.S. Office of Scientific Research and Development in 1945, called for such investment in the publication *Science, the Endless Frontier: A Report to the President*. Congress created the National Science Foundation to ensure that the flow of new scientific knowledge was, as Bush put it, “both continuous and substantial.” Cornell scientists and engineers were among the first to seek National Science Foundation support. For years afterward, their successful grant proposals brought Cornell University some of the highest levels of NSF funding among all the major research universities. The NSF remains a major source of basic-research funding at Cornell.

The allocations for Cornell radiophysics and materials science notwithstanding, Dean Corson identified three other sources of support—corporations that employed engineering graduates, charitable foundations, and Cornell engineering alumni. He had his greatest fund-raising successes with alumni, particularly with prominent industrialists, and with foundations.

Corson’s proposals for graduate education made sense to the Ford Foundation, which gave an unprecedented grant of nearly $5 million for faculty development and advanced study. Several endowed professorships were created, and Corson leveraged the Ford Foundation money to create additional professorships with support of the Given Foundation. Then IBM Graduate Fellowships made recruiting for research faculty easier, particularly in areas supported by other provisions of the Ford grant and by matching funds from other sources. Discretionary funds in the Ford grant allowed the dean to give selected faculty members “release time” to develop new courses and “venture capital” to pursue their research interests.

**Complementary Objectives**

Four years before Corson became dean, the Grintner Report, issued by the American Society for Engineering Education, recommended “the strengthening of graduate programs necessary to supply the needs of the profession, conducted in those institutions
that can: (a) provide a specially qualified faculty, (b) attract students of superior ability, and (c) furnish adequate financial and administrative support.”

The research and graduate education programs carried out by Corson—and by Andrew Schultz Jr., the dean who followed him in 1962—demonstrated that Cornell could produce two kinds of engineers: engineering professionals whose bachelor’s degrees certified competence to meet the changing demands of new technologies (in part because Cornell responded to another Grintner Report recommendation and taught engineering science to undergraduates), and doctoral graduates who would advance engineering research and education.

Dean Schultz insisted that the two aims were not in conflict, but complemented one another:

*Leadership in undergraduate education cannot exist in the absence of quality advanced study and research by the faculty. The goal of the college, therefore, is to provide high-quality engineering education at both undergraduate and graduate levels and to do this in an integrated program in which the faculty teach at both the graduate and undergraduate levels and carry out research and advanced study with their inevitable effects on undergraduate education.*

Schultz also recognized that many advanced degree-holders were going directly into teaching “with little or no experience in the practice of engineering.” So while Corson had brought corporate engineers to campus as adjunct professors, Schultz sent Cornell faculty members away, with residence-in-industry programs that were sponsored, in part, by the Ford Foundation.

**Looking Back, Looking Inward**

In 1971, eight years into his term as dean and two years after an associate dean alerted colleagues to new engineering fields (see “Be Alert to Special Opportunities,” page 33), Schultz presided over a year of celebration that marked several significant anniversaries: the 1871 awarding of the first engineering degrees by Cornell University; the 1921 formation of the consolidated College of Engineering from individual schools (called “colleges” at the time); and establishment of the School of Electrical Engineering, also in 1921. Also to be celebrated were the 1931 establishment of programs in chemical engineering and in administrative engineering (now the School of Chemical and Biomolecular Engineering and the School of Operations Research and Information Engineering, respectively) and the 1946 founding of a graduate program in aeronautical engineering (now in the Sibley School of Mechanical and Aerospace Engineering). In addition, 1946
was the start of engineering physics (now the School of Applied and Engineering Physics) and metallurgical engineering (then part of the School of Chemical Engineering and now within the Department of Materials Science and Engineering).

Dean Schultz managed to keep all the new and old names straight when he delivered his State of the College Address to the Engineering College Council at the October 1971 Centennial Convocation. He addressed criticism about “our apparent preoccupation with research and advanced study,” saying:

Our motives in this are most pure and involve two goals, both directly educational. One is operational; that is, the desire to do a good job in educating students in research. This is best done by doing. The second objective is more precautionary. The best teacher of today who fails to maintain mastery of a fast-changing subject (and none changes more rapidly than engineering) becomes an ineffective teacher tomorrow. It is equally important for the faculty to be able to shift areas of emphasis . . . . Failure to adapt to changing needs may result in good teachers with nothing to teach.

Educating “the TV generation” wasn’t easy. Matriculating freshmen in the 1970s, Schultz predicted, “will find the set pace of the lecture incompatible with their backgrounds and abilities and will undoubtedly begin to chafe and object to such uniformity.” Schultz recommended an early version of distance learning, and Cornell was one of about twelve universities testing the waters in 1971 with videotaped lectures.

But television-reared students, including some taught by the builder of the Moog synthesizer (see “Einstein of Music, or Toolmaker for Musicians,” page 35), wanted to push their own buttons. So professor of materials science Arthur Ruoff seated his students in auto-tutorial cubicles—surrounded by push-button controls, rear-view projection screens for slides, tape recorders with earphones, and electrical power for experimental apparatus—to learn “Elements of Materials Science” at their own pace. An assistant was always on hand to answer questions and collect answer sheets. Exams in the materials-science classes were given in a wired classroom of the future, called the Student Response System. As many as 150 students answered multiple-choice questions at desks equipped with panels of push buttons.
“If we are to educate engineers who can reach out to the real world and contribute to areas having the greatest need of attention, we must be able to recognize and, in some cases, anticipate new fields.”

Edmund T. Cranch, associate dean of engineering, 1969

Bioengineering, ocean engineering, geophysical problems, and technology and urban quality were, as Edmund T. Cranch, dean from 1972 to 1978, said in 1969, fields in which “the College of Engineering must be alert to special opportunities.” Indeed, the college has excelled in each of the areas, and in crossing interdisciplinary borders between them and other fields. By biotechnology, Cranch may have meant devices that today are goals of the college’s newest field, the Department of Biomedical Engineering, which started in 2004 under the direction of chemical engineering’s Michael L. Shuler. He could not have known that in 2001 applied and engineering physics professor Harold Craighead would build a microscopic nanofluidics device to sort individual DNA molecules.

During Cranch’s tenure, the college’s Department of Geotechnical Engineering already was studying landforms, landslides, and the growth of river deltas from the Mississippi to the Niger to the Ganges. Later, geophysicist Jack Oliver and his Consortium for Continental Reflection Profiling (COCORP) would document the thrusting, shearing, colliding, and uplift of the continental plates where people build and live. A down-to-earth civil engineer, Thomas O’Rourke, would help cities like San Francisco make their infrastructures more earthquake resistant. Civil and environmental engineer Philip Liu and his studies of tsunami phenomena would make life on the shore a little less perilous.

Regarding “urban quality,” Cranch knew about environmental pollution. He quoted the English poet Percy Shelley (“Hell is a city much like London, a populous and smoky city.”) then added his own observation: “One of the by-products of affluence is effluence.” Thirty-five years in the future, civil and environmental engineer James M. Gossett discovered a bacterium that detoxifies the pollutant PCE (perchloroethylene). Gossett had found the enterprising “bug” detoxifying its way through the sludge in the City of Ithaca’s sewage treatment plant (Gossett collaborated with Cornell microbiologist Stephen H. Zinder). Today, the commercial strains of the bioremediation agent *Dehalococcoides ethenogenes* are cleaning up Superfund sites across the country, treating chlorinated solvents like PCE as well as TCE (trichloroethylene).

“It is not a wild postulate,” Cranch opined, “that engineering will one day interact with biological sciences in as fruitful a way as it has in the past with physics and mathematics.”

**Science and Conscience**

Like the rest of the Cornell community and American society in general, the College of Engineering experienced a period of heightened social awareness in the late 1960s and early ’70s.

Soon after Walter R. Lynn became director of the School of Civil and Environmental Engineering in 1970, he observed: “For many engineers the topic of ‘environmental concerns’ is troublesome, for it brings forth emotional responses that are alien to the mystique of cool, rational objectivity which we like to believe characterizes our professional contributions to society.” Adding “environmental” to the school’s name had been one way of reminding civil engineers of their responsibility to the natural and built environment.
Across campus, professor of engineering physics Mark Nelkin was leading one of the first “social awareness” courses. Engineering 205, “Social Implications of Technology,” played to a standing-room-only crowd of 135 students, complete with provocative guest lecturers and spirited discussions. Nelkin believed there were “crucial areas in which there are no experts, and where continuing to stand aside and await their spontaneous generation becomes irresponsible. However crude our intuitive understandings may be, we must try to communicate them.” A twenty-first century version of that class, “Engineering in a Social Context,” does try to produce experts (see “Beyond Technology,” page 37).

Nelkin’s class was offered in conjunction with the university’s newly established Program on Science, Technology, and Society (STS, later reconfigured as the Department of Science and Technology Studies). Students heard professor of civil and environmental engineering Alonzo Lawrence say: “We are finally beginning to realize that man cannot separate himself and his activities from nature, and that the principles of ecology which govern pond and field also govern the entire world in which we live.”

STS director Franklin Long was equally concerned about the bureaucratic environment in the nation’s capital, telling Engineering 205 students:

There must be much more citizen knowledge of and participation in solving problems of national security. . . . To contain and decrease the spread of military technology and the growth of military spending call for positive action at both the national and international levels. If we stand passively by, the many strong pressures toward more and more expensive technology will surely prevail.

Sometimes “social awareness” took a radical turn (see “Waging War on Defense Research,” page 36). On Wednesday, April 26, 1972, about 125 antiwar protesters, most of them students, marched from a noontime rally at Willard Straight Hall to Carpenter Hall, home to the Engineering Library and the College of Engineering administrative offices. The protestors blamed the university for “feeding the war machine” with research at the Cornell Aeronautical Laboratory, the Buffalo, New York, facility that was donated to Cornell by a military aircraft manufacturer after World War II. Newspaper was taped over Carpenter Hall’s windows, doors were secured with chains, and engineering college employees were ordered to leave the building—or join in the movement.

The protesters identified themselves as the Giap-Cabral group, honoring two resistance heroes of the time (General Vo Nguyen Giap, the economist who led the Communist forces under Ho Chi Minh, and Amilcar Lopes Cabral, the agronomic engineer from Portuguese Guinea who founded PAIGC, the African Party for the Independence of Guinea and Cape Verde). From the unofficially renamed Giap-Cabral Hall, protesters issued three demands:

• That the Cornell Aeronautical Laboratory halt research for the Department of Defense and be either “converted to humane purposes or dissolved”;

• that the university’s Board of Trustees “use their position as Gulf Oil Corporation stockholders to force Gulf out of Portugal’s African colonies”; and

• that the university “make a binding commitment “to end ROTC activities on campus and replace ROTC cadets’ scholarships with financial aid from Cornell.
EINSTEIN OF MUSIC, OR TOOLMAKER FOR MUSICIANS

Trumansburg, New York, was the manufacturing site for the R. A. Moog Co. and the R&D lab for Robert A. Moog (rhymes with “rogue”), the 1965 Ph.D. in applied and engineering physics whose entrepreneurial spirit nearly kept him from graduating.

The inventor of the Moog music synthesizer, now recognized as the first thoroughly original musical instrument since the saxophone, was having trouble selling enough of the costly devices to keep assembly-line workers employed. When ’60s kids switched to electric guitars, the R. A. Moog Co. built thousands of cheap ($9.65) amplifiers under brand names like Amper and Segova.

Then engineering physics professor Henri Sack, advisor for Moog’s long-neglected thesis research (on the solid-state physics of dielectric loss), lost patience with the young businessman. Sack set a short deadline for the dissertation defense. Moog had some extra time when he got into the Clark Hall elevator—and commenced an experiment in natural frequencies and resonance of elevator cars by jumping up and down. The vibrating car stopped between the fourth and fifth floors, on a hot summer day when Clark Hall had few occupants. Moog was rescued four hours later.

Somehow Moog found a few minutes to teach a Cornell class, during the 1970–71 academic year, on the psychoacoustics of music and perceptions of sound. By then, business was picking up for R. A. Moog Co., following the release of Wendy Carlos’s 1968 album *Switched-On Bach*. Lacking a delivery truck, the struggling businessman crammed a full-sized Moog synthesizer into a Greyhound bus for a personal hand-off to Carlos in New York City.

Previously, Moog synthesizers had been used by the Beach Boys (*Good Vibrations*, 1966) and the Beatles (*Sergeant Pepper*, 1967), but suddenly the Trumansburg music machines were everywhere: The Byrds; Cream; the Doors; Emerson, Lake, and Palmer; the Grateful Dead; Kraftwerk; Enoch Light; the Moody Blues; the Rolling Stones; Simon and Garfunkel; Sun Ra; the Who; Stevie Wonder; and Frank Zappa became believers.

So did a young Cornell composer, David Borden, who ventured into the Trumansburg laboratory, demonstrated his technical ineptitude by repeatedly “frying” the costly electronics gear, and was credited by Moog for “idiot-proofing the equipment.” Borden eventually got the knack and formed the synthesizer band Mother Mallard’s Portable Masterpiece Co. He became director of the Digital Music Program at Cornell, and the R. A. Moog Co. sold some 13,000 of the much smaller, easier to operate, and more affordable Minimoog synthesizers.

Three years before his death in 2005, Robert Moog won the legal right to use his name on synthesizers again, after selling the company in 1973. He began building the Moog Voyager, this time with digital controls for an analog system and with a hardwood case cut from forests around his relocated home in Asheville, North Carolina.

The physicist some called “the Einstein of music” had his own idea of a job title. He once said “I’m an engineer. I see myself as a toolmaker and the musicians are my customers. They use the tools.”
Engineering Associate Dean Edmund T. Cranch warned students in the building that they were violating the university’s Rules for Maintenance of Public Order. President Dale R. Corson and Provost Robert A. Plane attempted to negotiate an early end to the occupation. Students were threatened with suspension if they failed to leave, and nonstudents would be arrested, administrators said.

Regarding the Gulf Oil divestiture demand, Board of Trustees Chair Robert W. Purcell refused to convene a special meeting of the board. “We’re not going to travel to Ithaca on a futile trip,” he replied by phone from New York City. “We [cannot] give instantaneous satisfaction to anyone.”

The occupation lasted five days and ended peacefully, just minutes before a May 1 court injunction obtained by the university was to take effect. Before leaving Carpenter

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**SO THEY SAID**

**WAGING WAR ON DEFENSE RESEARCH**

“Boy, that’s farfetched. Wow. If our research has any success, we might make a contribution toward reduction of aerodynamic noise in the world.”

William B. Sears, professor of mechanical and aerospace engineering and accused “contributor to aggression,” interviewed by the Cornell Daily Sun, April 28, 1972

The protesters occupying Carpenter Hall found evidence there of government-funded research—evidence, they said, that “Department of Defense contracts held by professors in this college contribute directly to the maintenance of American aggression in Indochina.”

Sibley School Professor William R. Sears vigorously defended his project “Research in Helicopter Noise” by saying: “There are phenomena that really are not understood, some very unpleasant phenomena like bangs and noise. Since the military agencies are willing to support this research, we think it’s to everybody’s advantage to take that money and support it.”

Professor of operations research Robert E. Bechhofer, also cited for “complicity” because of government-funded studies “clearly tied to the military counter-insurgency efforts,” described his work as basic statistical research. There was “no person working in statistics,” he added, “whose work cannot be used by the military.”

Organizations ranging from the Faculty Anti-War Group to Tau Beta Pi, the engineering honorary, offered moral support to the occupation, while the Tompkins County Welfare Rights Organization provided something more tangible—food. Many faculty members, including historian Mary Beth Norton, urged administrators “not to send in the cops” to “bust the students,” fearing a repeat of the Kent State debacle as its two-year anniversary approached.

The officers of the university’s Safety Division kept their distance. To the relief of all involved, the takeover ended after five days with only flash bulbs being fired.

At a noon rally in front of Willard Straight Hall, professor of electrical engineering Benjamin Nichols declared the occupation successful because, he said, the protesters “have raised the issues of how this university is involved in death. These are issues which no one was talking about a week ago.” Others suggested that occupation was not the best way to promote discussion.
Hall on May Day, 1972, the students swept the floor and rearranged the furniture. College staff members returned, pulled newspaper off the windows, and the Engineering Library was back in operation by 4 p.m.

Later that year, without specifying reasons, the university Board of Trustees ended ties with the Cornell Aeronautical Laboratory. Cornell kept its stock in Gulf Oil, and kept ROTC, too.

**Manpower Is Not Enough**

Nationwide, engineering college enrollments had been declining since 1968. In 1972, Dean Schultz predicted that all the U.S. schools together would not produce the 48,000 new engineering graduates demanded by that year’s *Manpower Report to the President*—much less the 73,000 engineers called for by the Bureau of Labor Statistics.

The manpower shortage generated pressure to admit more women. In 1967, only two women were enrolled in Cornell engineering programs; by 1971 there were fifty. At a time when women engineers constituted less than 0.5 percent of the profession in the United States, many more were suddenly “in the pipeline.”
And not a moment too soon, declared Mary Ann Huber Franson, a 1963 civil engineering graduate. Writing in the 1972 report “The New Woman and the New Engineering,” Franson remarked that the profession offered “a challenge and an invitation to women who have traditionally been concerned with the harmony of society and the betterment of surroundings, to use their talents in yet another way toward these ends.”

In 1972, Dean Schultz reported that over the previous five years “the percentage of male Caucasian students in the college has declined from 94.5 percent to 77.5 percent. Women students among new matriculants have increased from 0.4 percent to 4.5 percent and minority students from 2 percent to 7 percent... Cornell University engineering ranks twelfth in the nation in absolute numbers of black students.”

**Woman’s Work**

Historically, Cornell’s women engineers had been few but frequently prominent in their professions. There was Kate Gleason, the “First Lady of Gearing,” who enrolled in the Sibley College of the Mechanic Arts in 1884, left before graduating to join the family machine-tool company, and perfected the technique for making beveled gears that a patronizing (but grateful) Henry Ford called “the most remarkable machine work ever done by a woman.” Gleason was the first woman president of a national bank in the United States, a promoter of American industrial prowess overseas, an inventor of a concrete-pouring process used in one of the first suburban developments in this country, and the first woman elected to the American Society of Mechanical Engineers (in 1918).

That was two years after America’s first woman civil-engineering graduate, Nora Stanton Blatch, Class of 1905, sought admission (although unsuccessfully) to her profession’s society. A brief digression into electrical engineering (Blatch helped Lee De Forest develop and popularize the radio-telephone) did not diminish her civil-engineering accomplishments—as a designer of bridges, subway lines, and public water systems. A paper written about the Washington, D.C., water system by Blatch soon after graduating from Cornell served as an industry standard for nearly fifty years.

Rail buffs associate Cornell’s second woman civil-engineering graduate, Olive Dennis ’20, with the streamlined steam locomotives she designed (notably the Baltimore & Ohio’s Cincinnatian series 5301–04), but her title, the “Engineer of Service,” came from meticulous attention to passengers’ well-being. Dennis’s patented ventilation system kept cinders out of passenger cars—while B&O travelers relaxed in her reclining seats that were equipped with headrests. She introduced air conditioning to train travel, then turned her sights to railroad terminals, where she specified the decor and designed the restaurant china as well. At a time when the rare women in the field were called “engineeresses,” Dennis harkened back to her beginnings as a designer of railroad bridges—and always called herself a “draftsman.”

By 1945, Cornell engineering had graduated a total of nineteen women—not a lot, but more than most schools and enough to rank the university sixth in the nation. The administration of William B. Streett (1985–94) made recruiting of women a special mission. By 1987, when Streett reported the largest freshman class ever admitted to
Cornell engineering, he included good news about the composition of the class. Some 22.5 percent of the freshman class that year was women (compared with 14 percent nationally at all engineering schools), and nearly 10 percent of first-year students were underrepresented minorities (defined, at the time, as African Americans, Hispanics, and American Indians).

And success in technical subjects was no longer enough, according to Streett: “The most frequent criticism I hear of our graduates . . . is the lack of effective communication skills.” That prompted the college to institute a program in technical writing with support from the President’s Fund for Educational Initiatives. Technical writing was integrated into upperclass courses with professional instruction and evaluation of written work provided, in part, by staff specialists as well as by faculty members teaching technology in the classes.

Kate Gleason, the first woman to study engineering at Cornell, left without completing a degree but found success in the machine industry, banking, and construction technologies. Her Concrest development in east Rochester, New York, resembled a quaint French village with a modern twist: each of the 100 homes, which sold for about $4,000 in the 1920s, featured eight-inch-thick walls of poured concrete.

Olive W. Dennis was marching in the 1920 commencement procession, on the way to picking up only the second civil engineering degree awarded to a woman by Cornell (after Nora Stanton Blatch in 1905), when a male voice called out: “What the heck can a woman do in engineering?” As the Engineer of Service for the Baltimore and Ohio Railroad, Dennis brought comfort, class, and a lot of stainless steel to streamliner coaches in the 1930s and 1940s.
To ensure more individualized instruction, John Hopcroft, first associate dean for college affairs and then dean from 1994 to 2001, reduced class sizes in freshman- and sophomore-year required courses. Calculus 191 and 193, for example, were divided into sections of twenty students or fewer. Cutting class size also could help Cornell engineering in the national ratings. In the 1995–96 academic year, Hopcroft observed with pride, Change magazine ranked Cornell engineering fifth in the nation, while the U.S. News rating had Cornell’s undergraduate engineering program tied for third. All Cornell engineering departments should strive to be in the top ten, Hopcroft directed, saying the college should be number one in three strategic areas: information technology, advanced materials, and bioengineering.

Gaining an Engineering Perspective

Electrical engineer and computer scientist Thomas E. Everhart, Cornell dean of engineering from 1979 to 1984, suggested that students from the College of Arts and Sciences, in particular, were enrolling in engineering courses “to gain a perspective about what engineers do and to gain the skills that engineers consider fundamental.” In 1984, one of those skills was computing (the College of Engineering offered most of the university’s computer-related courses):

> If our country is to remain competitive in international science, many of our citizens must be able to apply technology, to design new devices, systems, and processes for communication, transportation, computation, construction, manufacturing, power generation, and distribution. . . . The engineering education at Cornell, situated in a comprehensive university, and stressing humanities and social sciences as well as science and engineering courses, is an ideal education for the leaders of tomorrow.

Among those who stay the course and complete a Cornell engineering degree or two, many go into fields without a direct connection to engineering—medicine, for example, or business or law or public service. College alumni affairs officers hear from them that Ezra Cornell’s hopes have become a reality: a Cornell engineering education increases “powers of production through the agency of a better cultivated brain.”

Engineering, the Evolving Discipline

A twenty-first century College of Engineering continues to reinvent itself in order to explore and create solutions to future problems. Some strategic realignments were reflected in departmental names:
• The venerable agricultural engineering became agricultural and biological engineering—for a just short while, before evolving into biological and environmental engineering.

• The earth-bound Department of Geological Sciences joined specialists in other spheres to become Earth and Atmospheric Sciences.

• Soon after a “C” was inserted into “EE” to become electrical and computer engineering, engineering faculty members in computer science helped found the university-wide Faculty of Computing and Information Science.

• Biomedical engineering evolved from chemical and mechanical engineering, and immediately formed collaborations with other schools and colleges throughout the university.

Cornell engineering’s hearty embrace of biological sciences was presaged by the interim (2000–01) deanship of Harold C. Craighead, the biophysicist who had been the founding director of the NSF–supported Nanobiotechnology Center. Everywhere on campus, the New Life Sciences Initiative (itself an outgrowth of the Genomics Initiative) beckoned researchers, scholars, and entrepreneurs—including a major representation from the College of Engineering.

Consequently, biological sciences had a leading role when Cornell engineering faculty members, students, alumni, and administrators commissioned by Dean Fuchs developed a strategic plan for the college. They identified three “emerging areas” on which the college should focus its education and research resources, beginning with systems biology and biomedical engineering. (The other two emerging areas—nanomaterials, nanoscience, and nanodevices; and energy, environment, and sustainable development—also impinge on biological systems, the planners acknowledged.) To an engineer, systems biology integrates familiar analytical and design-driven approaches that can facilitate basic biological discovery and understanding of complex biological phenomena, and can ultimately guide the design of life-changing products, such as more effective pharmaceuticals.

Along with systems biology, the strategic planners observed, biomedical engineering gives engineering students and educators the opportunity to work with colleagues in veterinary and human medicine at Cornell. The emerging field of nanoscience has spurred engineers to envision electronic devices the size of molecules that interact directly with biological systems. Planners who took stock of the university’s academic environment declared: Cornell engineering is well positioned to make fundamental contributions to the discovery, development, and implementation of alternative energy sources. Their vision for sustainable development encompassed the globe while sustaining R&D for innovative solutions to problems (a fuel cell–powered laptop computer was one they named).

Excellence in the designated “emerging areas” could only be possible with a renewed focus on what the strategic planners called “enabling research.” They named three fields on which to concentrate: information, computation, and communication; advanced materials; and complex systems and networks.
Begun in 2004, the engineering college’s Strategic Planning and Advisory Council (SPAC) gave its ambitious plan a ten-year window. If the plan worked, SPAC participants were confident, 2014 would be remembered as the year Cornell University’s College of Engineering actualized a “vision of leadership”:

- by fostering a challenging, enlightened, and collaborative academic environment that demands excellence, encourages innovation, and supports groundbreaking discovery;
- at a college where the esteemed faculty is world renowned for its creative scholarship and innovative teaching;
- to student engineers who go forth and become valued for their commitment to excellence, enthusiasm for learning, ethical behavior and integrity, and exceptional leadership.

When you’re already doing most of that, full achievement is within reach.
The Planet Is Your Campus
The Planet Is Our Campus

“The cheap and nasty policy as to new building is detestable . . . . $3,000.00 has been saved by making the new Civ. Eng. Building a mere barrack.”

Cornell President A. D. White’s diary entry for April 19, 1888, regarding the plan to build Lincoln Hall of red brick

At Cornell, engineering doesn’t stand still for long. Plans change, visions evolve, and the places where we work and learn bear scant resemblance to what once was or might have been.

About that “cheap and nasty” Lincoln Hall brick, for instance: plans were changed, again and yet again, for that first home of civil engineering. It was finally built of red stone and red brick, at an additional cost of $7,000. Then, civil engineering moved to a red and tan, metal and masonry building named for Solomon Cady Hollister, the dean who built a new engineering campus. Now the Department of Music occupies Lincoln Hall.

Franklin Hall, the first laboratory building for chemistry and physics (and for one of America’s first two departments of electrical engineering, an honor Cornell shares with MIT) was handed off to the College of Architecture, Art, and Planning. North light illuminates the art studios there, and although they renamed the building Tjaden Hall, the medallion images of eminent scientists on the hall’s facade still inspire passersby.

Some—but not all—of the contents of the Sibley Hall technology museum (see “No Twain Brain, But . . .” page 46) are in the Sibley school’s current quarters.

Behind mechanical engineering’s Sibley Hall and overlooking Fall Creek, Rand Hall and the wooden foundry building across the street have also switched from the mechanic arts to the visual ones. Rand is where architecture students build their annual Green Dragon, which they parade along the edge of today’s Engineering Quad.
When Cornell Hockey Had Real Ice

Farther upstream at the base of the Beebe Lake dam, the turn-of-the-century hydraulics lab—five stories of Florentine-style stonework—was abandoned in 1959, but its picturesque ruins still cling to the gorge wall and figure prominently in one of the most photographed campus scenes when the gorge ices up in the winter. Another fan of winter was Professor John T. Parson, who taught mechanical drawing from 1895 to 1935, an in-veterate ice skater. He started a subscription-based program to support ice maintenance on Beebe Lake and always reserved one section for Cornell's hockey team. The Cornell Outing Club's headquarters on the lake's north shore now bears his name.

SO THEY SAID

NO TWAIN BRAIN, BUT . . .

“Marvelously ingenious and perfect, from a mechanical standpoint, worthless commercially, the costliest machine ever built will stand in a Cornell university laboratory as a monument to Mark Twain’s vanished fortune.”

New York Evening Telegram October 9, 1893

Samuel (Mark Twain) Clemens semi-seriously promised to leave his brain to Cornell, for the study collection that Dr. Burt Green Wilder, the university’s first professor of animal biology, began assembling in 1889. Although hundreds of “educated and orderly persons” filled out Wilder’s “Brain Bequest” forms, Clemens was never among those whose final wishes were fulfilled. However, one large Clemens artifact did come to Cornell—as evidenced by this 1890s photograph of the technology museum in Sibley Hall.

The Paige Compositor, the brainchild of inventor and promoter James W. Paige, was a keyboard-operated typesetting machine that caught the fancy and consumed the fortune of Clemens. Royalties from the popular Mark Twain novels and Clemens’ lecture fees—in $4,000 monthly installments and lump sums of $30,000—were poured into the doomed investment. Weighing 7,550 pounds and built by hand with more than 18,000 pieces, the compositor could set type 16 times faster than a human could by hand—until it broke down, which it did repeatedly. Each time, Paige solicited additional capital from Clemens, who commented to his brother, Orion: “All the other inventions of the human brain sink pretty nearly into commonplaces contrasted with this awful mechanical marvel.”

The principal competition for the Paige Compositor was the slower—but simpler and more reliable—Mergenthaler Linotype machine. Only two prototype Paige Compositors were built before the rival effort was abandoned; the Mergenthaler company’s president, Philip T. Dodge, acquired the rights to the Paige technology and the prototype machines—lending one that had been tested at the Chicago Herald to Cornell. The New York Evening Telegram noted the increased complexity of the second, Chicago-built version, which by then had increased to 19,000 parts, saying: “A study of these parts and the difficult problems of engineering
that they have overcome will be invaluable to students in the mechanical courses at Cornell University." The 1893 newspaper story was headlined: "CORNELL WILL HAVE IT: Wonderful Machine that Consumed Mark Twain’s Fortune."

In Sibley Hall’s technology museum, the Paige Compositor was displayed alongside the Vail-Morse telegraph receiver that was on the Baltimore end of the 1842 “What hath God wrought?” message, as well as many of the 266 Reuleaux kinematic models that Andrew Dickson White had purchased from Franz Reuleaux and the Gustav Voight Mechanische Werkstatt, in Berlin, to teach Cornell engineering students how mechanical things work. Student visitors to the museum could also draw inspiration from devices like the Autographic Torsion Testing Machine (at right), patented (in 1874) by Robert Henry Thurston before he joined the Cornell faculty to lead mechanical engineering for 18 years.

Soon after Thurston’s arrival, an October 17, 1885, issue of Scientific American (with a front-page engraving of a less-cluttered Sibley Hall museum) marveled at the growing collections, before offering this advice:

“Thus much for the material part of this great and growing school of mechanical engineering. But bricks and mortar and fine machinery and beautiful apparatus do not make a school. Brains, not buildings and museums of apparatus and machines, give real success, if worked into an organization of proper form. The organization and personnel of the establishment are of more importance than the buildings and plant, however elaborate.”

Thurston must have agreed when he relinquished the space-hogging Paige Compositor in 1897. The eleven-foot-long “awful mechanical marvel” belonged by then to the Mergenthaler company, which was busy making the more compact Linotypes that would dominate the publishing industry through the 1970s. In 1964, Mergenthaler donated the machine to the Mark Twain Museum in Hartford, Connecticut, where it is regarded as a one-of-a-kind. That is because the other prototype Paige Compositor, which had been built with Mark Twain’s money at the Colt Patent Firearms factory in Hartford, had been given to Columbia University. It was melted down for scrap during World War I.

Cornell’s Reuleaux kinematic models are safe in a mini-museum in the atrium that connects Duffield and Upson halls, where visitors can manipulate the levers and gears—the same way nineteenth-century students did—to learn how innovative engineers apply basic mechanical principles to modern-day gizmos like electric toothbrushes. The models have returned to the classroom (MAE 3780, “Mechatronics,” and MAE 2550, “Mechanical Systems”). But anyone with access to the Internet can see them and how they work at kmddll.library.cornell.edu.

The Thurston testing machine, which could record a strain diagram with a pencil attached to a pendulum, is on display in the dynamics laboratory of theoretical and applied mechanics’s Thurston Hall. Nearby is a bas-relief of the great man himself—by Herman McNeil, the sculptor who rendered Ezra Cornell (and the telegraph instrument that led to the university founder’s fortune), larger than life, on the Arts Quad. Thurston had hired McNeil as an instructor in the art department of Sibley College; the sculptor returned the favor.

Elsewhere, in the Sibley School’s Upson Hall, are displayed the university’s collections of vintage calculating devices, including some rare slide rules. The most precious machine of all, the actual Vail-Morse receiver, is kept under lock and key—except for special occasions like Ezra Cornell’s 200th birthday. That self-taught engineer never had a calculating machine. He made calculations the old-fashioned way: with a pencil in his “cipher book.”

The lake’s original stone dam, built in 1838 by Ezra Cornell to supply water power to Col. Jeremiah Beebe’s downstream plaster and flour mills, was replaced in 1897 by a concrete structure that still exists. There would have been a lot more water, in a three-times-bigger Beebe Lake, if a 1903 proposal by the Fall Creek Water Power Development Project had added another ten feet to the height of the dam. That scheme was shelved, but the university, in anticipation of flooding by the bigger dam, had already bought up the land that would have been inundated. This fortuitously preserved the land from development and added to
Cornell’s “natural areas” holdings. On this land, access to the east end of Beebe Lake from Cornell’s north campus and from Forest Home Drive is provided by The Tang Steps, a project designed and built by three dozen civil engineering students of Professor Mary Sansalone. The steps—which honor the memory of the grandparents of Martin Tang, Class of 1974—are said to enhance the site’s feng shui.

Farther up Fall Creek, in 1983, some twenty student members of the American Society of Civil Engineers observed the Brooklyn Bridge centennial by building a smaller one—the Stevens Suspension Bridge—in the Flat Rocks area. Student chapter president Bryan D. Clark led the team through computer-aided design and knuckle-bruising construction of the bridge. Working frantically to complete the project in an especially wet spring, Clark lost his voice and gave orders by scribbled notes. As foaming champagne opened the bridge, faculty advisor Thomas O’Rourke, professor of civil and environmental engineering, called the project “both a gift and a discovery.” The gift was to hikers who had waded across the creek since a 1981 flood washed out the last bridge. The student builders discovered, through cooperative enterprise, O’Rourke said, an application for the engineering principles they learned in class.

What’s in a Name?

The names on some engineering buildings can be confusing. Riley–Robb Hall, which houses the former Department of Agricultural Engineering (which has morphed into the Department of Biological and Environmental Engineering), honors two former department chairs, Howard W. and Byron B., respectively.

Rhodes Hall honors Frank H. T. Rhodes, Cornell’s ninth president, an eminent geologist and member of the engineering faculty. The facility was designed as the
home to the Cornell Theory Center and to provide additional space for the College of Engineering. Ground was broken to start construction of Rhodes Hall not by shovel-wielding dignitaries, but by a robot. By then the building’s footprint had been moved away from the edge of Cascadilla Creek Gorge, at the insistence of environmentalists, and now follows the bend in Hoy Road.

At the west side of the engineering campus, earth and atmospheric sciences’ Snee Hall features a similar curve along Campus Road. Some fossils and minerals are on public display in Snee Hall (and some really big specimens are outdoors in the Rock Park near the department’s former home of Kimball Hall), but the bulk of the university’s fossil collection was moved off campus (see “From McGraw Hall to the Museum of the Earth,” page 50).

Snee Hall is named for William E. Snee, a 1925 Cornell chemistry graduate who prospered in the oil and gas exploration business. When it opened in 1984, some passersby wondered why the geologists built their home of concrete—and whether that choice said something about the projected durability of rock as a construction material. The tan hue of Snee’s concrete was intended to match Hollister Hall to the north.

Another building material of choice is the locally quarried stone called Llenroc, which is Cornell spelled backwards. Llenroc also is the name of the post–Civil War Gothic-style villa that Ezra Cornell built west of campus for his family; sadly, Cornell died before the house was finished, and in 1911 it was sold to the Delta Phi fraternity.

There used to be a lot of Llenroc stone on campus—before a few of the earliest students were put to work quarrying it from the now sod-covered hillside of Libe Slope.

No gas–electric hybrids, these Cornell engineering productions were purebred electric cars—even if they didn’t run far. The more stylish of the two, a 1973 model, hummed around the campus with then-president Frank H. T. Rhodes at the wheel. The 1972 model reached the Ithaca countryside before needing a little encouragement from professor of electrical engineering Joseph L. Rosson.
Llenroc was back in the news in 1999 when Cornell paleontologist John Chiment spied a 300-million-year-old fossil of a glass sponge in the wall between Upson and Phillips Halls. The engineering college graciously ceded the fossil-bearing rock to paleontology students—so long as it was replaced with Llenroc. A couple of years later the wall itself was demolished during the construction of Cornell’s nanoscale facility, Duffield Hall (named for PeopleSoft founder David A. Duffield ’62, B.E.E. ’63, M.B.A. ’64).

Before nanotechnology (and before a Cornell chemical engineer named Lynn Jelinski coined the term “nanobiotechnology” to describe fabricated little things with biological components), the buzzword du jour was “submicron” (smaller than a micron, a millionth of a meter, compared with nanometer, a billionth of a meter). The National Submicron Facility, forerunner to the Cornell NanoScale Science and Technology Facility (CNF) in Knight Laboratory, was established at Cornell in 1977. The “bullets” for the first gene gun were made in the submicron facility. The name of Lester B. Knight, Jr., a 1929 mechanical engineering graduate, still appears on the new CNF laboratories.

Some of the high-tech start-up companies in the Cornell Business and Technology Park (formerly and more simply, the Cornell Research Park, located on the grounds of the Ithaca–Tompkins Regional Airport) were spun off when Professor Jelinski, an expert

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**ONLY IN ITHACA**

FROM MCGRAW HALL TO THE MUSEUM OF THE EARTH

The migration of Cornell's fossils began when Gilbert D. Harris, a professor of paleontology and stratigraphic geology from 1894 to 1934, was preparing to retire and asked the university to provide some place more fireproof than the stone-and-wood McGraw Hall that then housed the collections. The university declined, so Harris built his own museum with fireproof cinderblock and all-metal furnishings just off campus behind his home in Cornell Heights. There, in 1932, he founded the Paleontological Research Institution (PRI), which in 1968 moved up Ithaca’s West Hill to a William Henry Miller–designed edifice once run as an orphanage by the Odd Fellows fraternal organization. The modernistic Museum of the Earth was later connected to this PRI headquarters building, and in 2004 the university and the institution signed an agreement of affiliation.

Some of the fossils had been collected during one of the university’s perennial summer adventures (the other was civil engineering’s summer survey camps) led by Harris. For his trips, Harris travelled in boats named after fossils and lectured to students while he navigated down the Hudson River and along the Atlantic seaboard en route to his summer appointment as the chief geologist of the state of Louisiana. To get to the Hudson, Harris first motored up Cayuga Lake and through the locks of the Erie Canal.
A CENTER OF CENTERS

Major shared-use centers at Cornell enrich opportunities for faculty and students, but they also serve as powerful magnets, attracting outstanding engineers and scientists from all over the world. Cornell University is home to more than 150 interdisciplinary centers, institutes, laboratories, and programs. The university’s culture of collaboration further stimulates the innovation and discovery these centers foster.

In 2007, Cornell ranked second in the nation in National Science Foundation (NSF) funding. The NSF funds four national research centers at Cornell, which provide significant, unique resources for the worldwide scientific community. The Cornell High Energy Synchrotron Source (CHESS), located in Wilson Lab, attracts researchers in physics, chemistry, biology, and environmental and materials sciences from many universities, national laboratories, and industries. The Cornell NanoScale Science and Technology Facility (CNF), housed in Duffield Hall, provides state-of-the-art resources and expert staff to support a broad range of interdisciplinary research in physical sciences, engineering, and life sciences. The F. R. Newman Laboratory for Elementary-Particle Physics (LEPP) is engaged primarily in experimental and theoretical elementary-particle physics and accelerator physics. The National Astronomy and Ionosphere Center (NAIC) enables research in the areas of astronomy, planetary studies, and space and atmospheric sciences. NAIC’s main facility is the Arecibo Observatory in Puerto Rico, the world’s largest, and most sensitive, single-dish radio telescope.

In addition to CNF, Cornell is home to four other nanoscale science and technology centers that receive significant NSF funding. The Cornell Center for Materials Research (CCMR), with facilities in Clark and Bard Halls and several other locations, brings researchers together in four major interdisciplinary research groups along with other, smaller “seed” research groups. The Center for Nanoscale Systems (CNS) develops electronic, photonic, and magnetic nanoscale systems that collectively have potential to revolutionize information technology, including electronics, communications, information storage, and sensors. The Nanobiotechnology Center, which has six member organizations, features a close collaboration among life scientists, physical scientists, and engineers, and also provides education and outreach. The National Nanotechnology Infrastructure Network is a thirteen-member consortium that enables university students and researchers, as well as scientists from corporate and government laboratories, to have open access to specialized resources for molecular and higher length—scale materials and processes.

The most recent addition to Cornell’s nanoscale research centers is a Global Research Partnership Center established in 2008 between Cornell University and King Abdullah University of Science and Technology (KAUST) in Saudi Arabia, launched with funding from KAUST. Designed to become a leading research hub for nanomaterials science and technology, this interdisciplinary research center will focus on nanoparticle ionic materials (NIMs), a new class of hybrid nanomaterials with potential applications for emerging technologies in water desalination, carbon capture, and solar energy.

The research conducted through LEPP is enhanced through two important Cornell research facilities: CHESS and the Cornell Electron-Positron Storage Ring (CESR) accelerator, which is an electron–positron colliding beam facility for research in high-energy physics. It is also used to produce high-energy X-rays for CHESS studies in areas such as materials science, biology, and medicine.

Cornell engineering faculty members and students make use of the university’s robust computing resources, too. The Cornell University Center for Advanced Computing (CAC) (formerly the Cornell Theory Center) in Rhodes Hall provides high-performance computing systems, database, storage, programming, porting, tuning, and training services to Cornell and external clients. The Institute for Computational Sustainability, launched in 2008 with significant funding from NSF, brings together researchers from several institutions to apply sophisticated computing technology and applied mathematics to environmental, biological, and economic problems.

Other environmental engineering challenges are being addressed in still other Cornell facilities. The Cornell Network for Earthquake Engineering Simulation laboratory is used by the university’s Multidisciplinary Center for Earthquake Engineering Research, which is a member of the Multidisciplinary Earthquake Engineering Research consortium.
on the molecular structure of spider silk, was in charge of technology transfer at Cornell, which operated out of the Biotechnology Building.

Even a cursory scan of these photographs through the years shows that more than Cornell engineering structures have changed. Three-piece suits in classrooms were replaced by “bunny suits” in clean rooms. Beards came and went and still come back periodically, but long sideburns haven’t been seen for a long time. Engineering students with neither beards nor sideburns are more numerous now that Ezra Cornell’s “poor young men” have been joined by smart young women.

The engineering physics building named for John D. Rockefeller in 1904 was supposed to sit between White and Lincoln Halls. But physicists worried that proximity to an electric trolley line passing White Hall might spoil their experiments—as could
Cornell engineering’s newest department, biomedical engineering, is in Weill Hall, named for benefactors Joan and Sanford I. Weill.

“tremors” coming from civil engineering experiments in Lincoln Hall. Sited instead across the road, alongside the home of founding president Andrew Dickson White, the hall consumed $250,000 from the Standard Oil tycoon’s fortune.

Cornell engineering plays a part in a broad variety of research centers across the campus (see “A Center of Centers,” page 51, and “Facilities for Research and Innovation,” above).

High (Voltage) Hopes

One near-campus facility, electrical engineering’s High Voltage Laboratory on Mitchell Street—sometimes mistaken for a moving company warehouse—has had an illustrious history. Rebuilt on the present site in 1953 (after a nighttime fire in 1947 destroyed...
The first one), the big gray building once housed experiments that lit the land (with high-voltage electrical transmission), simulated lightning (a Marx generator produced three-million-volt surges), and tried to harness the power of the Sun (controlled fusion). Those studies passed, but the cavernous space hasn’t gone to waste and the lab’s electric bill is lower lately. Engineering students’ Solar Decathlon houses, clad with photovoltaic panels, are designed there, and hauled through the big overhead doors to win prizes for energy-saving ingenuity.

Clearly, not all the subjects pictured on these pages were taken on Cornell’s Ithaca campus. That’s because Cornell engineers conduct their studies wherever there’s work to be done, on every continent including Antarctica. A nineteenth-century survey of Brazil was one of the earliest such adventures. More recently, the Himalayas, the Andes, and Hawaiian volcanoes appear in the background of snapshots sent home by peripatetic Cornell engineers and their students. Indeed, the planet is Cornell Engineering’s campus.

Arecibo Observatory was itself “moved,” thanks to cinematic special effects in the James Bond film *Goldeneye*. While looking for a secret satellite dish in Cuba, Agent 007 and Natalya Simonova crash-landed and watched as a lake drained to reveal . . . a radio observatory that was familiar to most Cornellians.

**C is for Cornell**

While E. T. and James Bond were fictional characters, a more frequent Arecibo visitor is very real—although she nearly dropped out of Cornell. Astrophysicist Jill C. Tartar, director of the Center for SETI [Search for Extraterrestrial Intelligence] Research (and the inspiration for the “Dr. Ellie Arroway” character played by Jodie Foster in the movie *Contact*), was studying engineering physics on a scholarship in the 1960s when she made the “mistake” of marrying an undergraduate. That was discouraged at the time
The Planet Is Our Campus

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Built by students in the High Voltage Laboratory on Ithaca’s Mitchell Street and displayed on the National Mall in Washington, D.C., Cornell’s 16-by-40-foot house returned to the campus after taking second place (among eighteen university entries) in the 2005 Solar Decathlon. Cornell’s entry impressed Department of Energy judges with two special features: ERV (energy recovery ventilation) with humidity-absorbing silica gel in a rotating wheel—the work of mechanical engineering grad student Tim Fu and his collaborators—and edible landscaping with 1,500 vegetable plants. U.S. Secretary of Energy Samuel W. Bodman (inset), a 1961 Cornell graduate in chemical engineering, toured the 2007 entry.
and it nearly cost her the scholarship. Fortunately, the former engineering dean and then-provost Dale Corson intervened. The scholarship was restored, and Ms. Tartar went back to class and completed the five-year program in four years. Turns out the C. in Jill Tartar’s name stands for Cornell. She is the great-great-great grandniece of Ezra, who wrote in an 1867 letter to his granddaughter:

I want you to keep this letter until you grow up to be a woman and want to go to a good school where you can have a good opportunity to learn, so you can show it to the President and Faculty of the University to let them know that it is the wish of your grand Pa, that girls as well as boys should be educated at the Cornell University.

Sibley College had been named in 1871 for the father-and-son philanthropists Hiram and Hiram W. Sibley, respectively, who gave the then-princely sum of $300,000
The elder Sibley was a Rochester engineer and one of the first ten trustees of the university. On June 15, 1892, Sibley College Director Robert Henry Thurston dedicated a bust of Hiram Sibley in Sage Chapel (which had opened in 1875 for an under-budget $24,775 of Henry Sage’s money). Thurston began his oration by saying: “We honor Hiram Sibley today, not because he gave to Cornell University of his troublesome superfluity of wealth; not that he erected structures that his own State should have raised as her share of the great work inaugurated by the general government . . . .” He went on to laud the philanthropist’s faith in the future of Cornell engineering. Forty-five years later, the College of Engineering decided not to tear down Sibley Hall and replace it with an up-to-date art deco edifice. (See “The Donor Who Saw No Problem,” page 58.)
Beauty of Purpose

Another close call—and ultimately a smart one for Cornell engineering—was the decision not to knock down Sage Hall and put an electrical engineering building in its place. Instead, they built across the street. Phillips Hall opened in 1955 to honor Ellis L. Phillips, the 1895 electrical engineering graduate who founded the Long Island Lighting Company. (Cornell’s neighbor on South Hill, Ithaca College, has a Phillips Hall, too, named for Princeton-educated Ellis L. Phillips Jr., president there from 1970 to 1975.)

Cornell’s Kimball Hall is named for the founding (1921) dean of the consolidated College of Engineering, Dexter S. Kimball (1865–1952), who in his previous twenty years of faculty service had launched the Department of Industrial Engineering. Kimball worked his way up from the logging camps of Puget Sound and mines of Montana to become an innovative leader in heavy industry—before “retiring” to engineering education.

SO THEY SAID

THE DONOR WHO SAW NO PROBLEM

“Time will weather, materials will blend, vines will soften and the differences of style will lose their importance when there is a better perspective.”

A. L. Harmon, “Architect’s Statement of Design”

The year was 1937, and one principal of the architectural firm of Shreve, Lamb, and Harmon, Arthur Loomis, was defending his design for a cluster of new engineering buildings on what is now the Arts Quad. Anticipating objections to the contrast between the university’s oldest structures and his art deco vision, Harmon wrote: “One has only to consider Oxford to realize how much of charm, of interest, of character and of sentiment would be lost if each succeeding generation of buildings there had been made to conform with the first buildings.”

The firm’s Empire State Building had opened in 1931 to critical acclaim in Manhattan. Here in Ithaca, Harmon’s plan would have razed and replaced mechanical engineering’s Sibley, civil engineering’s Lincoln, and electrical engineering’s Franklin Halls with lots of sleek limestone and glass. Although engineering dean Solomon Cady Hollister kept his opinions to himself, detractors likened the Harmon design to the Empire State Building, “lying on its side, in pieces.”

Previous plans for Cornell engineering buildings were different in their own way. A 1910 proposal called for a row of Rand Hall clones sandwiched between Sibley Hall and the Fall Creek Gorge. A 1925 design reminded some of Barton Hall and was derided as “military gothic.”

Construction of a whole new engineering complex on the Arts Quad would have cost $11,226,000 in Depression-era dollars, but it was not to be. Administrators and university trustees decided in 1940 to move the whole thing—Shreve, Lamb, and Harmon designs included—to the more spacious site of the current engineering campus.

So the Arts Quad was spared the indignity of art deco, but controversy followed engineering’s plans across campus. The university’s Architecture Advisory Board published a harsh critique in the Alumni News, and alumni, as well, weighed in. One suggestion was to add more “native stone” to the sides of buildings facing Willard Straight and Myron Taylor halls.
Also on the quadrangle is the administration and library building that some—mistakenly—believe to be named for Rolla Clinton Carpenter, professor of experimental engineering in Sibley College from 1890 to 1917, head of its mechanical laboratory, textbook author, patent expert, and the first manager of the fledgling football team that became the Michigan State University Spartans. In fact, Cornell’s Carpenter Hall is named for Walter S. Carpenter Jr. (1888–1976), an engineer whose summertime student internships at DuPont chemical plants proved more enticing than academic studies. He dropped out of Cornell in the fall of his senior year (1909) to manage DuPont’s nitrate interests in Chile, subsequently rising through the corporate ranks to become only the second president of E. I. du Pont de Nemours and Company without the family name.

The sign on Upson Hall, the 1958-vintage home of the Sibley School of Mechanical and Aerospace Engineering, is not a misspelling of a founding director’s name. George B. Upton, a 1904 Cornell graduate, was the first head of the Department of Automotive and Aeronautic Engineering when it opened in 1936 (although “aerial engineering” was
dubbed military gothic and art deco, respectively, the 1925 and 1937 plans to enlarge Cornell engineering’s footprint on the Arts Quad would have changed everything. Some elements of the 1937 designs were retained when the engineering college campus moved to its current location.

A looming war accentuated the need for more chemical engineers when Dean Hollister announced, to a 1940 meeting of the university Board of Trustees, that he had found a patron for the first of the new buildings. The unnamed philanthropist pledged $35,000 to prepare final plans for a chemical engineering building that was estimated to cost $700,000. Hollister sweetened the pot by adding that the donor “saw no problem” with the chemical engineering building’s design as depicted in architect’s renderings and scale models. The board accepted the gift and ordered construction to begin.

On January 18, 1941, Dean Hollister entered a New York City meeting of the board with an octogenarian on his arm. The dean introduced the man as a member of both the Cornell University Board of Trustees and of its Buildings and Grounds Committee. The chair of the board was handed a prepared statement and he read to the board an offer of $685,000 for the construction and outfitting of the chemical engineering building. “The gift, if accepted, shall be a memorial to Franklin W. Olin Jr., the deceased son of the founders of Olin Foundation Inc.,” the statement stipulated.

Acknowledging the trustees’ applause, Franklin W. Olin apologized for missing so many board meetings. His “impaired vision,” he said, did not permit him to travel alone.

Olin Hall was built—with some elements of the Shreve, Lamb, and Harmon design and with some native stone, too—and opened in 1942 as a memorial to the 1912 civil engineering graduate who had died in 1921. His father (an 1886 Cornell civil engineering grad who had captained the university baseball team and financed his education by playing as a professional in the summers) had established the Olin Foundation in 1938 with proceeds from the blasting powder and munitions company he started in 1892. Franklin Olin lived into his nineties, dying in 1951.

After the war, two more engineering buildings (Kimball and Thurston Halls) rose from Harmon’s designs before the college switched architects (to Perkins and Will) and built the rest of the campus in a style one 1980s dean called “1950s elementary school.” Remarkably, the Cornell engineering campus that is Dean Hollister’s legacy was completed for the original estimate—less than $12 million in 1950–60s dollars—and less than some renovation projects cost today.
THE PLANET IS OUR CAMPUS

WHAT EVER HAPPENED TO BACKWARDS TRICYCLES? TO PORTABLE COMPOSTING TOILETS? OR TO PLAID-PATTERNED TROUSERS, FOR THAT MATTER? CORNELL ENGINEERING STUDENTS TRIED TO SAVE THE PLANET BEFORE IT WAS FASHIONABLE.

THE PLANET IS OUR CAMPUS

“Beauty of purpose.”

Dexter S. Kimball, Dean, Cornell College of Engineering

The beautiful, purposeful design that Dexter Kimball described was the handle of the double-bit axe that he had swung, as a youth, against the Douglas firs of Puget Sound. (Unlike the curved handle of a single-bit axe, the grip on the two-blade kind fits the user’s hands in either direction.) Kimball’s credo was invoked again in 1980 when the bow string sundial—accurate to within thirty seconds a day and easily adjusted—was dedicated at its original site on the Engineering Quadrangle.

The same might be said of the gnomon sundials on the Mars rovers, Spirit and Opportunity. Designed, in part, by 1977 mechanical engineering graduate Bill Nye, “The Science Guy,” the Mars sundials not only told Red Planet time but also served as photography color charts to calibrate the rovers’ Pancams.

The Engineering Quad sundial, designed by Richard M. Phelan, professor of mechanical and aerospace engineering, and his MAE 325 students, and by former engineering dean Dale R. Corson, also moved—but not as far as the Mars-roving timepieces. It was uprooted and stored during construction of nearby Duffield Hall, then replaced in a reconfigured Joseph N. Pew Jr. Engineering Quadrangle in 2004. Joseph Pew’s widow, Alberta, pondered the equation of time that Corson had derived, via Fourier analysis, to specify the shape of the adjustment cam, then proclaimed: “A sundial is a perfect timepiece for an engineer.”

taught here as early as 1910–11 and the School of Aeronautics began in 1917). The building actually is named for Maxwell M. Upson, who graduated with a degree in mechanical engineering in 1899 and served on the university’s Board of Trustees for thirty-five years.

An off-campus facility underwent a name change in the 1970s. The Cornell Aeronautical Laboratory at the Buffalo airport became Calspan. It produced advances in aviation, automotive safety, and even moviemaking. (See “Skulls and Agent 007 Stunts,” page 62.)

There is no building at Cornell named for Thomas Alva Edison, although Sibley College Director Thurston tried his best in the 1880s when the new Department of Electrical Engineering was getting on its feet and $200,000 could buy bricks-and-mortar immortality. (See “The Wizard, the Prince, the Carrier, and the Builder,” below.)

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**SO THEY SAID**


“Get the money out of the plutocrats.”

Thomas Alva Edison, 1886

All Sibley College Director Robert H. Thurston wanted from Thomas Edison was $200,000, and the “Wizard of Menlo Park” could have his name on Cornell University’s new electrical engineering laboratory. Thurston hoped his previous acquaintance with Edison (Thurston was the head of mechanical engineering at Stevens Institute of Technology, until President A. D. White recruited him with a then-enticing salary of $5,000 a year) would help when he asked for a donation.

But Edison wrote back: “It would benefit the world at large more for the college to get the money out of the plutocrats who acquired it easily and don’t deserve it and have no other means of perpetuating themselves.”

Rebuffed but not discouraged, Thurston went after another potential benefactor, Andrew Carnegie—without calling him a plutocrat of course. Instead, the academic flattered the Prince of Steel, inviting Carnegie to lecture to Cornell engineering students.

Carnegie finally agreed to talk in 1893. By then he was a trustee of Cornell University. Carnegie later donated money to build a water purification plant on Fall Creek—after the typhoid epidemic of 1903 struck the community, sickening 1,350 residents and killing 82. Some who died were Cornellians. “Typhoid Mary” Mallon reportedly had cooked for at least one Ithaca household before that “healthy carrier” moved on, spreading *Salmonella typhi* germs elsewhere.

Carnegie’s gift, updated several times with modern technology, still treats drinking water for the campus. The philanthropist known for endowing public libraries (Carnegie money built 2,509 of them, beginning in 1881) said of Ezra Cornell, who would have been 100 if he lived to 1907, “During all the years I knew him he went about doing good.” One good deed that inspired Carnegie had been Ithaca’s first, free public library, which Ezra Cornell built to open in 1866.
SO THEY SAID

SKULLS AND AGENT 007 STUNTS

“The only place we can find that knows anything about it is Cornell Aeronautical Labs.”


Former Secretary of Defense Robert S. McNamara was recalling his days as president of Ford Motor Company when he gave Fog of War filmmaker Errol Morris Lesson #6 (“Get the data”) as well as an idea for one of the more bizarre scenes in the Oscar-winning documentary. “We lacked lab facilities,” McNamara said, “so we dropped the human skulls in different packages down the stairwells of the dormitories at Cornell.”

That the film showed variously wrapped skulls shattering at the bottom of multistoried stairwells can be attributed to the director Morris’ artistic license. Neither the university’s Ithaca campus nor the Cornell Aeronautical Laboratory (CAL) at the Buffalo airport had high-rise dormitories in the mid-1950s. But CAL’s reputation for crash safety research—in aircraft as well as automobiles—was well established by then. Two of the first crash test dummies, Thin Man and Thick Man, were born there.

Led by Bill Milliken and sponsored by General Motors, engineers in the lab’s Flight Research unit were the first to translate aircraft equations-of-motion to automotive applications, allowing comprehensive analysis of automobile dynamics. The result was an improved understanding of tire performance and of automobile stability and control.

A year after CAL patented an automobile seatbelt in 1951, the lab was commissioned by the Liberty Mutual Insurance Company to design the Cornell-Liberty Survival Car. Many of the 1957 model’s innovations are now standard equipment—energy-absorbing padding in the cabin, headrests to prevent whiplash injury, the headlight-dimmer switches on the steering column instead of the floor, and retractable seat belts. Other Survival Car ideas did not survive the marketplace: rear-facing passenger seats proved to be unpopular, and five windshield wipers in front and three in back seemed excessive.

One incongruous element—for a car without pedestrian-wounding hood ornaments and headlight visors—was the addition of tall, pointy tail fins; seven years later Ralph “Unsafe at Any Speed” Nader would describe the fate of bicycle riders who failed to brake for tail fins. But already, the auto industry was learning from experiments McNamara ordered at the Cornell lab. The 1956 model Ford introduced padded instrument panels, seatbelts, and steering wheels that would not impale the driver.

The Aeronautical Lab’s basic-physics research was also applied to some very unsafe driving. Raymond R. McHenry’s patented Astro Spiral Jump enabled James Bond to leap a Thai river—with an AMC Hornet doing a 360-degree barrel roll—in the 1974 film Man with the Golden Gun. Roger Moore’s stunt double earned a $1,000 bonus for completing the jump in the first take, and Aero Lab engineer McHenry got to publish a scholarly paper on “An Automobile Stunt Designed via Computer Simulation.”

Tailfins and all, the Survival Car is now safely off the road in the Henry Ford Museum in Dearborn, Michigan.
Edison did give thousands of dollars worth of electrical equipment to Cornell, but few remember his generosity today.

**The End of an Era**

The J. Carlton Ward Jr. Laboratory of Nuclear Engineering was named in 1968 for the 1914 mechanical engineering graduate and engineering-college-council chair whose company had designed the building. It housed the university’s ZPR (zero power reactor) and TRIGA (teaching, research, isotopes, General Atomic) reactors that had “gone critical” six years earlier under the direction of David D. Clark. The graduate field of nuclear science and engineering was established with newly recruited, enthusiastic faculty members joining distinguished colleagues. Nuclear engineering education at Cornell had “gone critical itself and was on a roll,” in the words of engineering physicist Paul L. Hartman. Graduates of Cornell’s nuclear engineering program took leadership roles in a then-burgeoning industry.

But even before the Chernobyl meltdown (1986), fewer and fewer nuclear plants were powering up in the United States, which meant there were no new ones to design and operate. Interest in nuclear engineering degrees dwindled and research funding was limited. The university administration decided in 2001 not to renew the license for the TRIGA reactor and initiated plans to decommission Ward Laboratory.

In Olin Hall, the spirit of TGIF brought students and faculty together in the Fred H. Rhodes Lounge. The 1949 mural on the lounge’s east wall depicts the five-year journey—from beanie-topped freshman to graduate chemical engineer. Part of the mural documents the traditional Friday afternoon beer parties, hosted in the lounge by
SO THEY SAID

COMPLAINTS FROM THE “OVERALL BRIGADE”

“. . . what once was and never will be on Campus.”

Romeyn Berry, May 18, 1915

“Dog” was campus slang for a less-than-elegant place to dine when Cornell engineering students lunched in the original Sibley Dog. Located in a wood-framed farmhouse where Rand Hall now stands, the Sibley Dog was privately owned and operated—rather like today’s “hot trucks” parked along campus streets to compete with Cornell’s dining franchise for students’ lunch money.

The house, a gift to the university from Ezra Cornell, was considered the oldest building on campus and it had already been moved a few yards to the east for the convenience of road builders. The 1912 construction of the Rand Hall machine shop required another move, this time all the way to Ithaca’s Slaterville Road, and engineering students were getting awfully hungry.

A temporary site in a converted trolley car dubbed the “Sibley Pup” was far from adequate. So students welcomed another Dog migration—this time to a more spacious and still privately operated, but reportedly dank, spot in the basement of Sibley Hall.

In the spring of 1915, the university, which ran dining operations in several campus locations, announced a takeover of Sibley Dog—and a noteworthy change in ambiance. Along with new tables (without carved initials) and sanitary kitchen equipment came two rules: women students were allowed in the Sibley Restaurant (not “Dog” anymore) and men who smoked tobacco were not.

By October that year, engineering students’ vocal displeasure caught the attention of editors at Cornell Alumni News. Reporting on “Complaints from the ‘overall brigade,’” the weekly said: “Sibley men contend that the women students have plenty of places on or near Campus for the noon meal—Sage College and Risley Hall, and the Cascadilla and home economics ‘cafeterias,’ and that the only place where the overworked mechanic could drop in for a quick lunch in his working clothes is now catering to dolled-up respectability.”

Then, Romeyn Berry (a 1904 Arts graduate, former Cornell Daily Sun columnist, and lawyer who later became the director of Cornell athletics) weighed in on the issue of terminology. Highfalutin’ labels like “restaurant” and “cafeteria” were not necessary, and “dog” had not been slang for twenty years, said the wordsmith (whose 1905 football song, “The Big Red Team,” gives Cornell its hefty, colorful name). Opined Berry: “The term ‘Sibley Dog,’ even though it be applied to a vast and beautiful dining hall, recalls pleasantly to your sentimental alumnus what once was and never will be on Campus.”

That should have been a clue to complaining engineers, that their sacred space had been invaded by Arts students, but they weren’t ready to let go. “Objection is made to the rule against smoking,” the Alumni News continued, “because the liberty to smoke was one of the factors in the agreeable freedom of the old Dog. Those that complain of the new order of things say there wasn’t smoke enough to make the air bad.”

Well, they should see the old dog now. Abandoned by mechanical engineering when the entire college moved south, Sibley Hall calls its dining spot the “Green Dragon” for the rite-of-spring monster built next door, in Rand Hall, by first-year architecture students.
then-director “Dusty” Rhodes. He believed that responsible drinking behavior was best learned in the collegial company of faculty members and students. Nowadays, Cornell Orchards apple cider is served.

**All’s Well**

That brings us back to the place where Cornell engineering started, in Sibley Hall.

Back in 1938, when workers opened the floor of the old mechanical engineering laboratory behind Sibley Hall to install a new Olsen hydraulic tension–compression machine, they made a discovery. They uncovered an intact, thirty-two-foot-deep water well beneath the lab’s concrete floor.

Capped when the laboratory was built in the 1880s, the well was the last evidence of the very first structure on the site—a farmhouse owned by Ezra Cornell and deeded to the university in 1866. Its last known address was the corner of University and East avenues, where the house had been moved and converted into an engineers’ eatery called the Sibley Dog. (See “Complaints from the ‘Overall Brigade,’” previous page.) Then, Rand Hall was sited for the corner. The Sibley Dog was torn down, but the name prevailed on a diner made from a retired streetcar located near the Foundry.

Rand Hall was almost torn down, too, until the College of Architecture, Art, and Planning revised its plan and decided to connect Sibley and Rand halls with their new Milstein Hall. It’s the first time the architects have had classroom space that wasn’t designed by and for engineers.

Somewhere under Milstein Hall is Ezra’s well.
AEP: Bridging the Fields of Physics and Engineering

Ask any engineering student which field is the toughest, or which unit in the college has the brightest of the “brains,” and the response is usually the same: the School of Applied and Engineering Physics. National leaders in education seem to agree: U.S. News & World Report consistently places Cornell’s School of Applied and Engineering Physics at the top of all undergraduate engineering physics programs in the country.

The school’s reputation for rigor goes back to its beginnings, just after World War II. Faculty members and AEP students alike take pride in recalling those who “couldn’t hack it.”

About two-thirds of those who stay the course subsequently go on to advanced study—in fields such as electrical, chemical, biomedical, or computer engineering—or astronomy, medicine, law, business management, or basic or applied physics research. Faculty advisors tell prospective majors to consider engineering physics as an apprenticeship, on the broadest and most fundamental level, for a career in engineering, the basic sciences, or any discipline requiring a technical education.

But before that technical education begins—before undergraduates can delve into topics like integrated-circuit technology, wave-function engineering, electron and ion-beam microfabrication, lasers and optics, superconducting devices, plasma physics, thermonuclear fusion, or biological, materials, or x-ray physics—there are some fundamentals to learn. Engineering physics students must take a year more mathematics than the college’s standard requirement for other fields. Mathematics is an engineer’s most important tool, students are told.

And then there’s the physics, and plenty of it: a year’s study of electromagnetism and a semester each in the fundamental areas of applied physics, which include: classical...
mechanics, quantum mechanics, statistical thermodynamics, and continuum physics. “It is our opinion that excellence in physics—particularly in developing the capability to do physics and not just having an awareness or knowledge of physics—is of vital importance for a practicing scientist or engineer,” the students hear again and again.

Their advisors are drawn from a faculty that provides one of the most favorable teacher–student ratios in the university (about fifteen faculty members work with about forty students in each engineering physics graduating class), which helps more than annual college rankings. In a curriculum that stresses development of experimental skills at the undergraduate level, there are more than enough research mentors to go around. “The problem-solving ability you develop in Cornell engineering physics is recognized and rewarded wherever you go,” students are reminded, and where they go is changing, too. Careers in nuclear physics, optics, lasers, and integrated-circuit development once beckoned, and some still do. More likely, Cornell engineering physics grads are exploring burgeoning fields, such as biotechnology, nanotechnology, communications, computer design, or software development.

The Urge to Apply New Knowledge

That engineering physics would be the third engineering field to emerge from the physical sciences at Cornell (the first was electrical engineering, from physics; followed by chemical engineering, from chemistry) seems inevitable, considering a predilection of some scientists: they welcome the opportunity to apply new knowledge to the problems of mankind.

One such scientist, according to the school’s historian Paul L. Hartman, was Frederick Bedell (1868–1958), recipient of Cornell’s first (1892) Ph.D. in physics and a professor of applied electricity (beginning in 1904). Bedell probably would have joined the engineering physics faculty if it had existed during his tenure at Cornell, but he kept busy enough applying physics principles to problems in aeronautics, electricity, medicine, and public transportation.

Bedell taught Army flight cadets, who were trained at Cornell during World War I, enough physics to know what kept their biplanes aloft and moving forward; then he wrote The Airplane: A Practical Discussion of the Principles of Airplane Flight (1918). Then he turned his attention to the electrical applications of physical principles: some of the first commercially produced oscilloscopes were based on Bedell’s sweep-circuit patent. Largely because of Bedell’s theoretical studies and mathematical analysis of alternating-current circuits (he initiated the use of the symbol \( j=\sqrt{-1} \) in AC circuit theory), public utilities now supply customers with AC instead of DC power.

Bedell’s Ph.D. thesis on Rochester’s electric trolley system—analyzing power losses all the way from the coal that fueled the steam boilers to turn the generators, through the overhead lines, to the most distant trolley car in the system during rainy weather—grew into a book, Alternating Currents: An Analytical and Graphical Treatment for Students and Engineers (1911). While still working on his Cornell doctorate, he invented an electric elevator, an improvement on the hydraulic elevators of the time (1891), which had trouble reaching the upper floors of New York’s rising skyline. Bedell was one of the founding editors of the journal Physical Review, which started at Cornell in 1893.
Another Bedell invention extended physics into a field now known as biomedical engineering. His bone-conduction hearing aid bypassed the middle ear and transmitted sound through human teeth. The so-called Deaf Speaker also could be held against the forehead or cheekbone, if the user preferred. It was demonstrated first at a meeting of the Ithaca League for the Hard of Hearing. “One man heard his wife’s voice for the first time,” Bedell reported after the meeting. He filed for patent protection in 1931, demonstrated the device for the National Academy of Sciences in Washington, D.C., and tested it for three years in schools for the deaf.

Cornell’s First Physicist–Engineers

Physicist and inventor Frederick Bedell with his Deaf Speaker hearing aid in Rockefeller Hall in 1931. Holding the title of Professor of Applied Electricity, Bedell applied physics to engineering problems—including applications such as transportation and biomedical engineering. He retired from Cornell before the School of Engineering Physics began in 1946.
Claiming infringement of a 1935 patent on the Deaf Speaker, Bedell battled through the courts—all the while developing a teaching device for deaf children that was based on his earlier sweep oscilloscope work—and ultimately prevailed.

The first director of Cornell’s Department of Engineering Physics, which began in 1946, was nearly as wide ranging as Frederick Bedell. Lloyd P. Smith discovered the emission of positive metal ions from hot filaments (during his physics Ph.D. thesis research at Cornell in the late 1920s) that yielded the FP-54 Pliotron electrometer. He also built one of Cornell’s first linear accelerators before the war, worked on isotope separation for the Manhattan Project, and led microwave research at RCA.

When Cornell President Edmund Ezra Day tried to coax Smith back to Cornell—where the physicist had launched the university’s first courses in mathematical methods of physics in 1935 and wrote the textbook, too—Smith made one demand: that Cornell open a school of engineering physics. He thought the school’s curriculum should include a heavy mix of mathematics, physics, and engineering, according to school historian Hartman, whom Smith recruited from Bell Laboratories. Smith told the university president that some students needed education that was neither entirely that of the physicist nor that of the engineer, an aim that “only can be realized by breaking down the traditional barriers that have divided the provinces of science and engineering.”

That proposal made sense to the university president and to engineering dean Solomon Hollister. They hired Smith to be both chair of the Department of Physics in the College of Arts and Sciences and director of the new Department of Engineering Physics in the College of Engineering.

**Interdisciplinary from the Start**

The founding faculty came from both colleges. Charles R. Burrows was a professor and director of the School of Electrical Engineering. Jacob Roland Collins was a professor of physics and James Norman Goodier was chair of the Department of Mechanics in the Sibley School of Mechanical Engineering. Guy Everett Grantham and Hartman were physics professors, Alexander Berry Credle was an electrical engineer, and William Rees Sears was the founding director of the Graduate School of Aeronautical Engineering, before that division joined the Sibley School. Only two faculty members—Trevor Rhees Cuykendall and Henri Samuel Sack—had sole appointments in the Department of Engineering Physics.

During the World War II, Sears (1913–2002) had been chief of aerodynamics and flight testing at Northrop Aircraft, where he helped design the P-61 Black Widow fighter and the Flying Wing. At Cornell, he became the founding director (1963) of the university’s Center for Applied Mathematics.

During the World War I, Grantham (1886–1970) had survived one collision (between *HMS Otranto* and *HMS Kashmir* in 1918) to avoid another kind: one that he would hazard dozens of times, in the name of physics education. Teaching introductory engineering physics, he would demonstrate the law of conservation of energy by suspending a heavy pendulum from a center rafter of Rockefeller Hall’s Lecture Room A, pulling the pendulum back to the tip of his nose and releasing it to swing over the
students’ heads while Grantham stood his ground. Of course the pendulum returned to its point of origin and no farther, saving face and illustrating conservation of energy in a memorable way. Later, Grantham was among the first physics instructors to use closed-circuit television in lectures.

The Swiss-born and -educated Sack (1903–72) made early contributions to the physics of dielectric relaxation and was one of the first investigators to use ultrasonic techniques to study related molecular mechanisms. Following World War II, when he used his experimental talents to solve a number of problems in applied physics, Sack was a leader in the use of ultrasonic and dielectric techniques to study the solid state. Some seventy-five Cornell students earned master’s and doctoral degrees with Sack. (See “Einstein of Music, or Toolmaker for Musicians,” page 35, for one who almost didn’t, Robert Moog.) He was one of the founders, and the second director beginning in 1963, of Cornell’s Materials Science Center.

What’s Engineering Got To Do with It?

The director of the Department of Engineering Physics from 1956 to 1962, and again beginning in 1967, Cuykendall (1905–85) drew on his World War II experiences to establish the curriculum for the new program. Cuykendall was a specialist in high-energy X-ray physics, and tried to apply his science to engineering, in collaboration with S. C. Hollister, in photoelastic modeling of structural shapes.

But wartime stints at the Naval Ordinance Laboratory and the Los Alamos Scientific Laboratory found Cuykendall working with hundreds of young engineers and physicists on projects that required background training in both engineering and physics. Few of his fellow workers, Cuykendall said, were properly prepared for the demands set by the fast-paced war effort. There was no time to cross-train during the war, but the post-war influx of GI Bill veterans, he observed, afforded that opportunity for the brand-new field of engineering physics. Cuykendall helped build the graduate program in engineering physics and taught nuclear engineering courses at the university’s Ward Laboratory TRIGA reactor, which he urged Cornell to install as a teaching and research tool.

Microscopic Vision

In the field of Cornell AEP now called instrumentation, two faculty members made important early contributions in electron microscopy. Benjamin M. Siegel (1916–90) joined the faculty when electron microscopy was in its infancy (1949) and soon was teaching summer courses to faculty researchers in physical and biological sciences. Siegel’s interest in achieving the highest possible spatial resolution led him, through theoretical explorations of phase-contrast mechanisms, to image single atoms. His experimental work in the 1970s—with field-emission electron guns, superconducting electron lenses, digital image acquisition and image processing, and ultrahigh-vacuum techniques—brought products to the marketplace in the 1990s.

Miriam “Mika” Salpeter (1929–2000) began a scientific career in psychology. (The subject of her 1953 Ph.D. research at Cornell was stress-induced maladaptive be-
behavior in goats.) But her interest in the anatomy and function of the nervous system turned her to microscopy. Beginning as a research associate in Siegel's electron microscopy lab (1961–67)—before gaining a faculty appointment in applied and engineering physics and in the newly formed section of neurobiology and behavior—she applied physics to neuroanatomy in the company of her husband, astrophysicist Edwin Salpeter.

Fresh from his landmark Initial Mass Function work with galactic material, probability, and star formation, Edwin Salpeter joined with postdoc Luis Bachman and Mika Salpeter to develop the technique for detecting radiologic decay in tagged molecules called quantitative electron-microscopic autoradiography. The technique enabled Salpeter to make some of the most detailed observations of synaptic function when she quantified the density of important molecules, such as the acetylcholine receptor and acetylcholinesterase at the neuromuscular junction. Her mathematical models of the turnover of critical signal-transducing molecules explained both development of the nervous system and the effects of peripheral nerve injury.

Pre-Historian History

Paul Hartman (1913–2005) earned his historian’s stripes in a seventy-one-year association with Cornell engineering and with physics. An electrical engineering degree from the University of Nevada had him polishing eggplants in a Safeway grocery’s produce department, so he took a Ph.D. in physics at Cornell (1938) and developed centimeter-wave radar generators during World War II. Beginning in the 1950s, Hartman sought an application for X-rays, an unused byproduct of high-energy electron accelerators, which he and Diran Tomboulian encountered when measuring the spectrum of electromagnetic radiation from synchrotrons. His work formed the basis of X-ray diffraction studies at facilities such as Cornell’s High-Energy Synchrotron Source (CHESS). A specialist in X-ray and neutron diffraction, Boris Batterman headed CHESS (and also was director of AEP from 1974 to 1978).

Subsequent research by Hartman focused on ultraviolet radiation, optics, and solid-state physics. The school’s associate director from 1971 until his retirement in 1983, Hartman taught laboratory courses for upper-level undergraduates and graduate students. He is remembered by former students and faculty colleagues as a hands-on experimentalist who built many lab experiments himself, and then added more as phys-
ics research advanced the field. Writing his own obituary in advance (he died at 91), Hartman preferred to be remembered for other things, including his love of camping, winemaking, and amateur astronomy.

**School for the “Ferociously Smart”**

Unlike some Cornell engineering fields that began as graduate-level programs, engineering physics catered to undergraduates from its start. But graduate students were enrolled in engineering physics as early as 1947; the graduate fields of nuclear science and engineering and of applied physics were established in 1962, the same year the program began a series of name-and-mission changes. Having merged with Materials Science in 1962, the Department of Engineering Physics and Materials Science reverted in 1965 to Engineering Physics; became the Department of Applied Physics in 1968; and finally the School of Applied and Engineering Physics in 1971.

The seventeen pioneering freshmen who embarked on a five-year engineering physics degree program in 1946 (the same year the five-year requirement, which began with chemical engineering, became uniform across the College of Engineering) certainly benefited from individual attention and a favorable faculty–student ratio.

Soon the school developed a reputation for attracting the best and brightest; by 1962 university historian Morris Bishop called engineering physics “the hardest on the hill” and said its students were regarded by other Cornellians as “intellectual supermen.” One of the first, Leonilda Altman, transferred from electrical engineering, thrived in the engineering physics program, and went on to graduate study at MIT.

Hartman questioned the super-scholar designation (while calling the Engineering Physics curriculum “the most rigorous in the College of Engineering, if not the university”). But a faculty member since 1989 and director, from 2000 to 2007, of the school with a still small-but-bright undergraduate contingent speaks in awe: “They are ferociously smart, they work very hard, they’re very talented, and we faculty members are very fortunate because they make teaching and advising a wonderful experience,” said Joel D. Brock.

“We do have the smartest students in the engineering college,” based, at least, on GPAs (grade point averages) after two years in the college’s core engineering curriculum, “and that’s what you dream of as educators,” added Brock.

Brainy athletes from AEP include Meredith “Flash” Gourdine ’53, the inventor, and Derrick Harmon ’84, the San Francisco 49er. (See “Putting Physics to Work,” page 75.)

Recipients of the Ph.D. in applied physics are expected to demonstrate competence in five major study areas: applied mathematics, classical mechanics, electrodynamics, statistical mechanics, and quantum mechanics. About half the Cornell Ph.D.s in applied physics find
jobs in industry, while the remainder go to work in national laboratories or research institutes, or assume postdoctoral and faculty positions in universities.

The one-year master of engineering program in engineering physics requires a core curriculum in three areas—applied quantum mechanics, statistical mechanics, and applied mathematics, with electives in applied physics, computer science, engineering, and biotechnology—and a research-and-design project. One thing that distinguishes the engineering physics master’s degree from most others in the college is the expectation for an individual research project. While most engineering master's students join teams of fellow students to collaborate on joint projects, each engineering physicist does it all, herself or himself—with guidance from faculty members and postdoctoral researchers.

Opportunities for research affiliations with the school’s faculty members span applied physics. Alexander L. Gaeta, for example, a faculty member since 1992, experiments with intense and rapidly pulsing (femtosecond) laser light in optical materials and fibers, such as photonic nanowires. Then he puts on the brakes with optical delays to examine the applications of so-called “slow light” in telecommunications and computing.

Manfred Lindau, a specialist in cellular and molecular biophysics, studies the mechanisms of endocytosis and exocytosis (the motion of the contents of cell vacuoles in and out, respectively, though cell membranes). Lois Pollack and associates in her lab work on RNA folding, electrostatics and DNA, and protein conformational dynamics.

Robert A. Buhrman, a faculty member since 1973 and a former director of the school, was a charter member and associate director of the original National Research and Resource Facility for Submicron Structures at a time when he was studying high-temperature superconductor films and Josephson junction SQUIDs (superconducting quantum interference devices). He still works in high-temperature superconductivity, while trying to advance a “hot” application of nanomagnetics—spintronics—that could lead to quantum microchips.

Seemingly Impossible Problems

Buhrman’s lead professor when he earned his doctoral degree was Watt W. Webb, a metallurgist who left industry (Union Carbide) in 1961 to join the Cornell faculty. Subsequently, he applied physics to even more problems than Frederick Bedell had attempted. An undergraduate researcher helped Webb design the first intrinsically stable superconducting magnet, the basis for nuclear magnetic resonance imaging and for the niobium superconducting magnets in Cornell’s synchrotron and similar facilities.
THE PRIDE OF CORNELL ENGINEERING

PUTTING PHYSICS TO WORK

Millions of dust particles danced in the shaft of late-afternoon sun as a teenaged Meredith Gourdine (1929–98) pushed the janitor's broom. The lanky high school junior—who had yet to acquire the nickname “Flash,” in reference both to his running speed and to comic book character Flash Gordon—longed to join his classmates, outdoors, on the athletic field.

One of two notable African-American student-athletes to come from New York City schools to Cornell Applied and Engineering Physics (Derrick Harmon ’84, from Bayside High School in Queens to the San Francisco 49ers, via Cornell AEP, was the other), Gourdine needed a fatherly nudge to make the grade.

“If you don’t want to be a laborer all your life, stay in school,” Gourdine’s father said. The janitor and painter was glad to have his son accompany him on the job—weekends and after classes at Brooklyn Technical High School—but he worried that a youthful work ethic was getting in the way of homework.

Advice well taken: young Gourdine put down the broom and paint bucket, hit the books his senior year, and found time for athletics. Standout performances in swimming and track and field earned the BrooklynTech lettermen a scholarship bid from the University of Michigan, an offer he declined.

Instead, Gourdine’s aptitude for math and science got him into the then-new engineering physics program at Cornell, where the six-foot-tall, 175-pound athlete excelled in multiple events for the league-leading Big Red track team. Here is one breathless account from the Cornellian (yearbook) of 1952, the year Gourdine went on to the Olympics in Helsinki: “Gourdine, one of the day’s main stars, tied the Cornell record and set a heptagonal record by winning the 220 low hurdles in 23.2, won the broad jump with a 24’ 3 3/8” leap, and though later requiring six stitches as a result of being spiked on the first turn, set the winning relay team off ahead.”

Cornell won the “Heps” that year, but Gourdine’s Olympic silver medal (7.53 meters in the long jump, while another American, Jerome Biffle, went an inch and one-half farther) was a personal disappointment. He said: “I would rather have lost by a foot.” Gourdine came back to Ithaca, finished the five-year bachelor’s degree in 1953, served in the Navy, completed a Caltech physics Ph.D. in 1960, and commenced a career of—if not manual labor—hard work and invention.

Many of the more than two dozen patents from the R&D companies he founded (Gourdine Systems in New Jersey, then Energy Innovation, Inc., in Texas) were based on electrostatic and electro-gas-dynamic phenomena. The principle behind electrostatic precipitation (negatively charged airborne particles fall to the ground) was used in Gourdine’s patented “Incineraid” system to remove smoke from burning buildings, fog from airport runways, and dust from indoor spaces.

Electrostatic precipitation also found applications in printers for acoustic-imaging devices and for industrial painting. His “Focus Flow” heat sink removed heat from computer chips, and many of his later innovations aimed to improve efficiency of heating, cooling, and energy transfer.

Before his death (at age 69, from side effects of diabetes), he served on the university’s Board of Trustees and the Engineering College Council, and saw his name perpetuated, in 1976, in the Meredith C. Gourdine Awards for minority students at Cornell. Especially cherished was the opportunity to officiate at Heptagonal track meets.

Diabetes had cost Gourdine his eyesight and one leg, but he continued to lead his Houston-based company while advocating for education. His father’s advice (about school and manual labor) still applied, Gourdine insisted again and again, even though the son’s invention (electrostatic air cleaning) eased the labors for janitors everywhere.
Then came fluorescence correlation spectroscopy—from the laboratory led by Webb—as he continued to push the physical limits of resolution in space, time, and sensitivity with improved methods for nanoscopic molecular tracking and nanostructured molecular dynamic probes. According to Webb, the solution of “seemingly impossible experimental problems” drives the creation of new experimental technologies. One key technology, multiphoton microscopy—developed by Webb and Winfried Denk, Ph.D. 1989, one of his more than 45 Ph.D. students over three decades at Cornell—was first used in biological studies, where it produced high-resolution, three-dimensional images without damaging living tissues. Now the technique is poised to move to a more applied field, medical imaging, with the promise of “optical biopsies” at the microscopic level.

Endoscopes that can bring Webb’s multiphoton microscopy wherever in the body it is needed are one of many projects for Chris Xu, an engineering physics faculty member since 2002 and an M.S. and Ph.D. graduate of the program. Besides biomedical imaging, Xu also works on optical instrumentation and optical communication problems. Moving from new concepts and devices to the design of full-scale systems, Xu engages both in numerical modeling and experimental investigations—often with industrial partners that have capabilities for fabrication of specialty fibers and optoelectronic devices. Those industry connections assist Xu in
another role, as coordinator of the Engineering Physics Cooperative Program.

A 1980 Ph.D. graduate, Harold G. Craighead returned to Cornell from research positions in industry to lead the university’s education and research programs in nanofabrication methods and the application of engineered nanosystems. He heads one of Cornell engineering’s most active research groups, with studies in five areas: nanomechanical systems; single-molecule studies; biosensors, microfluidics, and chemical analysis; surface patterning for biological applications; and nanofabrication, nanomaterials, nano-optics, and electron transport. In addition, Craighead is a multititled administrator: he was director of Cornell’s National Nanofabrication Facility (1989–95), director of the School of Applied and Engineering Physics (1998–2000), interim dean of the College of Engineering (2001–02), and founding director of the Nanobiotechnology Center.

Attogram Attaboys

After all those ponderous titles, a featherweight accolade was a welcome relief. The 2006 Guinness Book of World Records credited Craighead and research assistant Rob Ilic with the “lightest object weighed.” As reported in the Journal of Applied Physics, Craighead and Ilic used changes in the vibration of a nanoscale oscillator to detect the mass of a single E. coli bacterium: 6.3 attograms. For the record, an attogram is one-thousandth of a femtogram, which is one-thousandth of a picogram, which is one-thousandth of a nanogram. A nanogram is a billionth of a gram.

Among other engineering physics faculty–researchers are Lois Pollack, whose laboratory studies self-assembly and folding of biological macromolecules; Vaclav O. Kostroun, a faculty member since 1970, whose research with highly charged ions has relevance in everything from astrophysics and thermonuclear-fusion plasmas to the fabrication of semiconductor devices and nanostructures; and Terrill A. Cool, whose research in chemical physics and combustion diagnostics aims for real-time continuous monitoring of toxic emissions from solid-waste incinerators.

Another traveler on the frequently traveled career path—Cornell to Bell Laboratories and back to Cornell—was Frank Wise. He returned in 1988 to develop femtosecond-pulse lasers and amplifiers, but he also studies the electronic, optical, and vibrational properties of the semiconductor crystals known as quantum dots. Wise, who became the director of AEP in 2007, advocates the use of quantum dots as fluorescent labels in biology and medicine.
Another EM Pioneer

Long-time faculty member (since 1961) and two-time director of the School of Applied and Engineering Physics, John Silcox pioneered development of the scanning transmission electron microscope (STEM)—coupling atomic-size electron beams with electron spectroscopy to examine processes at the atomic scale—one atom at a time. The price tag on such a machine, equipped with quadrupole and octupole magnetic “lenses” to correct spherical aberration, as well as video systems and other bells and whistles, is around $2 million. Fortunately, part of the tab for building and installing the next-generation STEM in Duffield Hall was borne by the National Science Foundation—in recognition of where important advances in STEM research began.

David A. Muller (another follower of the Cornell–Bell–Cornell path and a 1996 Ph.D. student of Silcox) uses the super STEM, with its atomic-scale electron-energy-loss spectroscopy, to determine the fundamental physical limits on device scaling. By removing oxygen atoms from layers in thin films of the oxide, strontium titanate, for example, Muller can precisely control the conducting ability of materials by creating empty spaces: the vacancies themselves act as electron-donating dopants, Muller and a University of Tokyo collaborator discovered, and the STEM tells exactly where the material’s missing atoms came from.

Location, Dislocation, and the Physics Bond

Exactly where to locate engineering physics was a contentious issue in the late 1940s, according to AEP historian Hartman. The engineering dean, Solomon Hollister, wanted the program on the new campus with the other engineering disciplines, while most of the engineering physicists wanted to stay near their physics colleagues. The physics
“bond” was stronger, although two related programs—materials science and nuclear engineering—moved to Bard Hall and Ward Laboratory, respectively, on the engineering quadrangle.

The engineering program that arose from Rockefeller Hall’s physics department now has research and teaching collaborations across the campus. Lately, the school’s biological physicists tend to do a lot of work with the university’s life scientists. Biophysicists who need a protein to do folding experiments, for example, can collaborate with molecular biologists whose specialty is generating specific proteins. Another node in engineering physics’ growing network of collaborations is the recently established Institute of Cell and Molecular Biology, which comes alive in the university’s life sciences technology building, Weill Hall.

Those kinds of interdisciplinary links are especially important for graduate students, because Cornell’s full-spectrum perspective is nearly unique among the small peer group of engineering physics programs at American universities. When prospective graduate students discover that at Cornell they can have a chemist, a physicist, a computer scientist, and a molecular biologist working together on a problem they are interested in, it makes recruiting much easier. Now that government funding agencies favor interdisciplinary research, Cornell’s capabilities make grant writing a little easier, as well.

Watt Webb agrees with colleague Brock and with a former colleague, the late Paul Hartman, about the attraction of cross-disciplinary opportunities in engineering and the sciences, but he is even less hesitant to proclaim: “We get the very best students in engineering, and our graduates have always been in strong demand.”
Engineering Physics Pride

Webb is thinking about graduates like Malcolm Beasley (B.S., 1962, Ph.D. 1968). As an undergraduate, Beasley helped with Watt’s first big achievement soon after the young professor switched to academia from industry, the invention of the first intrinsically stable superconducting magnet. That was pretty heady stuff for an undergraduate, and it started Beasley on a career path. Low-temperature condensed-matter physics and superconductivity continued to be Beasley’s research focus as he rose through the ranks to become a professor of engineering physics, chair of Stanford’s Department of Applied Physics, and the dean of the School of Humanities and Sciences at Stanford.

Not every would-be engineering physicist stayed the course. One such example is Robert F. Engle III, the 2003 Nobelist in economics. Aiming first for a master’s degree in physics, Engle studied quantum mechanics with Hans Bethe and worked in Webb’s lab, doing low-temperature physics. “Watt Webb was a great advisor with lots of insight and creativity,” Engle said in his autobiography, “and the study of superconductivity was certainly exciting.”

But partway through the first year, Engle began to realize “that [he] did not want to spend the rest of [his] life as a physicist.” He crossed East Avenue and knocked on the door of Alfred Kahn, chair of the Department of Economics. Another prospective graduate student had just turned down a prestigious fellowship to study economics at Cornell.

His head was spinning, but Engle decided on the spot to accept the economics fellowship. Then he had to break the news to Webb and to his father and Cornell alumnus in chemistry, Robert F. Engle Jr. “My father trained me to be a scientist and now
I was leaving for one of those ‘soft’ science fields,” Engle remembered. “At that point, neither he nor I realized how important all that scientific training would be in my contributions to economics.”

But Webb is equally proud of another graduate, David R. Fischell, who started in Cornell engineering physics—earning a bachelor’s degree in 1975, a master’s in 1978, and a Ph.D. in 1980—before applying physics to medical problems. The oldest son in a family of inventors, Fischell came up with the first radioisotope cardiovascular stent, now known as Johnson & Johnson’s BX Velocity Stent, and started biomedical companies of his own.

Fischell, the object of Cornell engineering physics’ pride, returned the compliment when he agreed to serve on an advisory board—not for engineering physics but for one of the departments the physicists count as close collaborators, the new Department of Biomedical Engineering. That’s fine with Webb, who gets plenty of advice (and accepts it graciously) because now he’s busy trying to apply what started as a physics-based biology tool, multiphoton microscopy, to medical problems: “Now I have to go back to what I was doing in my teens and early twenties, and that’s engineering.”

At New York City’s Weill Cornell Medical College—another collaborator with engineering physics in Ithaca—more than two dozen surgeons and diagnosticians are anxiously waiting for multiphoton microscopy to go endoscopic, Webb said. “That’s development and product design, and I haven’t done that for a long time. Product development is at least ten times as hard as the original laboratory science.”

That’s why one physicist is glad to be in the company of engineers.
They used to call themselves ag engineers (and long before that, farm mechanics), but times have changed, and so have students in the renamed and reinvented Department of Biological and Environmental Engineering.

Today Cornell’s biological engineers learn to work with human, animal, and plant systems to improve medical devices and diagnostics, develop safer pharmaceuticals, explore biobased industrial products, and enhance the world’s food supply—while preserving natural resources and the environment.

Cornell’s environmental engineers, while sharing some of the same lectures and laboratories with the biological engineers, learn more about the biological, chemical, ecological, economic, hydrological, physical, and social processes involved in balancing society’s material and energy needs with the desire for sustainable environmental quality.

Students in the Department of Biological and Environmental Engineering, whichever major they choose, have solid backgrounds in the sciences, mathematics, and computation—and a chance to explore their options in a required class called “The BEE Experience”—before beginning to specialize. Classes like “Molecular and Cellular Bioengineering” prepare would-be biological engineers to work within their domain; “Environmental Systems Analysis” or “Sustainable Energy Systems” give environmental engineers insight into life at the planetary scale.

Agriculture isn’t out of the picture; the department is still firmly rooted in Cornell’s College of Agriculture and Life Sciences, after all. Rather, today’s biological and environmental engineers view agriculture—along with other complex human endeavors—in a much larger context.
For water-resource engineer Michael F. Walter, it took a devastating storm (Hurricane Agnes in 1972) to raise his sights above the individual farm and its drainage problems to reconsider his profession’s impact on water on a larger scale. Norman R. Scott, chair when it was the Department of Agricultural Engineering, has a similar story of shifts in career focus. So do other long-term faculty members, such as J.-Yves Parlange, who once participated in the original study of the wing of the supersonic Concorde airplane and now is concerned with how erosion takes place in the landscape and how water flow can be unstable in the soil and flow in unsaturated soil as near saturated columns.

Cornell’s Department of Farm Mechanics in 1907 changed to Rural Engineering in 1913, Agricultural Engineering in 1930, to Agricultural and Biological Engineering in 1987, and to the current Department of Biological and Environmental Engineering in 2001. It continues to change its educational offerings, its research focuses, and its public service to reflect the evolving needs and expectations of an ever-expanding constituency. Take, for example, the careers of the two agricultural-engineering educators whose names top the doorway to BEE’s headquarters building, Riley–Robb Hall.

Gas Engine Riley’s Epiphany

Howard Wait Riley (1879–1971) was a Cornell-educated mechanical engineer hired by College of Agriculture Dean Liberty Hyde Bailey to develop educational programs that would apply engineering “to improve the life of rural people.” With a background in mechanical engineering and the charge of establishing the Department of Farm Mechanics, “Gas Engine” Riley’s answer to better rural life was the mechanization of farm practices by means of the internal-combustion engine. Many of the courses (like “Dairy Mechanics”) that he taught during his forty-year tenure on the faculty took a decidedly mechanical approach to problem solving.

Riley’s epiphany came while pondering the effects of an early twentieth-century improvement to rural living—running water in the home. His solution for safe disposal of household water was a new design for the concrete septic tank. Loading a truck and
trailer with demonstration equipment in the summer of 1920, Riley toured New York state in a 3,500-mile road show to teach new methods for sewage disposal for farm homes.

Byron Burnett Robb (1882–1961), an agricultural engineering faculty member for thirty-seven years and department chair for three, pioneered the extension of Cornell research to the agricultural community. Robb was known for his exceptional ability to translate technical subject matter into “the farmer’s language.” The series of Cornell Cooperative Extension bulletins written or edited by Robb set the national standard for understandable and authoritative information in agricultural engineering.

Laborsaving Devices and How to Use Them

Thirty-eight-year faculty member Forrest B. Wright (1896–1991) anticipated changes in rural America by writing science-based instructive books like *Electricity in the Home and on the Farm* (1935) and *Rural Water Supply and Sanitation* (1939). He then invented equipment to use those resources, such as machines for automated egg handling, washing, and drying.

Another effective extension educator was Fred G. Lechner (1915–83), whose published bulletins and radio broadcasts told farmers about innovations in farm shop

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**SO THEY SAID**

SOMETHING USEFUL

“Most folks like to make things and the satisfaction which comes through having constructed something useful has great recreational value.”

Louis M. Roehl, 1923

There was a time when broken things could be fixed—given the proper tools and know-how. American farmers in the 1920s and ‘30s got the know-how and guidance on which tools to acquire from a book by Cornell’s Louis M. Roehl that would become a classic, following its publication in 1923.

*The Farmer’s Shop Book* went through nine subsequent editions and sixteen printings. It was filled with plain-English instruction, measured drawings of what Roehl called appliances (such as the “Rack for Chisels, Screwdrivers, Countersink, Wood Files & Nail Sets,” made from a scrap of wood) and photographs of the finished products in their farm shop settings. Near the end were plans to build the shop itself, as well as thorough treatments of “Ropework and Tackle Blocks” and “Harness Repairing.”

“With the decreasing number of harness makers and blacksmiths in rural communities and the increased cost of having carpentry work done,” Roehl explained in the book’s introduction, “it is growing more and more imperative to have a farm shop on every farm to make it possible for farmers to do at home much of the work which was formerly done by these artisans.”
practice, welding, and gasoline-engine maintenance. Adept at developing mechanical solutions to agricultural needs, Lechner could easily switch gears when needs changed. As farmers began to grow more crops “under glass,” he turned his livestock feed-distribution system into an automated plant grower. Rotating shelves carried potted plants through lighting and watering cycles, with their movement periodically adjusted for the day-length regimens of different crops. Both inventions won prizes for agricultural-engineering innovation.

Corrosion research by Burton Aaron Jennings (1895–1964) set the American Society for Testing Materials standards for farm fencing and metal roofing materials. But when the United States entered World War II, Jennings turned to educating agricultural engineers who traveled the state for the War Emergency Farm Machinery Repair Program and kept the tractors running.

John W. Layer (1927–75) improved controlled-atmosphere storage systems for fruit, potatoes, onions, flowers, and other crops, and wrote the extension bulletin “bible” on the subject, Farm Refrigerated Storages, before amyotrophic lateral sclerosis (Lou Gehrig’s disease) cut short his career.

Edward W. Foss (1914–88) was a prodigious inventor of laborsaving devices for farm woodlots (the logging arch, fence post sharpener, portable sawmills, firewood bundler, and a combination delimber and debarker). Then he became concerned about the high rate of injury and death from farm accidents and started both the Farm Tractor Certification Program for youth and one of the first agricultural engineering safety courses for college students.

The first ever Ph.D. in the profession of agricultural engineering was awarded in 1917 to a Cornell student, Earl Archibald White, whose thesis was entitled “A Study of the Plow-bottom and its Action on the Furrow Slice.”

**Rural Community Development**

Howard Riley was one of the charter members of the American Society of Agricultural Engineers, which was founded at a meeting in Madison, Wisconsin, in 1907, the same year Cornell’s BEE department was established. At that founding meeting, Riley identified the five most pressing areas in need of support by the new profession. One of these five was providing access to marketing centers by improving local roads. As part of the department’s extension program, Riley, Howard Robb, and other early faculty members focused their efforts on soil conservation, water management, farm structures, and machine mechanization as well as local transportation. Conferences were organized for county and town highway superintendents in 1938 and 1940, but it was following World War II that the Cornell Local Roads Program was established to provide comprehensive applied research and extension support. The CLRP currently offers dozens of workshops each year to more than 1,000 local highway officials. A highlight of the CLRP is its Highway School, which has 700 to 800 attendees and has been held annually for 63 years running. The program was started by James Spencer in 1947, who was succeeded in 1973 by Lynne Irwin, who has led the program for 35 years. Spencer moved to CALS associate dean and Cornell vice provost positions prior to his retirement.
Engineering Goes Global

Decades before a Cornell president coined “transnational” to describe the university’s breadth of outreach, Cornell ag engineers were broadening the extension mission to the world.

Alpheus M. Goodman (1885–1956), half the Cornell team behind the Fairbanks–Goodman ventilation system for dairy buildings, worked to control malaria and increase agricultural production in British Guiana, Cuba, the Dominican Republic, Haiti, the Philippines, Tobago, and Trinidad. Clesson Turner (1908–2001) and William F. Millier (1922–2002) further improved upon and elucidated the rationale of the slot-inlet ventilation system that led to its widespread adoption for environmental control in animal structures worldwide. The system was recognized as an ASAE (American Society of Agricultural Engineers) Historic Landmark in 1998.

Collaborator Frank L. Fairbanks (1884–1939) stayed closer to home in his development of illumination and air-handling systems for farm buildings.


Work in Peru and the Philippines by Joseph K. Campbell (1927–97) led to his Dibble Sticks, Donkeys and Diesels, a practical guide for appropriate technology transfer and sustainable agricultural mechanization in developing countries.

Wesley W. Gunkel (1927–2000), who discontinued research in pesticide sprayers to invent an environmentally friendly alternative, the potato beetle vacuum, shared Cornell-developed technologies with Ghana, Nigeria, and the Philippines.

Initially known for creating mechanized fruit-harvesting equipment, Richard W. Guest (1932–97) took his expertise in animal-waste management overseas as a consultant to the World Health Organization on farm sanitation practices.

Paul R. Hoff (1903–74) was a specialist in water supplies, sewage disposal, and heating systems who organized programs for instructors who taught the use of farm machinery in Mexico and rice irrigation and farmland drainage at the Philippines’ College of Agriculture at Los Baños.

Gil Levine was one of several Cornell faculty members to be chosen to participate in a major program to revitalize the University of the Philippines at Los Baños, which was devastated during World War II. A major part of this program was to develop a graduate school at UPLB. In the early 1960s, Levine and his graduate students relocated to the Philippines, where they conducted field research aimed at better water management to improve the production from the new high-yielding rice varieties developed by the International Rice Research Institute, also based in the Philippines. Development of infrastructure support systems to provide inputs, especially water, was essential to the successful use of the new high-yielding crop varieties and the ultimate success of the Green Revolution. The approach Levine used for this research was to pair his students with those of colleagues from social science disciplines to conduct “action research” on operating irrigation systems in real communities. In this way the root cause of biophys-
This early work led to a Cornell course called “Socio-technical Aspects of Tropical Irrigation,” taught by Levine and faculty colleagues in the university’s Departments of Rural Sociology and Ag Economics. Subsequently, this effort propelled several ag engineering graduates to leadership roles in the Sri Lanka–based International Irrigation Management Institute (now known as the International Water Management Institute). Levine, a frequent consultant on water issues to the Ford Foundation, was offered the job of founding director of the institute after the Ford Foundation assembled startup funding. When he declined, the honor went to a former Levine student, Thomas Wickham. Subsequently, many more BEE graduate students became senior researchers, country program directors, and leaders of the International Water Management Institute.

Levine’s approach to international research became a model for the department’s continuing international research programs, including those of Mike Walter and Tammo Steenhuis. Walter spent several years in India helping universities develop research programs aimed at solving system-wide irrigation problems. Steenhuis’s students have done action research in numerous countries in Asia, Latin America, and Africa. He is leading an initiative in Ethiopia at Bahir Dar University that will offer master’s degrees to Africans taught by Cornell faculty members without the students setting foot on the Cornell campus.

A Watershed Event

Back in this country, inappropriate drainage of wetlands took partial blame for many of Hurricane Agnes’ 129 deaths from flooding and $11 billion in damage, particularly in Pennsylvania and New York’s Southern Tier. The fact that cresting rivers had too few natural wetlands to absorb the rainfall made a lasting impression on water-resource engineer Michael Walter. Instead of narrowly focusing on water and soil management for farming, he said, he began to look at the big picture of water quality and flood control: “When I came here [to Cornell in 1974] from the Midwest, I knew a lot about drainage and I thought I could show people in northern New York how they could drain their fields and make production twice as great. Agnes made me realize that probably wasn’t the right thing to do, because agricultural drainage can have a terrible effect on the wetlands and the ecology of the area.”

That is one mistake graduates in the new field of biological and environmental engineering won’t be making, Walter predicts. “They won’t ask, ‘How can I drain this field?’ They will ask, ‘Is it the right thing to do?’ If they still decide to intervene, they know enough to ask: ‘How can I do this in such a way that the neighbors upstream and downstream are not hurt—and that the environment won’t be damaged?’”
What’s the Big Picture?

This change in the outlook of one hydrologist is repeated again and again across the Department of Biological and Environmental Engineering. There is a growing recognition that agriculture interacts with the environment and that integrating biology into engineering helps practitioners of the combined discipline understand how both natural and manmade systems work—and what’s going wrong when they don’t. This interaction of agriculture and the environment has become especially obvious in the Catskills where New York City gets its water. New York City has an agreement with the U.S. Environmental Protection Agency that if they manage the watershed well, the water does not have to be filtered. The department’s faculty members, Steenhuis and Walter, are doing research with graduate students to figure out exactly where the runoff is being generated so that management practices can be targeted to those areas of high runoff. Their work has resulted in changes in farm practices that maintain farm viability while helping to clean up the water.

Waste-management engineering is another example of what Michael Walter calls a more holistic and systematic way of thinking: “Our graduates are not going to go out, as they did at one time, and design a waste-management facility for the city of Philadelphia. They’re more likely to look at the problem holistically and say: ‘Where is the waste coming from? Where is it going on the other side? What is the big picture? How can waste be managed in a sustainable way?’”

The same view guides the department’s work in bioprocessing and renewable energy sources. New ways to convert plants into energy must be not only cost-effective but also must not contribute to global warming and other environmental problems.

For enlightened and enabled practitioners of biological and environmental engineering, Walter says that large-scale dairy farming holds suitable challenge to go beyond merely managing toxic substances after the fact: “We can work in the bioenvironmental area to get in front of the curve before problems are created. I think we can have a dairy farm where there is zero discharge of waste anywhere. Every piece of waste generated on a dairy farm should have an economical and environmentally sound value. That’s turning a problem into a resource.”

As Cornell biological and environmental engineering strives to remain the national leader in education (both U.S. News and World Report and the Gourman Report have placed it as high as number one in the country), undergraduates are already voting with their feet—even if they hadn’t considered the department when they applied to the university. Many undergraduates are on the premed track—hedging their bets while they explore engineering and learn the science they need for medical school. Some premeds stay another year to complete a Master of Engineering degree in BEE. The master’s degree makes them attractive to the pharmaceutical industry, and they can always try for medical school if they change their minds.

Most graduate students in BEE, in contrast, know of the program’s national reputation before they come to Cornell. Ph.D. recipients often have their choice of jobs in industry, government agencies, or academic research and teaching.
A New Kind of Engineer

As the BEE department has undergone its evolution from a mechanical and physical sciences emphasis to a biology-based engineering discipline, research in machine harvesting systems and agricultural structures and their environments received national acclaim. Harvest mechanization research began in the late 1950s. Everett D. Markwardt, Richard W. Guest, and colleagues developed a shake-catch harvesting system for cherries. E. Stanley Shepardson, Gerald E. Rehkugler, and researchers at the New York State Agricultural Experiment Station at Geneva developed a mechanical grape harvester. Rehkugler led the development of mechanical harvesters for cabbage and lettuce; he also worked in ergonomics (human–machine interface) with a particularly significant impact on the development of roll-over protection systems for tractors that have become common to all tractors today. In the mid 1960s, William F. Millier began work on fresh market apple harvesting systems. All of this research clearly pointed to a need for better understanding of the fundamental biological and material properties of fruits and vegetables for which this group led the way nationally.

Beginning in the late 1950s, agricultural structures and their environments became a key research area—from dairy and poultry facilities to fruit and vegetable storages. Landis L. Boyd, Wilmot W. Irish, Ronald B. Furry, Richard W. Guest, and Robert T. Lorenzen contributed to structural design, building layout, and thermal environments for animals and plants. A major focus in the 1970s, directed by Raymond C. Loehr, William J. Jewell, and Douglas A. Haith, was animal waste management, treatment, and utilization. Triggered by energy issues, Jewell developed a nationally recognized initiative using anaerobic digestion systems to manage manures to address then increasing environmental concerns and also produce electricity and heat for on-farm needs.

Now, whichever degree path they choose, BEE students at Cornell gain not only a comprehensive understanding of biology but the skills and strategies necessary to use biology as an engineering tool. One example of putting molecular biology to work in engineering is BEE faculty member Dan Luo’s technology for self-assembling DNA buckyballs that can potentially deliver vaccines and drugs. The director of the Molecular BioEngineering Laboratory, where BEE undergraduate researchers work alongside graduate students and postdoctoral researchers, Luo says he has two career objectives: “To establish biological engineering as a biology-based, core engineering discipline by integrating modern biology with engineering, and to educate a first-rate new generation of biological engineers.”

Luo, who was a postdoctoral fellow in Cornell’s School of Chemical and Biomolecular Engineering before joining BEE, coined the term “nucleic acid engineering” to describe his laboratory’s approach to the protein that evolved—in stick-like strands and circles—to store genetic information. More generic than genetic, Luo’s nucleic acid molecules are engineered into unnatural shapes like Y’s, X’s, and T’s that
become units of directed, self-assembling nanostructures. Further engineering can make DNA nanostructures perform diagnostic functions (the so-called “DNA barcode” process of detecting pathogens and other biomolecules in the human body) and a therapeutic function (multiple drug delivery on engineered DNA hooks and sockets) as well. Using biology, Luo says, has given him tools “at the molecular level, such as enzymes, to design DNA molecules in a true engineering sense” with exacting control over shape and architecture.

Ecohydrologist M. Todd Walter was hired into the department as part of a university-wide biogeochemistry and biocomplexity initiative. His growing program is an example of the emphasis on linking ecological and physical sciences to issues such as human impact on ecosystem services. He has teamed with Luo in the use of the DNA barcode as a innovative tool to study hydrologic flow paths and the movement of pollutants.

Biology for Chickens, Math for Cherries

Thirty years before bioengineer Luo began in BEE, Norm Scott brought a distinctly biological perspective to agricultural engineering. He took up Cornell ag engineering’s tradition of innovation in animal-housing ventilation by making thousands of chickens more comfortable. Scott’s thermoregulation experiments asked chickens about their preferences. (See “Peck for Heat,” page 92.) He also developed earth–air heat exchangers with underground pipes to cool poultry house air in the summer and warm it in the winter.

Meanwhile, J. Robert Cooke, a faculty member since 1966 tried to bring more precision to the mechanical harvesting of fruit. Cooke knew of his predecessors’ efforts (including William F. Millier’s mechanical fingers that combed fruit from trees and a brute-force clamp that shook apple trees until the fruit fell), and he added mathematical analysis to the equation. Each piece of fruit—swinging from its stem as the tree swayed back and forth—experienced a double-pendulum effect, Cooke determined. By changing vibration frequencies of the fruit trees, Cooke learned how to selectively harvest cherries—with or without the stems.

Scott’s earth-tempered ventilation system worked well enough for the chickens, but eventually most of the state’s poultry-farming industry moved to southern states. As a statutory unit of the College of Agriculture, the Department of Agricultural Engineering tried to help New York state farming. (Another ag engineering faculty member who had worked on poultry problems, Michael Timmons, switched to aquaculture to develop indoor fish-farming systems for New York and other northern states.) Scott refocused his bioengineering studies on an industry that has managed to hold its own in New York, dairy farming. He developed the ultrasonic milk-flow meter that measures squirt-by-squirt production, and then a series of patented estrus detectors that tell farmers when to artificially breed cows.
ONLy i N iTHACA

PECK FOR HEAT

In Norm Scott’s “peck for heat” study in 1970, the major objective of the work (supported by the NSF and NIH) was to develop an understanding of thermoregulation of homeotherms (those animals that are able to maintain a constant body temperature). The thermoelectric gradient layer calorimeter made it possible to study thermoregulatory physiology through measurement of the chicken’s energy balance (heat loss and heat production) while carrying out heating and cooling of the hypothalamus and spinal cord and measuring other physiological parameters such as body and skin temperatures and heart and respiration rates.

David L. Ludington contributed to energy savings and electrical safety in the agricultural industries. Ludington, Daniel J. Aneshansley, and others patented a dual-vacuum system and variable frequency drive for dairy vacuum systems. This reduced energy use of vacuum pumps by 50 percent or more and provided significant savings to farmers. Ludington and Aneshansley collaborated on measurement techniques for livestock facilities that determined the safety of the electrical environment for workers and livestock. Scott, Ludington, and Aneshansley also assessed the effects of stray voltage, which had become a major issue for many dairy farmers.

Toward Truly Sustainable Agriculture

Now, after time out to serve as the university’s vice president for research, Scott is back on the farm with the Cow Power project, studying the potential of biogas energy con-
version. The potential of fuel cells on dairy farms, Scott hopes, could be a 20 percent increase in profitability and at least a 25 percent reduction in farm waste that pollutes the environment—a major step toward sustainable farming.

Sustainable energy sources have long been a goal for another BEE faculty member, Larry P. Walker, director of the fourteen-state Northeast Sun Grant Institute of Excellence, which aims to increase the use of plant biomass for fuels and chemical production. Walker’s ongoing research into biofuels (from plant materials, such as corn and grasses, and from animal waste and other organic wastes) was hardly the first at Cornell. He points to the pioneering work of William J. Jewell, whose biomass research on anaerobic digestion for methane production was underway when Walker joined the faculty more than twenty years ago.

The fruits of Walker’s laboratory research have a short trip to the classroom in classes such as BEE 7880, “Biomass Conversion of Energy and Chemicals.” When Walker isn’t teaching, brewing biofuels, or running the Northeast Sun Grant Institute of Excellence, he’s collaborating in Dan Luo’s nucleic acid engineering lab, trying to turn DNA into nanofabricated devices to track microbes through high-solids degradation processes.

These are examples of Cornell biological engineering today, but the definition has changed nearly as often as the department’s name, Walter and Scott agree. As early as the 1960s, Cornell agricultural engineering was getting National Institutes of Health grants for biological engineering, said Walter: “But in those days it was the engineering of biological systems.”

Bringing Life to Engineering

“One of the first of the new generation,” says Scott, “was Ron Pitt, who joined the faculty in 1980 when a department was moving toward a name change.” Pitt initiated a new course, “Introduction to Biological Engineering.” That course was followed with another new course developed by Ashim Datta in biological and environmental transport processes. Jean Hunter taught “Bioseparation Processes,” Scott recalls, and she helped develop a recommended course list so that students who wanted to become biomedical engineers could concentrate on genetics, physiology, and biomechanics—rather than take just engineering courses.

Today, Hunter focuses part of her research on enzyme and microbial engineering for fermenters that reclaim food and agricultural wastes. She teaches “Bioengineering Thermodynamics and Kinetics” as well as “Bioseparation Processes.”

Cooke, who brought mathematical principles to the orchard, brought mathematical models to BEE classrooms with courses like “Biological Engineering Analysis.” He says the new biological dimension “lends a special challenge and excitement to research in agricultural engineering.” But his research was on a more basic level—plant physiol-
ogy and the role of gas exchange in photosynthesis. Ever the engineer, however, Cooke adds: “My research in fundamental issues might provide a more rational approach to equipment design and perhaps even a redesign of the plants.”

A renewable energy design by the late Wesley Gunkel—in which wind turbines rotated paddles in a closed container until the water got hot enough for farm applications—never really took off. But today’s BEE students can help improve technologies with classes like “Renewable Energy Systems,” taught by Louis Albright.

Albright pioneered development of Controlled Environment Agriculture (CEA) systems that led to commercialization of the CEA system to produce high-quality lettuce and other plant crops using hydroponics. Challenge Industries, a local nonprofit organization that provides vocational services to adults with disabilities, took over management of Albright’s original CEA greenhouse to produce lettuce for nearby supermarkets. These successes were the result of extensive research in plant environmental relationships of light, temperature, relative humidity, and nutrients, leading to the ultimate development of a computer algorithm for greenhouse management and control.

In addition to his biomass conversion class, Larry Walker also teaches “Industrial Ecology of Agricultural-Based Bioindustries.”

Antje Baeumner teaches “Principles of Biological Engineering” as well as “Biosensors and Bioanalytical Techniques.” This course builds upon Bauemner’s research at the nanoscale level of biotechnology. Special emphasis is on analytical biotechnology to develop innovative biosensors for detection of hazardous biological and chemical substances in the environment (pathogenic microorganisms, pesticides, and natural toxins), in food, and in medical diagnostics.

Ashim K. Datta teaches BEE 3500, “Biological and Environmental Transport Processes.” Datta’s research focuses on the application of transport phenomena (for example, energy and water transport, fluid flow) in biological processes in an effort to better understand their complexities with the intent of improving them through optimization in two broad application areas—industrial food processing and medicine.

Michael Timmons teaches “Principles of Aquaculture” to Cornell students, while participants in his classes for the general public are building an indoor fish-farming industry. For college students, he also teaches “Engineering Entrepreneurship, Management, and Ethics.”

William Jewell taught “Environmental Management” and another course called “Ecological Engineering,” which he defines as “the language of sustainable living.”

If BEE students want to learn more, “Science and Engineering Challenges to the Development of Sustainable Bio-Based Industries” is taught by Beth A. Ahner. She employs environmental biotechnology to explore how organisms adapt to trace metal stress in the environment and how they in turn influence the form of metals in the
environment—for example, how plants solubilize, take up, detoxify, and sequester metals and how plants can be used to remove metals from contaminated soils.

Norman Scott teaches “Sustainable Development” both as a seminar and as a web-based course.

No one teaches tractor maintenance anymore, and the word “mechanic” turns up only once, in BEE 3310 “Bio-Fluid Mechanics,” taught by Kifle Gebremedhin. There’s still a lot to learn from the natural world, so it seems. Gebremedhin, in addition to his research in animal environments, made important contributions to analysis and design of two-dimensional and three-dimensional structural systems, including diaphragm principles that have been widely applied in wood frame structures.

“We used to have a motto,” said Walter. “We used to say, ‘This is the department that brings engineering to life.’ I hope the future motto will be, ‘This is the department that brings life to engineering.’”
The list of courses for the newly created undergraduate minor of biomedical engineering in Cornell’s College of Engineering looks a lot like a medical school curriculum, with titles like “Genetics,” “Orthopedic Tissue Mechanics,” “Principles of Neurophysiology,” and “Principles of Biochemistry: Proteins and Metabolism.” But read further through the list—to courses like “Properties of Biological Materials,” “Nanofabrication,” and “Computer-Aided Engineering”—and it becomes clear: biomedical engineering is at the exciting three-way intersection of biology, medicine, and engineering.

The Department of Biomedical Engineering went through a thirty-plus-year gestation period, and had more than just two parents. Biomedical engineering (BME) became a program in April 2001 and a full-fledged department in July 2004. But BME’s founding chair, Michael L. Shuler, who also serves as the S. B. Eckert Professor of Chemical Engineering and the James and Marsha McCormick Chair of Biomedical Engineering, cites important work in the field in several Cornell departments as far back as the mid 1950s.

Shuler, who joined the faculty of the School of Chemical Engineering (now Chemical and Biomolecular Engineering) in 1974, points to the work of then-faculty members Robert K. Finn, Kenneth Bischoff, and James Stevenson: “Jim’s work on the artificial kidney and biomaterials like collagen would be called biomedical engineering today. So would Ken Bischoff’s physiologically based pharmacokinetic models for drug metabolism.”

Stevenson’s work with hollow-fiber membranes involved collaborators across the road from Olin Hall, in the Department of Materials Science and Engineering. In nearby Upson Hall, Donald L. Bartel, the Willis H. Carrier Professor of Mechanical and
Aerospace Engineering, was pioneering computer-aided-design tools to custom-build prosthetic components for joint replacements and bone implants. Bartel’s work in biomechanics fostered a long-standing collaboration with the Hospital for Special Surgery, the orthopedic affiliate of Weill Cornell Medical College.

Cornell graduates who made their mark in biomedical engineering—even though that term was not on their diploma—including Robert Langer, David Lederman, and Wilson Greatbatch. Langer, who earned a bachelor’s degree in chemical engineering in 1970, holds some 500 patents for medical technologies and devices in such areas as controlled drug delivery, biomaterials, and tissue engineering. The recipient of the National Academy of Engineering’s highest award, the Draper Prize, Langer was called “one of history’s most prolific inventors in medicine” when he won the 1998 Lemelson–MIT Prize.

After earning a Cornell Ph.D. in engineering physics in 1966, Lederman led his company, Abiomed, in the development of the first implantable artificial heart. Greatbatch (B.E.E. ’50) earned his place in the Inventors Hall of Fame for the implantable cardiac pacemaker. (See “The Heart of the Matter,” page 171.) A summer job at Cornell sparked his interest in medical devices. Inventions and life-saving technologies continue to flow from the biomedical engineering program. (See “Sparing Trees and Animals, Too,” page 99.)

**Catalytic Reaction in Bioengineering**

In 1993–94, a faculty committee formed by Associate Dean of Engineering John Hopcroft and chaired by Shuler recommended formation of an undergraduate bioengineering option within the College of Engineering. The committee defined bioengineering broadly, but recognized that biomedical engineering was the subset of bioengineering that focused on human health. Cornell bioengineers took a minimum of two science-based

Studies by Claudia Fischbach-Teschl of microenvironmental conditions around tumors might lead to new drug-delivery technologies that fundamentally change the way tumors are treated.
The “animal-on-a-chip” is the work of biomedical engineering department chair Michael Shuler and Ph.D. student Daniel A. Tatosian. It is used to test the efficacy of drug combinations used to treat multidrug-resistant cancers. The one-inch-square chip’s five chambers contain (1) liver cells, (2) normal tumor cells, (3) multidrug-resistant tumor cells, (4) marrow cells, and (5) adipose tissue cells. Cell-culture medium (here stained yellow) flows through the interconnected fluid channels, and is recirculated by an external pump that mimics the action of the human heart.

The patented plant-cell fermentation (PCF) technique used to make the anticancer drug Taxol™ in commercial quantities is the work of Venkataraman “Bobby” Bringi and Chris Prince, who both completed Ph.D. dissertations with Michael Shuler in 1991. At the time, Shuler was a professor of chemical engineering. (Taxol was Bristol-Myers’s trademarked version of the secondary metabolite that protects yews and also prevents cancer cells from multiplying in humans.) Bringi took the process from Olin Hall to the Cornell Business and Technology Park, cofounding Phyton Catalytic (now Phyton Inc.) in 1990. Bringi and Prince, along with cofounder Rus Howard (Cornell M.B.A. 1991), and the other Phycats, as they called themselves, aimed for an environmentally benign and cost-effective way to make Taxol without harvesting trees (the original extraction process required the bark of several 100-year-old Pacific yews for each patient’s Taxol) and without elaborate chemical synthesis processes that left toxic wastes behind.

The Phycats’ R&D diligence paid off in 2002 with a long-term, multimillion-dollar contract to supply Bristol-Myers Squibb with Ithaca-made paclitaxel, the active ingredient of Taxol. The pharmaceutical company got a ready source of one of the most effective drugs against ovarian and breast cancers (and a national “green” award for lessening harm to the environment). Phyton got to go back to work, adapting its PCF platform to discover and produce more compounds with applications in the pharmaceutical, cosmetic, and specialty chemical industries.

While Phyton was growing bigger (It was purchased in 2003 by DFB Pharmaceuticals, Inc.), Shuler was back in Olin Hall, trying to shrink animals’ organ systems to chips the size of postage stamps. Variously called “mouse-on-a-chip,” “body-on-a-chip,” or “the silicon guinea pig,” the concept was to package living tissue with life-support “plumbing” while potential pharmaceuticals were tested—for their beneficial effects or toxicity—without endangering whole animals. In the 1980s, when Shuler first connected pumps and flasks with surgical tubing to test his mathematical models of physiological systems, he realized his organ analogs would have to become much smaller if they were to have a role in the automated, high-throughput pharmacokinetics protocols and in vitro assays that industry was demanding. In 1997 Gregory T. Baxter, a molecular biologist with expertise in microfluidics at Cornell’s Nanofabrication Facility helped Shuler eliminate the bulky glassware and tubing and to sandwich all the silicon reservoirs, living tissues, and “blood surrogate” plumbing into small acrylic packages. By 1999, Shuler was confident enough to call the technology “animal-on-a-chip” and patent applications were filed.

Baxter left Cornell to cofound Hµrel Corporation (with the Greek letter µ in the company name and “human relevance” as its credo). He hopes to make “hurel” the generic term for human-on-a-chip devices. One of the first proof-of-concept tests put human liver cells and colon cancer cells on one hurel to test an anticancer drug that has to pass through the liver on the way to the colon. One potential application is a personalized “you-on-a-chip” for cancer patients facing chemotherapy; alternative chemotherapy agents could be tested for efficacy and side effects on samples of cancerous tissue and healthy tissues—concurrently on the microfluidic chip instead of serially in the patient.

and two engineering-based classes, plus what is now BME 5010, the Bioengineering Seminar. Cornell’s graduate field of biomedical engineering was approved by New York state in 1997 to award the M.S. and Ph.D. degrees. The M.Eng. was initiated in the fall of 2004.

When biomedical engineering became a full-fledged Cornell University department in July of 2004, approximately 100 American institutions had BME programs, some going back thirty to forty years. Shuler predicts that every Top 10 engineering col-
College will embrace biomedical engineering in the next ten years, because it has become “an essential part of how engineers think and how they apply their skills.”

**Growth without Detriment**

Aiming to grow to a full-time faculty of around fifteen, the department had six by the end of its first year, and by 2007 had grown to ten. “It takes time to hire good faculty members because everyone else wants them,” Shuler said. “All the faculty members we hire have other opportunities, and we are usually able to convince them that Cornell is the right place for them.” The few select recruits are joining a department with strong, healthy roots in both engineering and the life sciences. “We are good collaborators,” he said, noting that the forty-six members of biomedical engineering’s graduate field faculty come from thirteen different Cornell departments.

Undergraduates who minor in biomedical engineering (as well as the M.Eng. and Ph.D. students) acquire a quantitative understanding of the human body across all scales—from molecules to cells to tissues to physiological systems. That understanding will facilitate rational design of therapies, diagnostics, and devices to improve human health. Ph.D. students can choose from five areas in biomedical engineering: imaging and instrumentation, biomaterials and drug delivery, biomedical mechanics, nanobiotechnology, or cellular and tissue engineering.

Some undergraduates will consider their biomedical engineering background as preparation for nonengineering careers in medicine, law, or business. Others will enroll in Ph.D. programs. Shuler encourages undergraduates with an eye on the job market to stay an extra year, to attain what he calls “the professional polish” of a Master of Engineering degree in biomedical engineering.

That additional year affords the chance to take applications-related courses and increase technical breadth; to do a 6-credit design project in collaboration with mentors at biomedical companies, at Weill Cornell, or on the Ithaca campus; and to take a capstone course that brings a preview dose of reality to the classroom.

**Reality-Based Education**

The capstone course helps students think about engineering design in the context of FDA (federal Food and Drug Administration) regulations, of healthcare reimbursements, and of physicians as customers, Shuler said. They learn to ask what physicians value in the design of a particular device or therapy, and what makes it easier for them to use to achieve a successful outcome.
“This is the business end of biomedical engineering,” Shuler adds, “and we look at this five-year program as a way to polish professionals who will be attractive to companies where they will be successful in the long term.”

The word must be spreading. Cornell biomedical engineering graduates are being hired by manufacturers of biomedical devices and major pharmaceutical companies, by government laboratories, and by smaller companies that specialize in nanobiotechnology. They are designing new biomaterials and more capable prosthetics, they are creating the next generation of imaging instruments (either by producing physical designs for the instruments or writing software to make them more effective), they are pushing the envelope in tissue engineering, and they are engineering better systems for controlled drug delivery.

The challenges of controlled drug delivery illuminate the difference between biotechnology and biomedical engineering. While biotechnology for medical applications has been oriented toward the production of molecules—such as therapeutic proteins—biomedical engineering traditionally has been associated with devices to deliver these proteins. Diabetics look to biotechnology to make insulin. How insulin is delivered to the body is the concern of biomedical engineers.

**Ink Jet Printers and Tissue Engineering**

Until BME’s consolidated facility opened in Weill Hall, faculty member Larry Bonassar and mechanical engineer Hod Lipson operated out of Upson Hall, where inkjet printers are learning new tricks.

In his administrative office in Olin Hall, Shuler summarizes Bonassar and Lipson’s vision for the future of tissue engineering: “Say I cut off one of your ears. Then I lose it. Sorry about that, but let me make amends by taking a CT scan of your other ear, reversing the scan as a mirror image, and instructing an inkjet printer—with special cartridges, of course—to “print” a cartilage-based ear prosthesis that would look just like the one you lost—one that can be implanted on your head.”

Shuler believes there are now many more opportunities to apply engineering approaches to biology. Problems that no one knew how to attack fifteen years ago are now being solved by biomedical engineers at Cornell and at the research labs where graduates of the new department are needed.
Fundamentals and Fundamental Changes in ChemE: Now It’s Chemical and Biomolecular Engineering

If students venturing into Cornell’s Olin Hall think they’re preparing to design and run big chemical plants, they could be right. But there are more options than ever before in a degree program that is strong in fundamental sciences and mathematics—combined with the practical education of a professional engineer.

They can learn to do what Cornell chemical engineers have excelled at for decades in classes like “Unit Operations,” “Reaction Kinetics and Reactor Design,” “Process Dynamics and Control,” “Chemical Process Design,” or “Separation Processes.” In addition, they can learn bioprocess engineering, biomedical engineering, processing of pharmaceuticals, microelectronics, the intricacies of polymers and other complex fluids, and the promotion of sustainable economic development through responsible management of energy and the environment. All that in four years, from the school that invented the five-year engineering degree at Cornell and showed other engineering fields (and other universities) how to do it.

The five-year degree was reincarnated as a four-year bachelor’s degree—plus the option to add a Master of Engineering degree in two additional semesters—in the mid-1960s. As the school entered the twenty-first century and added “Biomolecular” to its title, teaching changed again.

Learning from the Social Scientists

The first book that comes to hand when Paulette Clancy, director of the School of Chemical and Biomolecular Engineering, reaches across her Olin Hall desk is not a text on thermodynamics or some table-filled technical manual. She picks up How People
Learn, the National Research Council’s blueprint for applying cognitive psychology and other people-based sciences to the practice of education.

“We’re trying to understand—and we’re trying to learn from the social scientists—what it is that helps people learn,” Clancy said. (For one veteran professor’s idea, see “Potent Pictures and Mnemonic Music,” below.) “We’re seeing a massive change.

**SO THEY SAID**

**POTENT PICTURES AND MNEMONIC MUSIC**

“Then you’ve got a number that will see you through, it’ll tell you what the fluid’s going to do.”

*The Reynolds Number Song,* 1970

When magazines like *U.S. News & World Report* rate colleges, the photographs depicting generic engineers almost always show hard-hatted men on construction sites. That outdated image, Clancy said, discourages many an impressionable young woman of high school age from considering the broad range of endeavors that today’s engineers pursue.

Peter Harriott has a better way to inform prospective students of the “best” engineering schools. Instead of asking other academics, who tend to know a school’s reputation from awards won by the faculty (not that Cornell engineers don’t win their share of accolades), Harriott suggests the magazines poll employers of engineering graduates. There is a reason why recruiters return again and again to Cornell—even from distant states with their own accredited engineering schools.

Employers lucky enough to attract Cornell chemical engineering graduates will be getting individuals who are solidly grounded in the fundamentals of their discipline, who are versatile enough to apply engineering principles in a variety of tasks, and who were educated with the latest, most effective methodologies—and who learned one of the fundamentals in a nontraditional way. In 1978, Harriott wrote the “Reynolds Number Song,” which has become a Cornell chemical engineering tradition. He has performed the mnemonic ditty before engineering classes and social occasions, usually accompanying himself on the guitar. (See music below.)

Another veteran educator in Cornell chemical engineering, Julian Smith, who also wrote a history of the discipline at Cornell, arranged the music to Harriott’s lyrics. An audio recording of Harriott singing the “Reynolds Number Song,” with commentary, as well as the Smith history in PDF format, are available in the Engineering History section of the Open Access Repository at dspace.library.cornell.edu.
Not everybody learns by just reading the book, or by the standard ‘You listen to the professor and you transcribe.’ That’s why we experiment and try out other ways of learning. Teamwork and project-based learning are big parts of this, and we’re trying to increase communication skills by focusing on oral communication. We still make them write a lot of reports, but the way we look at these reports is a little different.”

Clancy reflects the value that Cornell has long placed on excellent teaching. The College of Engineering Excellence in Teaching Awards recognize some of the most effective and dedicated faculty members, and the field of past and potential winners is very deep. A number have become legends.

Professor Raymond G. Thorpe inspired students in his chemical and metallurgical engineering classes for nearly four decades. A superb teacher who maintained high standards and told wonderful stories, Thorpe earned numerous awards for his teaching. George F. Scheele, another legendary teacher known for his dedication to his students, was awarded the Excellence in Teaching Award in 1970, the first year it was made jointly by the Cornell Society of Engineers and Tau Beta Pi. A Dow Chemical–sponsored outstanding junior award and an undergraduate study lounge in Olin Hall, both named in his honor, further attest to his impact on students.

In 2007, T. Michael Duncan was selected as New York State’s Professor of the Year, an honor bestowed by the Carnegie Foundation for the Advancement of Teaching and the Council for Advancement and Support of Education. It is one of many teaching awards Duncan has earned, including a Weiss Presidential Fellowship for effective, inspiring, and distinguished teaching of Cornell undergraduates. Duncan is acclaimed for his determination to keep material fresh and relevant to students, while also grounded in the scientific fundamentals of chemistry, physics, and math.

Another Kind of Rhodes Scholar

Peter Harriott remembers the infamous ChemE reports for two reasons: as a student, he struggled through the required class in technical report writing before graduating from Cornell chemical engineering in 1948, and when he returned to teach (rising through the faculty ranks to stay for forty-eight years, and continuing to guest-lecture after retiring with emeritus status in 2001), he took over the course originated by F. H. “Dusty” Rhodes, founding director of the school and author of *Technical Report Writing* (1941).

“One of the traditions we kept for years was Dusty’s method of grading written reports,” said Harriott. “We would grade once for technical content—and maybe we’d give that an eight—but if the English was so poor that you had trouble understanding it, you might give a grade of seven for English. Dusty then reasoned that if 80 percent was correct but only 70 percent of that was understandable,” the student was communicating at a level of only 56 percent $\left(\frac{8 \times 7}{100}\right)$.

Students could revise their reports and try to bring up their grades, according to Harriott, who kept samples graded by Rhodes from his own student days. “I had some 90s but some less than 60, too. We finally decided that that [grading system] was too
discouraging to the students. But some of the older students, our graduates who went through that and had the two grades, remember report-writing as one of the toughest courses they ever took—but one of the most valuable, and they insist that the people who work for them maintain similarly rigorous standards.”

**A Prof Who Published and a Polymer Pioneer**

One chemical engineering professor who held his own in writing was Clyde Mason (1898–1983), co-author (with Emile M. Chamot) of the classic *Handbook of Chemical Microscopy*. Mason joined the school’s faculty as a professor of chemical microscopy

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**ONLY IN ITHACA**

**THE GRANDFATHER OF CES**

“A productive engineer can no longer expect to further his career on ‘boiler codes,’ handbooks, or empirical equations.”

Julian C. Smith, 1967

Nowadays, Cornell offers plenty of distance-learning opportunities for practicing engineers in the workplace—via the Internet. Back in 1966, fifty-five miles of copper telephone wires between Cornell’s Ithaca campus and a Tonawanda, Pennsylvania, division of Sylvania Electric Products Inc. carried voices and “blackboard” notations for a bold experiment in continuing education.

The first use of Blackboard-by-Wire, in teaching a 4-credit course in physical metallurgy, simultaneously, to fourteen Cornell students and to ten engineers at Sylvania’s Chemical and Metallurgical Division, would keep engineering education from becoming obsolete, according to Julian C. Smith. He had been a chemical engineering faculty member since 1946 and was a champion of what he called continuing engineering studies, or CES. In “Obsolescence Rx: CES” in one of the first issues of the college’s *Engineering: Cornell Quarterly*, (Vol. 1, No. 4), Smith said:

> The flowering of large-scale research, which began about fifteen years ago, has hastened the output of knowledge and brought many practicing engineers face to face with obsolescence. A productive engineer can no longer expect to further his career on “boiler codes,” handbooks, or empirical equations. Actually, he never could, but it was easier to keep up when changes were less rapid.

In 1967, Smith—by then a full professor and director of continuing education for the college—had some ideas to make Cornell engineers more numerous and prosperous. He described Blackboard-by-Wire as follows:

The professor does not use a conventional blackboard: he does all his writing while sitting at a desk, drawing figures or writing equations with an ordinary ball-point pen on a six- by eight-inch panel. The pen is connected to a lever arm whose position is sensed electronically, and the resulting signal is coded and appears as an image on a television screen (at the remote location). A similar screen is used for the benefit of the Cornell students, and one is used as a monitor by the instructor. The technique saves much precious time, quite apart from travel. The professor need give his lectures only once; furthermore he is assured that the course he gives off-campus is identical to that offered to regular enrolled students, always an important consideration in offering a credit course off-campus.

Blackboard-by-Wire was developed by a Massachusetts-based Sylvania division, and was briefly tested in the fall of 1966 at Purdue University. Cornell’s 1966 metallurgy class, taught by Robert W. Baluffi, is believed to be the first use of such a system for continuing education.

Today’s distance-learning features wireless modems, touch-screen recognition, and built-in cameras and microphones. But the basic principle hasn’t changed much in four decades. Courses like “Systems Architecture, Behavior, and Optimization” are taught to practicing engineers who never set foot in Ithaca.
and metallography the year Olin Hall opened (1942) after having taught chemistry in Baker Hall since 1924.

Besides Mason’s publishing (such as his 1947 textbook, *Introductory Physical Metallurgy*), colleagues remembered his love of teaching. “I knew from the beginning that I was not a great lecturer,” he said, “so I concentrated on becoming a good teacher. I particularly liked the beginner or struggler.”

That meant Mason liked just about everybody, because his microscopy students did a lot of struggling. “Don’t tell me what the book says,” Mason told eye-weary students as they bent over the microscopes. “Tell me what you see.”

Cornell used video technology to extend engineering education as early as 1959.

Smith went on to teach for a total of forty years at Cornell, serving as director of the school from 1975 to 1983 and guiding Cornell chemical engineering through an unprecedented period of growth—particularly in graduate education and research programs. His 1956 textbook, *Unit Operations of Chemical Engineering* (co-authored originally with Warren L. McCabe and in subsequent editions with Peter Harriott) became an industry standard that was translated into Greek, Indonesian, and Spanish. Smith also served as an advisor to the U.S. government on engineering education, and consulted with several major corporations on chemical-process design and the disposal of nuclear waste.

Two years after Smith became an emeritus professor in 1986, admiring former students from the Class of 1962, together with friends and colleagues, honored him by endowing the annual Julian C. Smith Lectureship.

In his 1967 essay, Smith predicted: “The engineering college of the future will bear little resemblance to today’s model; its structure, staff, and activities will be strongly influenced by responsibilities to continuing education studies.”
The eighty-four-year-old Mason lived to see publication of the fourth edition of his microscopy handbook.

Chemical engineering students from the 1940s remember another professor with a tough grading policy, Charles C. Winding (1908–86). Weekly quizzes in Winding’s chemical process design class were graded with either a zero or a ten—nothing in between—because he said: “An engineering answer has to be right. A bridge that’s almost long enough isn’t worth anything.”

Winding succeeded F. H. Rhodes (1889–1976) as the second director of the School of Chemical Engineering. Despite his prowess as a researcher—Winding was regarded as a pioneer in the field of polymer research, particularly for his work on cellulose acetate—he discouraged faculty research during his term (1957–70) as director. Research, he believed, took away from attention faculty members should be devoting to undergraduate education.

Winding’s 1943 undergraduate course on synthetic plastics was among the first at any American university. He continued to emphasize undergraduate education by leading a fund drive to endow the Fred Hoffman Rhodes Professorship in Chemical Engineering. His former students returned the favor by endowing the Charles C. Winding Scholarship.

Honored as one of America’s “Polymer Pioneers” and as “Educator of the Year” by the Society of Plastics Engineers, Winding relaxed by racing a sailboat in the Thistle class—with “Poly-Mer” painted on the hull. Winding knew that mer is French for sea—and also why Thistle boat-builders switched from the original material (formed plywood) to FRP (fiber-reinforced polymer).

The school’s next director, long-time faculty member Julian C. Smith, co-authored a classic text for chemical engineers and advanced continuing education for the entire college. (See “The Grandfather of CES,” page 106.)

Sink or Swim

In Paulette Clancy’s opinion, some traditions are worth maintaining but some are best remembered and abandoned.

“If someone from the Class of 1945 came back to Reunion and talked to us about their curriculum, they would find many similarities. We still teach a lot of the same fundamentals, but we teach in a different way,” she said. “There was a sense in the early days of Olin Hall that the philosophy was—and I’ve heard this so many times—‘Look to your right. Look to your left. Only one of you will be here to graduate,’ and when I talked to the Class of 1960 at their Reunion, they said it was true—around 150 students had entered as freshmen, but of those only about fifty graduated. That’s not true now.”

What has changed, Clancy believes, is what she calls “a great sense of family that didn’t exist before. People bonded in those early days, all right, because it was for survival. Sink or swim. I think they still bond today, but for a different reason. There’s a real sense of community here that I don’t know that you find anywhere else. Our curriculum is still demanding but the faculty is not so harsh. We want people to succeed and we’re actively engaging them in that.”
Much-improved retention and graduation rates are one measure of success for the teamwork approach. From the feedback she receives, Clancy knows that the quality is not diluted. “The top schools want our students to be their Ph.D. candidates, because they know Cornell chemical engineers are very well educated. Our students report back that they find the graduate courses at places like Stanford and MIT to be relatively straightforward, because they have been so well prepared. That’s our measure. We are educating students who can be top graduate students at any program in the country. I don’t think we’re different [from competing undergraduate programs in chemical engineering],” Clancy said. “I think we’re better.”

Focus on Fundamentals and Versatility

Employers and graduate schools that recruit Cornell chemical engineering bachelor’s degree holders are guaranteed a solid grounding in the fundamentals of the field: fluid dynamics, heat and mass transfer, and thermodynamics. Cornell chemical engineering students also learn to cross interdisciplinary borders, enabling them to communicate with chemists and biologists and industrial plant managers. As Harriott said, “They are expected to be versatile enough to handle a fluid-mechanics problem, and after that is solved, a mass-transfer or a kinetics problem. Cornell chemical engineers have the broad education for jobs that you might expect a mechanical engineer, or maybe a chemist, to solve.”

Clancy calls the school’s curriculum “in a sense canonical. There are unchanging parts of it. The dressing around them may look different. But we still feel that if you understand thermodynamics, if you understand fluid dynamics, if you understand reaction kinetics, it doesn’t matter what the application is. You can be making paper for Procter & Gamble, you can be making Taxol™ for a start-up company, you can be making agrochemicals for Pfizer—it’s all the same—the skills that you’ve learned here are broadly applicable.”

Harriott thinks that some of the versatility and can-do-almost-anything attitude begins when today’s chemical engineering students discover they are learning more of the fundamentals in less time, so that they have the opportunity to take electives—all that in a four-year undergraduate program that used to take five years. Improved teaching methods and harder-working students deserve equal credit: “One of the things that has changed is that there is more work in groups, beginning in their sophomore and junior years. With more chance for electives, the student who wants to prepare for a career in medicine can take biology and other courses, and the student who wants to get into drug delivery or biomaterials can take two or three electives in that area and be better prepared to go on to graduate study in that field or to join one of the pharmaceutical companies. But the basics are still there.”

About the chemical engineering canon, Cornell-style, Clancy said: “If we changed our name and said, ‘Chemical engineering is so twentieth-century. Let’s become nano-
chemical engineering or something,’ we’d be betting our book on one tiny, topical area. What if that doesn’t pan out? What if that’s not tomorrow’s thing? Applications may change, but we know the basic scientific principles are not going to change.”

**Betting the Book Anyway**

But what has changed is the school name—to “Chemical and Biomolecular Engineering.” The new topical area is anything but tiny, Clancy insists: “‘Biomolecular Engineering’ is a reflection of our conviction that the life sciences are a crucially important part of chemical engineering. Chemical engineers have a long history in this—the first large-scale synthesis of penicillin during World War II was possible because of chemical engineering processes—so this is not something new,” Clancy said. Emphasis on biomolecular engineering is a distinguishing mark for Cornell. Aside from MIT, Cornell has the largest percentage of chemical engineers in the life sciences. (For the story of the school’s legendary—but taciturn—benefactor, see “His Bat Did the Talking,” below.)

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**SO THEY SAID**

**HIS BAT DID THE TALKING**

“It’s impossible to put one’s foot in a closed mouth.”

Franklin W. Olin, civil engineering Class of 1885 and donor for chemical engineering’s Olin Hall

When the newly built Olin Hall was dedicated on October 3, 1942, some twenty months after construction began with funds from Franklin W. Olin and the family’s Olin Foundation, one awe-inspiring feature was the cavernous Unit Operations Laboratory. Equipped with a traveling overhead crane—so that chemical engineering students could design, build, and operate small-scale models of commercial chemical plants—the Unit Operations Laboratory was a full three stories high inside.

But that was only a fraction of the distance that a much younger Frank Olin could hit a baseball: some 540 feet, from home plate in the Arts Quad, where the Cornell baseball diamond was located in the 1880s, to the north wall of Sage Chapel.

Raised in the mountains of Vermont (where his father built waterwheels, dams, and sawmills), Olin (1860–1951) was 21 when he passed Cornell’s entrance exam (without a high school diploma) and dedicated himself to two pursuits: engineering and athletics. He never joined a fraternity and had little time for socializing—Olin earned tuition money by repairing farm machinery during the school year, and playing major league baseball in the summers—but the athletic feats of the muscular, taciturn student speak for themselves.

He rowed crew, threw the hammer and shot for Cornell’s track team, excelled at marksmanship, and captained the varsity baseball team he had joined as a freshman. His major league career batting average was .316 (at a time when college athletes were allowed to play pro ball), and the second-baseman’s power hitting for Cornell made the college team competitive against professional players.

A pro team from Toronto traveled to Ithaca on May 1, 1886, to test the mettle of the Class of ’85 engineer who was about to graduate. Olin did not disappoint. Swinging from his left shoulder with a bat he had carved from the wooden tongue of a farm wagon, he clobbered an eighth-inning curveball.

The ball might have broken windows in Olin Library—if the building named for one son (John M. Olin ’13) had been there at the time.
Many faculty members specialize in biomolecular engineering. Research in bio-processing by Michael Shuler, former director and now director of the Department of Biomedical Engineering, has led to significant advances in cell modeling and pharmaceutical production. Another former school director, William Olbricht, studies transport in biomedical systems, currently in drug delivery in the brain. Matthew DeLisa works on protein folding and expression, protein engineering, and the biomolecular evolution of macromolecular complexes. David A. Putnam creates new “functional materials” (materials with engineered characteristics that are optimized for specific applications) that range from drug- and gene-delivery vehicles to economical, biodegradable packaging materials. Abraham Stroock studies transport phenomena in microfluidics, microfluidic biomaterials, and the chemistry of colloids. Jeffrey D. Varner works at the intersection of systems biology and human health, trying, for example, to understand both the cell biology and biophysics of breast cancer progression at the level of a single cell. Susan Daniel studies artificial membranes with applications in biosensors and virus detection.
Three More Themes

While biomolecular engineering was the school’s biggest stake in the 2007 New Life Sciences Initiative at Cornell, three more strategic research themes aimed to improve life on Earth: complex fluids and polymers, electronic materials and microchemical systems, and energy and sustainable development.

Cornell’s concentration of expertise in fluid mechanics may be the largest of any American university. Fluid-mechanics engineers and the advanced mathematics they use are getting better at predicting how particles might move through places people ought to care about—the capillaries of our blood vessels, for example.

Faculty members working with complex fluids and polymers include Lynden Archer, who tries to determine how the physical chemistry of individual molecules and the so-called cooperative motion of molecular ensembles influence polymer properties in the liquid state. Claude Cohen studies polymer nanoparticles for soil remediation. T. Michael Duncan conducts experiments in heterogeneous catalysis and materials processing. Fernando Escobedo analyzes the structure–property relationships of soft materials, such as sealants, coatings, masks, and support materials for automobile manufacturing and biomedical applications.

Also working in the field of complex fluids and polymers are Yong L. Joo (nanofiber formation via electrospinning, among other projects), Donald L. Koch (processing of short fiber–filled composite materials), and William L. Olbricht (convection-enhanced delivery of therapeutics to the brain and other neural tissues).

In chemical engineering’s third emerging area, electronic materials and microchemical systems, products like flexible computer displays to roll up and stuff in a backpack and organic semiconductors are likely to make the headlines, Clancy predicted. She has her eye on another area in which Cornell chemical engineers can make their mark: the much-sought-after “living labs” on a chip. Researchers miniaturize representations of organs on an instrumented microchip and keep the systems alive with microscale “plumbing.”

Clancy’s research (silicon-based and organic semiconductors) is one example of the research focus on electronic materials and microchemical systems. James R. Engstrom studies reactive surface chemistry and thin-film deposition in the areas of microelectronics, optoelectronics, and sensors, and organic molecules and polymers.

On the energy and sustainable development front, A. Brad Anton tries to improve the enzymatic hydrolysis technologies that convert biomass cellulose into sugars that can be fermented into fuels and plant-based chemical products. Tobias Hanrath is developing new materials for solar cells. Energy-related research efforts help build interdisciplinary bridges to collaborators across the Cornell campus, such as Larry Walker in the Department of Biological and Environmental Engineering. Several more engineering disciplines at Cornell will be needed, however, to fulfill the dream of one chemical engineer: Alfred Center wants to generate electricity from the abundant sunshine in the American Southwest, then use the electrical power to drive the massive air compressors that fill long-distance pipelines.

Arriving in less-sunny regions, the high-pressure air could be fed to combustion-gas turbines that generate electricity, Center proposes. His piped-in air would eliminate
the need for the compression stage of the turbines—improving turbine efficiency and generating electricity with less fuel burned per kilowatt. Skeptics might check Center’s list of previous accomplishments—including continuous production of biodiesel fuel from both animal fats and vegetable oils, as well as a portable 250 KW fuel cell electrical generator, and new ways to improve the Claus process for sulfur recovery (using oxygen instead of air).

The fourth emerging field for Cornell chemical engineering, energy and sustainability, is closest to Clancy’s own research interests. While Cornell engineers and physical scientists work on fuel-cell technologies and better ways to make ethanol and other fuels from biomass, Clancy assesses the potential value of ice-like natural gas hydrates that form around the ocean-floor vents that spew methane and ethane. “I could go to the Antarctic where there’s lots of hydrate in the permafrost, scrape out a ‘snowball,’ set a light to it and a flame would appear. It’s almost magic—and in principle it could be a clean energy source—but there are down sides, both natural and unnatural,” she said. “With global warming, as the ice recedes in the glaciers and in Antarctica, we’re going to destabilize these hydrates. That puts methane and ethane and carbon dioxide into the atmosphere. That will accelerate the rate of global warming, so you get a nasty feedback loop—which is something we teach about, feedback process control. So what can you do to stop it? You need to understand the thermodynamics and the kinetics of those problems. They’re ChemE problems.”
Civil and Environmental Engineering: Structure and Systems for a Changing World

The lettering on the Bachelor of Science diploma reads the same no matter which major students chose in their quest to build a better world after graduating from the School of Civil and Environmental Engineering.

Cornell’s would-be environmental engineers were attracted to that field by the prospect of serving people while protecting the environment. They learned how to analyze contaminants in the atmosphere, land, and water; how to aid in the remediation of pollution problems; and to develop designs for hazardous-waste control facilities. “Microbiology for Environmental Engineering” was a required course for them, and so was “Environmental Systems Analysis.”

Seated in some of the same classes—“Uncertainty Analysis,” for instance, and “Fluid Mechanics”—were the civil engineering majors who aimed to be innovators, creators, and entrepreneurs. They learned to design and build structures such as bridges, buildings, dams, and even roller coasters; to devise complex systems for transportation and water-supply networks; and to navigate information systems that manage engineering projects. “Structural Modeling and Behavior” and “Introduction to Geotechnical Engineering” were among the required courses for the civil engineers. But so was “Environmental Quality Engineering.”

Some of the students in their classes were from other schools and departments, working on minors in environmental engineering, engineering management, or civil infrastructure. Clearly, knowledge in the School of Civil and Environmental Engineering is too valuable not to share.
Civil engineering was one of the two fields of engineering taught when Cornell first opened for business in 1868. The other, mechanical engineering, started out in the College of the Mechanic Arts, and civil engineering was not exactly that at first, either. It all began in the College of Mathematics and Engineering, although civil engineering—as in civilian, to distinguish it from its military cousin—was what the university’s founders set out to teach.

Those who earned civil engineering master’s degrees—including Henry Turner Eddy, who completed two years of study plus the requisite exam in 1870 and was the university’s first advanced-degree recipient in any field—could call themselves civil engineers. Not so for Bachelor of Science degree recipients, who had two years of general science and liberal arts before taking engineering classes: “Come back this summer,” they were told at a time when the university ran on the trimester system, “and get a master’s degree if you want to be a proper civil engineer.”
Turner Eddy went even further, earning his Doctor of Philosophy degree in 1872—a first in any discipline at Cornell.

Other pioneering Cornell civil engineering graduates did well, too. The men who became deans of engineering at Iowa State, the University of Wisconsin, and Northwestern—Anson Marston, Frederick E. Turneaure, and John S. Hayford, respectively—got their start in Cornell’s civil engineering class of 1889. By then it had become the College of Civil Engineering, having replaced the “Mathematics” with “Architecture” to be the College of Civil Engineering and Architecture for just a single academic year (1871–72). This started a debate—about what architects do, what structural engineers do better, and what’s the difference—that continues to this day.

Everyone agrees that Cornell civil engineering doesn’t teach some of the things it once did—like mining engineering—and certainly the names have changed. But what’s been lost and gained in transition and translation? That’s a question we posed to three Cornell engineers: James Gossett, Walter Lynn, and William McGuire.
Rails, Maps and Canals

Whenever Gossett, Lynn, and McGuire think about the history of civil engineering at Cornell, they remember past Cornell civil engineers.

They point to men like Fred Asa Barnes (1876–1950), the first director of the School of Civil Engineering in 1921, when the two engineering fields that had been discrete colleges became schools in the new College of Engineering. Barnes had been a mining engineer in Cuba and Chile, but he didn’t teach mining engineering at Cornell. Beginning in 1905, Barnes developed new curricula in railroad operation and management, railroad construction and maintenance of way, cost-keeping and management, engineering construction, and transportation. By the time Barnes retired forty years later, America was building airports. But the nation’s rails are still there and still carrying heavy loads, thanks to Railroad Construction and Railroad Surveying: two classic texts that Barnes coauthored with another Cornell civil engineer, C. L. Crandall.

Surveying was part of every Cornell civil engineer’s education until relatively recently. It was first insisted upon by the field’s patriarch, Estévan Antonio Fuertes (1838–1913). Fuertes was among the first American educators to advocate laboratory learning for civil engineers. At the end of each spring term, New York’s Finger Lakes region became the laboratory for Cornell’s Summer Surveying Camp. Every year a new site was selected as Cornell students mapped the topography around Cayuga, Seneca, and most of the other Finger Lakes. Under Fuertes’s tutelage, and later with Paul Halladay Underwood (1881–1963), camp director from 1917 to 1948, professional quality was paramount. The students’ work was good enough to be accepted by the U.S. Geological Survey for its series of topographic maps of the region. One who lugged a surveyor’s transit was Nora Stanton Blatch, the first American woman to earn a degree in civil engineering. (See “A Short Love Story, a Long Affair with Engineering,” page 120.)

Both Underwood and another long-time Cornell civil engineer, Francis Joseph Seery (1874–1947) honed their surveying (and mosquito-swatting) skills on crews for the Isthmian Canal Commissions, exploring canal routes across Panama. When they reached Cornell, they discovered that Fuertes had done it first—although not in the same place. Fuertes led an earlier expedition across Mexico’s Isthmus of Tehuantepec, studying the feasibility of a ship canal there. (Fuertes also had been the sanitation consultant for an entire nation, Brazil, so Cornell students and faculty alike paid attention when he spoke.)

Walter R. Lynn—director of the school in the early 1970s when “environmental” was added to its name, and this photo was taken—knows why civil engineering thinks it lacks for glamour . . . and why it shouldn’t be so modest.
SIX WEEKS IN THE WOODS . . .

“Something was lost when we stopped the Summer Surveying Camps,” says Walter Lynn, acknowledging that civil engineering students have more pertinent skills to learn in an age of digital instrumentation and satellite surveys. “Alums speak so affectionately about their time at camp—six or eight weeks of fieldwork around Keuka Lake, some remember—and it must have been rough, but it built camaraderie. We try to have pizza parties to mend the social fabric, but there’s no substitute for getting people together for six weeks in the woods.”

SO THEY SAID

A SHORT LOVE STORY, A LONG AFFAIR WITH ENGINEERING

“A life in the midst of invention appealed to me strongly.”

Nora Stanton Blatch, Cornell civil engineering Class of 1905

“She persisted in following her career as a hydraulic engineer and an agitator.”

Lee De Forest, Blatch’s befuddled ex-husband

The first American woman to earn a degree in civil engineering, Nora Stanton Blatch was caught up in the excitement of an electrical engineering invention—radio—when she declared a romantic attraction to her Manhattan next-door neighbor. Lee De Forest—the inventor (in 1906) of the Audion vacuum tube that amplified wireless voice transmission—and Blatch were married on Valentine’s Day, 1908. The honeymooners climbed the Eiffel Tower to broadcast a brief radio message that was heard 500 miles away. An obliging Blatch took graduate courses in mathematics and electrical engineering at Columbia, to fill the gaps in De Forest’s expertise, and worked in his laboratory before and after the wedding.

Not that De Forest objected to Blatch’s women’s-rights activism—or so he said at first. His bride was the descendant of feminists Elizabeth Cady Stanton and Harriot Stanton Blatch. Nora Blatch had started a suffragist club at Cornell, where she enrolled in civil engineering because, she said, it was the most male-dominated engineering field she could think of breaking into. She graduated with honors.

De Forest did object to her insistence on a level playing field for women in engineering, in general, and in his radio enterprises, which were largely funded by Blatch family money. Following a disagreement over her management role in the De Forest capacitor factory, a pregnant Blatch walked out on the inventor. She notified the father of her daughter’s birth by telephone, and resumed her career in civil engineering. When the 1911 divorce was finalized, De Forest told the New York Times the marriage had failed because Blatch was “all mentality and ambition” and that she “persisted in following her career as a hydraulic engineer and an agitator.”

The article was headlined “Warns Wives of Careers.” Blatch was about to become an agitator in the engineering establishment. Although by most standards she did the work of an engineer for more than ten years—for the New York City Board of Water Supply, the American Bridge Company, the Radley Steel Construction Company, the State of New York Public Service Commission, and for an architectural firm she started on Long Island—that was not enough for the American Society of Civil Engineers (ASCE). Blatch’s “junior” membership in the ASCE expired in 1915 because of her advancing age (32) and when she applied for full membership, it was denied. ASCE cited “inexperience” (the 1916 vote was 1,746 men against and 1,352 in Blatch’s favor), so she sued the organization for gender discrimination. It might have been a landmark case—except that the New York State Supreme Court ruled ASCE a private organization that could admit whomever it chose.

Eleven years later the ASCE admitted its first woman engineer to full membership. By then, Blatch had remarried (to naval engineer Morgan Barney), and redirected her civil engineering skills to real-estate development in Connecticut.

When Nora Stanton Barney sat down in 1957 to write her autobiography (tentatively titled “Spanning Two Centuries” and left unfinished when she died in 1971), she recalled civil engineering studies at Cornell, the first job after graduation, and her initial attraction to the young man who later called himself “The Father of Radio”: “I admired Lee tremendously,” she wrote, “and a life in the midst of invention appealed to me strongly.”

She had graduated near the top of her civil engineering class of 1905, won election to Sigma Xi, and was offered a job, “detailing” steel work, with the American Bridge Company. Recruiters said the company was “entirely unprejudiced,” while noting that she would be the first woman in a shop of fifty men. Before accepting the offer—at $12 for a forty-eight-hour week—she asked around: “Two men had already accepted at the same wage, and having satisfied myself that twenty-five cents an hour after four years education represented no discrimination on account of sex, I said, ‘Yes.’” Within three months, she was supervising nine men.

Entering Cornell’s civil engineering program as a sophomore in 1902, Nora Stanton Blatch had excelled in mathematics and technical subjects, and she found time to organize and agitate for women’s rights. She used Stanton family connections to bring to campus suffrage speakers like Susan B. Anthony, Harriet May Mills, and Ella Hawley Crossett. Suspecting Cornell President Jacob Gould Schurman of “evil intentions,” she led campus suffragists in silent protest when he gave a speech and said, to her recollection, “that only 10 percent of the students were women and that seemed a healthy percentage.”

As the only woman in the 1905 civil engineering class approached the dais on graduation day, hundreds of onlookers stamped their feet in unison. “My fellow students simply couldn’t give up teasing,” she thought—mistakenly, as it turned out. “President Schurman showed special honor to me by stepping forward and bowing,” as he awarded the first-of-its-kind diploma. “I started back to my seat fully expecting another demonstration of tramp, tramp, but complete silence reigned.” Then came the applause.

...and Summers Around the World

Perhaps not a perfect substitute—but in some ways a better opportunity to mend social fabric in today’s global milieu—is the Engineers for a Sustainable World (ESW) program, according to school director Gossett. He notes that the first American headquarters and a student chapter were established at Cornell in 2001, and that ESW encourages volunteers to spend their summer months developing and implementing engineering-based projects anywhere in the world. For example, Shawhin Roundbari, a graduate student in civil and environmental engineering, spent three months in Limpopo, South Africa,
teaching farmers to build rooftop rainwater-harvesting systems to irrigate crops during dry seasons. From its start at Cornell, ESW has spread to more than thirty campuses nationwide. They share a single mission: to engage engineers in reducing poverty by improving environmental, social, and economic sustainability worldwide.

AquaClara—“clear water” in Spanish—is another student-run organization whose mission is to improve water-treatment technologies and provide training so
that communities in developing countries can own, operate, and maintain safe-
drinking-water supply systems. Established in 2004, AguaClara is open to undergradu-
ate and graduate students. The group has designed two gravity-powered water-treat-
ment plants for communities in Honduras. The first began producing clean water in July
2005 and the second was inaugurated in January 2007.

All Things Hydraulic

Panama Canal surveyor Francis Seery turned to hydraulic engineering when he joined
the Cornell faculty in 1905. From his base in the recently opened hydraulics laboratory
on Fall Creek, Seery developed courses in water supply, hydraulic construction, water-
power and pumping plants, and conservancy and reclamation problems. A faculty mem-
ber for thirty-seven years, his teaching method stressed careful preparation for practical engineering problems, followed by hands-on learning. Seery quoted Aristotle (“For the
things we have to learn before we can do them, we learn by doing them.”) as his students
packed their gear for summer projects. They tackled the development of hydroelectric
plants in northern New York in 1909, military water supplies for New Jersey’s Fort Dix
and New York’s Fort Drum during World War I, water power for Canadian paper mills
in 1921, and flood protection on the Mississippi River in 1925–26. Returning to Ithaca
in the fall, Seery’s students were expected to write detailed reports on their summer
“camp” experiences.

Whereas Seery saw the then-new hydraulics laboratory as a teaching tool, its
director and professor of experimental hydraulics for more than forty years, Ernest W.
Schoder (1879–1968), valued the facility for its scientific as well as educational func-
tions. A 1902 Ph.D. graduate of Cornell engineering, Schoder and another graduate stu-
dent (August V. Saph) performed a classic experiment on the frictional resistance to the
flow of water in pipes. When the Saph–Schoder measurements were used subsequently
in German studies of turbulent flow, the Cornell laboratory was credited with reversing
the long-established migration of technical information from Europe to America. The
author of hydraulics texts and handbooks in the 1920s and 1930s, Schoder took satis-
faction in adding: “The majority of leading American hydraulicians in the first quarter
of this century either were educated, or participated in tests conducted, at Cornell.”

Structural Engineering in Transition

Even as Schoder was making that self-congratulatory assessment, civil engineering in
America was entering a period of transition. The 1931 completions of the Empire State
Building and the George Washington Bridge marked the start of an approximately
twenty-year hiatus in construction of major buildings and bridges. The great depres-
sions of the ’30s halted commercial construction, then World War II diverted structural
engineers to the design, construction, and maintenance of factories, ships, and aircraft
for the war effort.

William McGuire’s wartime and postwar experience was typical of many civil
engineers. Following graduation from Bucknell with a B.S. in civil engineering in 1942,
he was commissioned in the U.S. Navy, sent to MIT for a short course in aeronautical engineering, given hands-on training in aircraft engines, and served as an aircraft maintenance officer until the war ended. Structural engineering faculty members at Cornell and other engineering schools focused on the urgent training of Navy midshipmen and Army cadets during the war—an all-hands-on-deck effort that left little time for research. When the war was over, the influx of GI Bill veterans to Cornell and other engineering schools continued to strain faculty resources.

But one structural engineer who managed to both teach and conduct research was George Winter (1907–82), whom McGuire calls a mentor as well as a leader in the post–WWII renaissance of civil engineering. Born in Vienna and educated in Munich before working as an engineer in Russia, Winter earned his Ph.D. in structural engineering at Cornell in 1940 and went straight to work. One result, in 1946, was his first edition of the American Iron and Steel Institute’s *Specifications for the Design of Cold-Formed Steel Structure Members*. Winter helped write standards for heavier steel construction, guiding the design for most steel-framed buildings in the United States. Winter’s work with concrete folded-plate roofs introduced that form of construction to the United States in 1947. His specifications in the building code of the American Concrete Institute were the first to emphasize a rational approach to structural safety, with load and resistance factors based on probability theory.

Winter’s surviving colleagues, including emeritus professor Floyd O. Slate, acknowledge his vast influence on many aspects of structural engineering research and practice, while insisting that Winter’s greatest impact was in the role of teacher. “The atmosphere which he [Winter] consistently created in the classroom was exhilarating,” Slate recalled. “The clarity, the stimulation, the thought-provoking questions, the personal interactions . . . made his teaching both a challenge and an excitement.”

McGuire recalls the 1950s as a time of revival and renewal, when the school took fullest advantage of the five-year degree program to revitalize course content by “seeking a balance between teaching and research and—most challenging—contributing to the computerized revolution in structural analysis and design.” By the early 1960s, McGuire said, the school could claim success in all three areas (education, basic research, and technology development). “Much of our success,” he said, “was attributable to newer faculty members—most notably Dick White, Peter Gergely, Arthur Nilson, and Dick Gallagher.”

How Civil Engineers Filled Electrical Engineering’s Bowl

Cornell electrical engineering’s William E. Gordon had a bright idea in the mid-1950s—to study the wave scattering of free electrons in the atmosphere using a giant radar instrument—but only a general idea how to do it. So he called on Cornell civil and structural engineers to find a site and design the structure of what would become, when it opened in 1963, the world’s largest radio–radar telescope, the Arecibo Observatory. The site should be nearer to the equator than Ithaca, Gordon told Donald J. Belcher, who had been an aerial-photo interpreter for General Douglas MacArthur during World War II. Belcher found a suitable site for a large parabolic dish in Puerto Rico, while McGuire
made a preliminary structural design to demonstrate the feasibility of the device and to provide cost estimates. A potential sponsor of the radar project, the Department of Defense’s Advanced Research Projects Agency, was impressed enough with the Cornell proposal to ask for considerably more: a steerable system so that the observatory’s beam could be directed as much as 20 degrees off zenith, allowing it to function both as a wide-ranging radio telescope and as a radar probe aimed at the ionosphere directly overhead.

Together with Gordon, Benjamin Nichols, and other electrical engineers, McGuire and his structural engineering colleagues revised the proposal—then invited and judged designs from outside engineering firms. The scheme they selected was submitted by a consortium of four firms with combined experience in civil, structural, electrical, and mechanical engineering, a team led by a structural engineer named Thomas Kavanaugh. Completed for about $7 million and upgraded several times since, Arecibo Observatory remains one of the world’s major instruments in the field of radio astronomy.

**Systems Engineering an Entire College**

Today the kind of interdisciplinary cooperation required to build the Arecibo Observatory is called systems engineering, although that term was hardly used in the 1950s. Engineering systems and management, civil infrastructure, and environmental engineering are the three intellectual areas carved out by Cornellians who call themselves civil engineers. As Gossett explains, systems engineering is the application of mathematical and scientific principles to the definition, design, development, and operational evaluation of total solutions to a wide variety of engineering problems. The approach, he says, demands the integration of human, physical, energy, communication, management, and information considerations. (For more details on the college-wide program, see “Systems Engineering,” page 229.)

James Gossett credits Walter Lynn, a faculty member since 1961, as the architect of systems engineering at Cornell. For a professional role model, Lynn points to a civil engineer who “systems engineered” an entire college: Solomon Cady Hollister (1893–1982). Hollister had a prodigious aptitude for tools, machines, and materials—and little else—when he enrolled at Washington State University. He paid bills by working on surveying crews and took a University of Wisconsin correspondence course in reinforced concrete.

Transferring to the University of Wisconsin at Madison, where he earned his only academic degree (a B.S. in engineering in 1916), Hollister hit the ground running. Within two years, Hollister was designing seagoing concrete ships, the first of their kind, for the U.S. Shipping Board, and he followed by designing one of the first skew-arch concrete bridges, followed by the thirty-foot-diameter welded steel penstocks for the Hoover Dam. Appointed director of Cornell’s School of Civil Engineering in 1934 after four years on the Purdue faculty, he rose to become dean of the College of Engineering in 1937.
Civil engineer Hollister took over a college in disarray—with a minuscule research program, a dispirited and poorly paid faculty, faltering student enrollments, and a physical plant that had not been improved in twenty-five years. In his twenty-two years as dean, Hollister raised funds to build a new engineering campus in its present location and to hire and properly compensate a younger, energetic faculty with an interest in wide-ranging research and graduate education. Hollister filled the new classrooms and laboratories with students attracted to Cornell by an educational innovation of the time (1946–63): the five-year undergraduate curriculum in engineering. He added three fields to a reinvigorated college: engineering physics, chemical engineering, and aeronautical engineering.

Even in retirement, as national awards for a lifetime in engineering education and innovation accumulated, Hollister refused to rest. He pursued a vigorous research and consulting agenda in three very different fields: power plant construction and high-strength concrete, paleontology, and improved equipment for football players.

**Labeling “The People-Serving Profession”**

Walter Lynn was one of the founders of Cornell’s Science, Technology, and Society program, which later morphed into the Department of Science and Technology Studies. He was a director of the Cornell Center for the Environment (which was previously called the Environmental Research Center) and the dean of the faculty.

Looking back on this multiplicity of titles and labels, Lynn ponders their meaning and value, and wonders whether discrete departments in engineering colleges still make sense. “Of course you can never get rid of them [departments], because tradition is so important. Probably some civil engineers who do water supply would be more comfortable with chemical engineers who do that. But the difficulty is, you still have to label people, and labeling is very important.”

Labels and buzzwords are especially crucial in a time of changing technologies and priorities, Lynn believes, hinting that civil engineering—both at Cornell and nationally—thinks of itself as unglamorous. “Civil engineering will never have the cachet of something like nanotechnology. We deal with the changing problems of society—water, sewage, roads, buildings—and that’s not glamorous. Although we try. We make ‘green’ buildings, but a building is still a building. It has to stand up. We do worry about glamorous things like earthquakes,” Lynn said, referring to Cornell civil engineering’s extensive efforts to make buildings and infrastructure more tolerant of tremors.

The director of the school, Gossett, knows about labels and priorities, too: “We’re known as ‘The People-Serving Profession.’ We’re involved in design and construction of things people are going to use.” Christine Shoemaker’s research is a case in point; she applies sophisticated mathematical tools to improve water systems. (See “First, First, and First Again . . . ,” page 127.) Gossett’s specialty—environmental engineering—used to be called sanitary engineering at Cornell, but that has changed, too: “We were concerned with public health and clean water. Sanitary engineering reminds people of ‘Norton,’ the sewer worker in The Honeymooners,” Gossett said of the 1950s television show (whose bus-driving “Ralph Kramden” dealt with another civil engineering
SO THEY SAID

FIRST, FIRST, AND FIRST AGAIN: CHRISTINE A. SHOEMAKER, JOSEPH P. RIPLEY PROFESSOR OF ENGINEERING

“I chose the environment because it’s a social issue. It was an area where I could make a contribution with my technical knowledge that had an impact on policy.”

When Christine Shoemaker was named a research associate at the Center for the Environment in 1971, her newly minted Ph.D. in mathematics from the University of Southern California in hand, she arrived at a university whose co-founder had proclaimed, “I want to have girls educated in the university as well as boys, so that they may have the same opportunity [sic] to become wise and useful to society that the boys have.” Nonetheless, when she joined the faculty one year later, the proportion of female faculty and students was still very small. That’s something she has helped to change—dramatically. Thirty-one percent of the College of Engineering class of 2011 are women, and Cornell’s alumnae are making their mark in virtually every field of engineering throughout industry, academia, and government.

Shoemaker holds three firsts in the history of the College of Engineering. She was the first woman granted tenure (in 1979), the first to be named a full professor (in 1985), and the first to chair a department (the Department of Environmental Engineering, a post she held from 1985 to 1988). In her early years at Cornell, she found very few other women in the College of Engineering. “Society didn’t view being an engineer as being compatible with being feminine,” she says. “Women also needed role models.” So throughout the 1970s and 1980s, Shoemaker became an advocate for women in engineering, leading a college committee on the status of women for nearly a decade, recruiting women students, dealing with women’s issues at the college, and mentoring a number of those she helped to attract to engineering at Cornell. Her dedication and effectiveness in these efforts, along with her excellence in research, earned her the Distinguished Educator Award from the national Society of Women Engineers in 1991.

While she has worked tirelessly for women, Shoemaker has also carried on a robust research agenda that combines two passions: using her mathematical and technological gifts and making the world a better place. Her research focuses on finding cost-effective, robust solutions for environmental problems by using optimization, modeling, and statistical analyses of resource allocation and operations management. This includes development of numerically efficient nonlinear optimization algorithms, using high performance computing and algorithm applications for complex, nonlinear environmental systems. Her work is applied in physical and biological groundwater remediation, pesticide management, ecology, and surface water pollutant transport in large watersheds, and has resulted in improved policies for environmental remediation and protection.

Shoemaker’s research leadership is widely recognized. She was elected a Fellow of the American Geophysical Union, the Institute for Operations Research and Management Science, and the American Society of Civil Engineers. The American Society of Civil Engineers also honored her with the Julian Hinds Award, and she received a Humboldt Research Prize from the A. von Humboldt Foundation in Germany.
specialty—transportation). “But today, environmental engineering includes disciplines like environmental fluid mechanics and molecular biology, and the same principles that apply to transport of pollutants through the environment also apply to the study of tsunamis.” Tsunamis are another focus of study at Cornell, as civil engineers try to improve early-warning systems for these fast-moving deluges and make shoreline communities more tsunami-resistant.

Diploma Reading 101

Cornell undergraduates can specialize in environmental engineering, but they don’t have to commit at the beginning of their college careers. A flexible curriculum within the civil engineering bachelor’s degree program allows exploration—among civil infrastructure, engineering systems and management, or environmental engineering—that can lead to specialization at the graduate level.

A Cornell B.S. in civil engineering qualifies graduates to take Part A of the professional licensing exam, and counts for 8 education/experience credits toward the 12 needed for full registration and the title of Professional Engineer.

About half the bachelor’s degree recipients in civil engineering go on to advanced study—some seek master’s or doctoral degrees in engineering-related fields, while others study law or medicine or finance. Some undergraduates, although initially anxious to begin the practice of civil engineering, subsequently decide to stay at Cornell for another nine months of intensive study. Those additional two semesters, plus a project in any of eight engineering specialties—from civil engineering materials to transportation systems engineering—will add a Master of Engineering (M.Eng.) degree to their credentials.
Master of Science and Ph.D. programs can focus on any of eight areas: civil infrastructure systems, environmental engineering, environmental fluid mechanics and hydrology, environmental and water-resources systems engineering, geotechnical engineering, remote sensing, structural engineering, and transportation systems engineering.

What Researchers Teach

Labels and institutional reputations also come into play, Gossett said, “when disasters become recruiting tools. People who want to make a difference learn that Cornell civil engineering faculty members and graduates are involved people who care about the built environment and sustainability, and that reputation attracts more good people.” Recruits, whether potential students or new faculty members, may have heard about Philip Liu’s tsunami modeling that predicts wave patterns. Or the work of Thomas O’Rourke and Harry Stewart to make municipal infrastructure more resilient to earthquakes or terrorist attacks.

Some Cornell civil engineering projects escape public notice, Gossett said, because they are literally underground. For example, a project in Tokyo’s natural-gas distribution system resulted in the redesign of that city’s underground lines to better resist horizontal movements during earthquakes. If the retrofitted gas system works when it’s needed most, few will think to thank Cornell. Also almost certain to be taken for granted, Gossett predicts, “would be the work of Cornell transportation systems re-

Student members of the American Society of Civil Engineers built improbable boats like this 2006 model for the ASCE’s National Concrete Canoe Competition. The regional competition that year was held in Cayuga Lake, near an area called Portland Point for the cement and concrete ingredients once mined there.
searchers on airport grids—so that a disaster at one airport is less likely to shut down the whole network.”

Another sign of changing times, Gossett said, is what he calls a disconnect between the availability of research funding and the fundamental subjects an engineering college still needs to teach. “I have one new faculty member who teaches structural engineering,” Gossett said of Wilkins Aquino, whose research with finite element analysis is producing biomedical models of the functioning of human arteries. “By day, Professor Aquino teaches students how to design buildings; by night, he is working in biomechanics. That’s twenty-first century engineering for you.”

Mars-Moving Machines

Apparently weary of the popular stereotype associating civil engineers with earth-moving machinery, geotechnical engineer Harry Stewart began in 2001 to build a Mars-moving machine. The wheels of the twin Mars rovers, Spirit and Opportunity, were specially designed to spin and excavate Martian soil, thanks to insights of Stewart. He worked with a Cornell planetary geologist, Robert Sullivan; a Class of 2004 engineering physics student, Lindsey Brock; and the manager of Civil Engineering’s Harry E. Bovay Laboratory, Tim Bond, to test the wheels in Mars-like soil in Ithaca. Then the rovers were sent to the Red Planet, where they roamed and spun their wheels to dig trenches on command.

Each day in the first weeks of the rover missions—and occasionally for months afterward as the long-lived rovers continued to work beyond their designers’ expectations—Stewart watched the NASA briefings from the Jet Propulsion Laboratory. He had to learn some unfamiliar NASA jargon, but the data about the texture and strength of Martian soils was surprisingly down to Earth. “What we do in civil engineering is learn about soil as an engineering material,” Stewart explained. “Everything we build on Earth is founded in or on soil and rock. It (soil) is the number-one construction material, by volume, in the world.”

Transcending Tradition

When Gossett joined the Cornell faculty, his research interest was wastewater treatment, and that’s what he taught. His current research focuses on developing experimental methods for the bioremediation of groundwater pollution, but he still teaches aspects of wastewater treatment—because environmental engineers need to know enough about what works to make improvements.

Besides, there’s plenty of opportunity for undergraduates to do research of their own, and nearly a third of civil engineering juniors and seniors do so. One developing field of interest for students, as well as for civil engineering faculty members, is strategies that look beyond a product’s “first life” to the time structural materials can be recycled.

Increasingly, research into environmental engineering problems engages students in fields beyond the traditional range of civil engineering—like chemistry, microbiology, or molecular biology—and this has impressed the school’s administrators. Because so many undergraduates have research experience, the School of Civil and Environmental
Civil and Environmental Engineering

Engineering has waived the requirement that applicants for Ph.D. study must prove research prowess; qualified bachelor’s degree holders can now begin immediately with their doctoral studies and research.

Gossett says that he and his faculty aim for a curriculum that covers the necessary fundamentals without bogging down in the basics: “We teach our students how to work well in groups. We want them to have good analytical skills and we want them to learn how to think. I tell students we’re preparing them for a forty-year career, so they need to be adaptable. We don’t teach building codes so they can go out and build according to current practice. If they are naturally curious, they adapt to whatever the needs are—again and again as the problems change. We’re not producing ‘plug-and-play’ people.”

Thus, when Cornell civil engineering undergraduates return from summer internships, having worked with “plug-and-play” students from other schools, they sometimes tell Gossett: “We felt inadequate because we didn’t know how to read blueprints.” “I tell them not to worry, to look ahead, and I tell them...
what employers tell me. ‘Send me more Cornell civil engineering graduates! Three months on the job and they’re running rings around the other people.’ Our graduates tend to become industry leaders, so ten years out they’re not doing engineering. They are managing firms of engineers.”

Engineers without Intellectual Borders

Gossett is constantly learning where a Cornell civil engineer’s thinking skills might lead. Take, for instance, the alumnus with a Cornell master’s in structural engineering who went on to medical school and became a pulmonary specialist. Gossett asked, “How does your engineering fit into that?” He replied, “Perfectly. Basically the human pulmonary system is fluids and structures. My engineering background helps me understand the pulmonary system better than my colleagues will ever be able to.”

Hearing stories like that—about civil engineers without intellectual borders, bearing passports to seemingly unrelated fields—takes William McGuire back. He pauses momentarily to review his Cornell accomplishments (helping electrical engineers realize their dream of the monumental Arecibo Observatory and designing [with Dean S. C. Hollister] the Fall Creek Gorge suspension bridge), and then he gets to the Second World War: “I went into the Navy as a civil engineer, and in six months I was practicing aeronautical engineering. I spent three years learning how airplanes can fail—and that taught me how buildings can fail. I came to realize that our method of analysis—and our ways to prevent buckling, metal fatigue, and a host of other problems—cut across disciplines. One of the giants in development of the widely applicable finite-element method, Dick Gallagher, was educated as a civil engineer and worked in the aircraft industry. Some of the best structural engineers I know were educated in mechanical engineering. The way engineering educators break down engineering into disciplines has always been somewhat arbitrary.”

Seventy-five years before McGuire came to Cornell there was, ever so briefly, the kind of unity he envisions: the College of Civil Engineering and Architecture. Around the same time, the College of the Mechanic Arts experimented with a program called Industrial Art. Nominally, the engineers, architects, and artists went their separate ways—to the College of Civil Engineering and the College of Mechanical Engineering that became schools in the consolidated College of Engineering, and to the College of Architecture, Art, and Planning. Still, collaborators from different schools and named disciplines found a way, McGuire said. “Sometimes the relationships have been close, sometimes tenuous. Although the architect and the engineer may be equal partners in design, the expertise they contribute differs, and this influences how each is educated.”

He points to Cornell’s program of interactive computer graphics, which is housed in Rand and Hollister halls, as a chance for students to increase mutual understanding of one another’s abilities and contributions. Architecture and civil engineering students work side by side and often collaborate. “The time may have passed for the reintegration of the two schools,” McGuire said, “but not the need for more interaction.”

Colleagues Lynn and Gossett are right, McGuire agrees. Engineers actively engaged in “The People-Serving Profession” don’t have time for labels.
Computer Science: Creating the Art of Engineered Intelligence

A computer science degree from Cornell is a ticket to virtually any field in which computing plays a key role: animation, artificial intelligence, biotechnology, business management, computational finance, computer graphics, computer modeling, game design, hardware development, Internet systems and technology, medicine, robotics, security, and software engineering. The list is growing rapidly.

That's a first-class ticket, because Cornell computer science majors have more than the expected knowledge of algorithms, data structure, logic, programming languages, scientific computing, systems, and theory. A curriculum with intellectual elbow room gives them a chance to explore and excel in areas like artificial intelligence, computer graphics, computer vision, databases, networks, and multimedia.

There at the Start

Visionaries though they were, Cornell’s pioneers in computer-science education now acknowledge that they never imagined how integral computing would become in all fields of science and engineering, and in so many other areas of human endeavor. In 1965, their assigned task for the newly created Department of Computer Science was singular enough: to “populate” an emerging field with Cornell-educated professionals.

None of the founding faculty (three from other departments at Cornell and three from other places) considered themselves to be “computer scientists” at the time. Juris Hartmanis, the first department chair, was a research mathematician at General Electric. Richard W. Conway was a Cornell-educated mechanical engineer hoping to apply computing to manufacturing problems. Gerard Salton, who had programmed an early mainframe for Harvard, was an applied mathematician.
Succeeding in their profession-building goal (360 computer science Ph.D.s, 1,403 master's, and 2,408 bachelor's degrees by the department’s fortieth anniversary), the enthusiastic members of the computer sciences faculty exceeded even their own expectations. They essentially defined several major fields in computing, substantially advanced others with their research, and earned accolades from their peers. They wrote some of the most influential books in the field, and they saw a tiny department grow into a unit the size of some colleges, the university-wide Faculty of Computing and Information Science—all the while keeping education first and foremost.

Today Hartmanis, who shared the Association for Computing Machinery’s 1993 Turing Award for starting the field of computational complexity theory, credits cross-campus “collegiality” for the department’s success in all its missions.

“Dick” Conway, who served twice as acting director of the department, went on to demonstrate cross-campus collegiality when he joined Cornell’s Johnson Graduate School of Management and introduced M.B.A. students to the power of computer simulation for manufacturing management.

“Gerry” Salton (1927–95) worked on SMART (System for the Manipulation and Retrieval of Text, a.k.a. “Salton’s Magical Retriever of Text”) for thirty years—until his scheme for full-text indexing became the basis for modern search engines. He now is revered as the Father of Information Retrieval. As proof of the power of full-text indexing, a Google search for “Salton” and “SMART” turns up more than 594,000 results, in just over one-fifth of a second.

From Two Colleges to Every Corner of Cornell

The department Hartmanis was recruited to start in 1965 was intended to have roots in the College of Arts and Sciences and the College of Engineering, and until 1978 it offered only master’s and Ph.D. degrees. Until the 2000 creation of the university-wide Faculty of Computing and Information Science, computer science at Cornell was more closely identified with the engineering college, according to Hartmanis, for two compelling reasons: engineering dean Andrew S. Schultz Jr. proposed the Sloan Foundation grant that garnered $1 million in start-up funds, and he found space on the fourth floor of Upson Hall to house the original faculty members and students.

The task of persuading young “superstar” faculty members to move to rural Ithaca was facilitated by what Hartmanis calls a “flexible and academically opportunistic” dispensation from college administrators: immediate appointments as associate professors of computer science instead of the tenure-track waiting game that most assistant-professor appointees must endure. “We lured John Hopcroft away from Princeton by offering an associate professorship,” Hartmanis recalled, “and we lured David Gries from Stanford the same way.”

Hopcroft continued to rise through the academic ranks, serving terms as chair of the Department of
Computer Science and dean of the College of Engineering, while earning numerous accolades for excellence in teaching and research. The co-recipient of the 1986 Turing Award “for fundamental achievements in the design and analysis of algorithms and data structures,” Hopcroft was elected to the National Academy of Engineering in 1988, the same year Hartmanis achieved that honor.

Gries, a computer science faculty member since 1969, also chaired the department. The author of the first text on compiler writing, Gries co-authored with Conway the first programming text (An Introduction to Programming: A Structured Approach Using PL/1 and PL/C [1973]) that dealt with issues of correctness, such as loop invariants.

Emphasis on correctness issues has become the hallmark of introductory programming classes that Gries continues to teach. For his contributions to computer science education, Gries was one of the first ten Cornell Weiss Presidential Fellows and he received four national computer science education awards.

**Life after Computer Science**

Not that they’re still writing programs for a living, but more than a quarter of Cornell’s 360 computer science Ph.D. graduates returned to campus in 2005 to celebrate the fortieth anniversary of the department. Eleven of them, speaking in a symposium on leadership in research and education, had some stories to tell.

Jennifer Widom, a faculty member at Stanford and a former music student who earned her 1987 Cornell Ph.D. with advisor David Gries, remembered playing the trumpet at her admission-to-candidacy exam. Gries remembered another premiere achievement: Widom scored the first goal in the first game of the first Cornell computer science women’s ice hockey team.

Kurt Mehlhorn, who earned his 1974 Ph.D. with advisor Robert Constable, became the founding director of the Max Planck Institute of Computer Science just fifteen years later and also founded a company, Algorithmic Solutions GmbH.

Randy Katz, who studied computer science in the College of Arts and Sciences to earn a 1976 B.A. from Cornell, became a computer science professor at Berkeley—and the architect of the U.S. administration’s presence on the Internet, the much-visited web site www.whitehouse.gov. The increasing amount of information available on the web made Constable ponder the role of research universities and their faculties. (See “Tools of Digital Discovery,” page 138.)

Another arts college mathematician cum computer scientist is Barbara Grosz (1969 B.A.), who helped establish the field of computational modeling of discourse. She joined the Harvard faculty, where she is also known for her contributions to the advancement of women in science.

So is Robert Schnabel, in his way. The 1977 Ph.D. recipient is a co-founder of the National Center for Women and Information Technology and holds the position of vice provost for technology at the University of Colorado.
John Hopcroft’s 1973 Ph.D. advisee, Zvi Galil, formerly the dean of engineering and applied science at Columbia, is now president of Tel Aviv University in Israel. Another Hopcroft student, Cynthia Dwork, took her 1981 Ph.D. to Microsoft, where she is a senior researcher specializing in cryptography and data privacy.

Where the Jobs Are

Several of the ninety-odd alums returning for the fortieth anniversary celebration in 2005 had been elected to the National Academy of Engineering, including Widom, Katz, Galil, and Edmund Clarke, who earned his Cornell Ph.D. in 1976 with Robert
Constable and is now on the faculty of Carnegie Mellon University. Their distribution in the workplace typifies what Cornell computer science graduates do for a living, according to previous department chair Charles Van Loan. Clearly, Cornell computer science is fulfilling its original mission—to populate the ranks of academia with graduates who thrive in a learning environment of science, mathematics, liberal arts, and engineering—Van Loan reports. But Cornell computer science is just as well represented in the information-technology industry and in the business, finance, law, and medical professions.

Van Loan shares one goal of Robert Schnabel’s information technology center: to convince potential computer science students that there is a need for their skills and talents in the post-dot-com-bust economy. Undergraduate enrollments in computer science declined precipitously throughout the nation after 1999. Van Loan thinks those missing students must not have seen the federal government’s prediction; by the year 2012, the U.S. economy would add nearly 1.5 million information technology jobs that require a college-level, professional education.

Computer science graduates with the “Cornell” brand on their diplomas will find good jobs—and subsequently move into management, if they want to—because of two distinguishing features of the program here, according to Van Loan: “First, we value theory and mathematics. Our computer science major is by far the most mathematical in the country.” The second attractive feature is a favorite talking point when Van Loan recruits high schoolers: “I say we have a great engineering college. But next-door is a great arts and sciences college. You have the prospect of getting a very strong engineering degree—while also being liberally educated—and I think we’re very close to the top in that regard.”

**No Cookie-Cutter Degrees at Cornell**

Teaching in a field that is so essential to virtually every other art, science, and engineering discipline at the “Any person . . . any study” university, the computer science faculty tries to be flexible when students express mid-education second thoughts about choosing that field as a major. It’s not as if computer science is “losing” good students to other fields, David Gries figures.

Rather, they are “sharing” these inquisitive minds with other fields that need computer science skills. Gries tells the stories of two students to prove that Cornell engineering has great flexibility. One student aimed for a job with San Francisco’s BART transit system, “and he said he didn't want just the technical stuff. He wanted to learn to manage and he wanted to know what's happening.” By changing to an independent major in engineering, Gries said, the student was able to build a curriculum in architecture and planning, transportation, and government from two other colleges at Cornell while still covering “the technical stuff” in engineering.

Another spent a summer in Peru “and she came back changed,” Gries said. “She felt what she was doing in engineering wasn’t relevant anymore, that she wanted to learn things that would help her serve society, and she wanted to change her major.” Gries convinced the student to stick with engineering, while balancing the technical side with
classes in language and culture. “The students are seeing that they need a broader education, that a strictly technical one is not enough anymore,” Gries said.

Even students who want a by-the-book education in computing have plenty of options in the emerging field of computational biology. Biology majors in Cornell’s agriculture or arts colleges get a core education in biology, chemistry, and physics before bridging into computer science coursework. Another option for Cornell’s ag college students is a concentration in statistical genomics, whereas arts college students can opt for a concentration in mathematical biology.

A slightly different perspective on the topic is offered to computer science undergraduates in both the arts and engineering colleges. Their concentration in computational molecular biology starts with core courses in computer science before bridging to biology—and then branching to three possible tracks: a machine learning approach to computational biology as applied to pattern recognition, modeling of networks, and cell-wide processes; a track for students interested in computational problems of protein folding; and another focusing on statistical genomics.

The Liberal Art of Information Science

Or consider the undergraduate major in information science. In Cornell’s arts college it is called just that, while the engineering college offers a major in information science, systems, and technology. Whatever the title, Van Loan insists, “Information science at Cornell is not ‘CS Lite’. It’s not an easy version of computer science for students who can’t hack the CS major.”

Rather, information science, the major, tackles computer technology head-on while exploring the human–computer interface, the organization of online databases, privacy, and other sociolegal issues. Then the program delves deeply into design, “which is at the heart of engineering,” Van Loan added. “We see information science as the new liberal arts degree. We believe that, to be liberally educated, you have to understand the roles of information science in our society. We are able to do this because at Cornell information science transcends college boundaries.” Indeed, an information science minor is offered in all seven undergraduate colleges and schools at Cornell University, Van Loan notes.

When arts and sciences undergraduates want to specialize in computing applications that mesh with their interests—in music, psychology, dance, film, or some combination—they enroll in the Computing in the Arts minor. The introductory class is led by computer science’s Graeme Bailey, a mathematician, artificial intelligence expert, and concert cellist. Music majors can add classes such as computer
game design, digital music, computers in music performance, and the physics of musical sound. Psychology majors can study visual imaging in the electronic age, computer graphics, and cognitive psychology, among other subjects.

**Research and Graduate Education**

Wherever they obtain their undergraduate degrees, graduate students are ready to specialize when they reach Cornell computer science, and the department responds with its trademark: traditional as well as next-big-thing areas of excellence to explore.

For example, algorithm game theory, the science of networks, affects every citizen battling congestion on the freeways or the Internet—and often simultaneously for some multitasking drivers—notes Éva Tardos. She is chair of the department and a specialist in network-flow algorithms for communications networks that lack a central control. Her focus on algorithmic game theory to design systems for “selfish” users of networks led to the so-called Roughgarden–Tardos solution for relieving congestion. Together with Tim Roughgarden, a Cornell computer science student now on the faculty of Stanford University, Tardos showed that doubling bandwidth is at least as beneficial as any amount of central control. Previously, Tardos won the 1988 Fulkerson Prize, sponsored jointly by the Mathematical Programming Society and the American Mathematical Society, for her work on network flow algorithms. She was elected to the National Academy of Engineering in 2007.

Tardos’s 2005 text, *Algorithm Design*, was co-authored by computer science’s Jon Kleinberg, who uses combinatorial and randomized methods to design algorithms for data mining, computational biology, and information networks. His hubs-and-authorities plan for network analysis provided the framework for some of the web’s most effective search tools. Kleinberg won the National Academy of Sciences’ 2001 Award for Initiatives in Research for introducing link analysis techniques to web searches; he is also a MacArthur Fellow and was elected to the National Academy of Engineering in 2008.

The building of a world-class algorithms group at Cornell began early in the history of the department with a determined focus on the concept of asymptotic complexity. Fourteen years before Cornell’s John Hopcroft and Robert Tarjan (a Hopcroft student at Stanford and later a computer science professor at Cornell) got the 1988...
Turing Award for the linear algorithm to test planarity of graphs, Hopcroft published a best-seller. His *Design and Analysis of Computer Algorithms* (co-authored by Alfred V. Aho and Jeffrey Ullman) came out in 1974 and soon was used as a textbook in nearly every computer science department in the country.

Another Fulkerson Prize winner is David P. Williamson, who shared the 2000 prize with Michel Goemans of MIT for their design of approximation algorithms with semidefinite programming. Williamson joined the Cornell faculty in 2004.

The work of Daniel Huttenlocher and Ramin Zabih, using graph algorithms and network flow techniques, is widely regarded as having a major impact on computer vision and computer graphics. Computer security owes a debt to Dexter Kozen’s investigation of efficient code certification. Carla Gomes and Bart Selman are advancing artificial intelligence with their algorithmic approach to central problems in constraint satisfaction. Johannes Gehrke, whose research in data mining has connections with algorithms, also works with Alan J. Demers on distributed data management for wireless sensor networks.

**Data Mining, Deep Space, and Cyberspace**

Demers and Gehrke have another project that will take the futuristic field of data mining light years into deep space: a census by the Arecibo Observatory of distant and up-until-now innumerable pulsars by Cornell’s Department of Astronomy. Observations by the Puerto Rico–based radio telescope will add up to about a petabyte of data over the five-year term of the project, arriving in 14-terabyte batches every week at The Cornell University Center for Advanced Computing. Says Gehrke, “The data rates and processing requirements for the pulsar survey are truly astronomical,” a joke he can afford to make thanks to a $2 million research grant to build the necessary computing infrastructure for the ambitious project.

The new field of cybersociology awaits the results of a massive data-mining project by William Arms, Gehrke, Huttenlocher, and Kleinberg: a temporal analysis of 40 billion–plus web pages to see how technologies, opinions, fads and fashions, norms, and urban legends spread over time. The project will enable the research community, for the first time, to evaluate models of web growth and evolution over a wide range of time scales, according to Arms.

Two leaders of the Cornell Natural Language Processing group, Claire Cardie and Lillian Lee, developed some of the first algorithms for sentiment classification, extraction, and analysis. When applied to text samples, their learning algorithms can automatically infer which word-level indicators and phrase-based syntactic and semantic patterns are most useful for sentiment analysis.
Computer graphics became a focus soon after the department’s 1965 founding, through Cornell collaborations with General Electric’s Visual Simulation Laboratory. The 1973 establishment of the Program of Computer Graphics, headed by engineer–architect Donald Greenberg and supported by the National Science Foundation, set the stage to develop the theoretical basis for the interactive computer modeling and rendering techniques that are now used routinely in cinema and architecture.

While the tools for architects—scalable algorithms and representations for illumination, rendering, and modeling, for example—permit virtual tours through buildings yet to be built, the moviegoing public more likely relates to computer-generated characters in the Lord of the Rings, Harry Potter, Matrix, and Terminator series of films. The strikingly realistic skin and hair of the digital characters results from Steve Marschner’s efforts to simulate subsurface scattering of light in translucent materials. Marschner won a 2004 Technical Achievement Award from the Academy of Motion Picture Arts and Sciences for making Gollum (Lord of the Rings) and Dobby (Harry Potter) more credible than many Hollywood actors.

Four other Academy Awards have gone to graduates of the Program of Computer Graphics. Five faculty members and students have won SIGGRAPH prizes. Greenberg, who was the founding director of the five-university NSF Science and Technology Center for Computer Graphics, won the 1987 Steven A. Coons Award of the Association for Computing Machinery for his lifetime contributions to computer graphics and interactive techniques. As an institutional legacy, dozens of graduates of Cornell’s pioneering Program of Computer Graphics now populate departments at leading universities worldwide.

The department’s 2005 anniversary celebration also marked four decades of continuous and successful emphasis on numerical analysis and scientific computing at Cornell. Beginning with Roland Sweet and James Bunch and their early 1970s work with Fast Poisson solvers, computer science and mathematics at Cornell enjoyed the best of both worlds—advanced algorithmic ideas plus rigorous mathematical analysis and application. The establishment at Cornell of the Center for Applied Mathematics enabled more collaborative interactions.

Uri Keich now obliterates institutional borders with his work on statistical and algorithmic problems in biological sequence analysis. Computer scientists, mechanical engineers, and mathematicians are combining their talents in a major NSF–sponsored project to simulate turbulent combustion.
Computing Machines Near and Far

As the science of computing developed and matured, machines gained capability, although not always apace with users’ expectations. Hours spent punching instructions into IBM cards—for batch processing on machines in the IBM 360 series that the university maintained off campus in Langmuir Laboratory in the late 1960s—might be rewarded with the message, “SYNTAX ERROR IN LINE 10,” according to John Rudan. The computer operator of the university’s Burroughs 220 in Rand Hall, beginning in 1959, Rudan later wrote The History of Computing at Cornell. His account from the 1950s to the ’90s is published, digitally of course, by Internet University Press.

An IBM 650 was the basis for the university’s first computing course, taught by industrial engineering’s Richard Conway as IE 3281, “Computers and Data Processing Systems,” beginning in the fall of 1956. Forty-five undergraduate and graduate students signed up for the class.

Compared to the massive mainframe computers, the 1970s’ so-called minicomputers for scientific and engineering applications, such as DEC’s PDP and VAX machines, were relatively minuscule in size and affordability, which allowed the university’s departments to house computers in the same buildings as the laboratories and classrooms. The advent of desktop personal computers in the 1980s meant that students and professors could have their own.

Only a handful of institutions worldwide had supercomputers when the Cornell Center for Theory and Simulation in Science and Engineering—renamed in 2007 as the Cornell University Center for Advanced Computing—was founded in 1984 by a physical scientist. Kenneth G. Wilson, Cornell’s 1982 Nobel Laureate in physics, leveraged the clout of a freshly minted Nobelist to convince the scientific and governmental communities to share his vision: that high-performance computing is just as essential to scientific inquiry as theory and experimentation.

Computer scientists already knew that, of course, and department faculty members eagerly joined the theoretical physicist in a grant-winning proposal to the National Science Foundation. Among the co-authors were John Hopcroft, Kenneth Birman, Robert Constable, and Charles Van Loan. Their proposal brought to Cornell one of five NSF-funded national supercomputer centers—each charged with providing high-performance computing across the disciplines and around the country, for the needs of academic and governmental institutions and industry.

Cornell’s “Theory Center,” the program that would be housed in Frank H. T. Rhodes Hall, became a proving ground for the increasingly complex computer industry,
whose leaders eventually came to agree with Ken Wilson that parallel processing is the best way to handle massive computing tasks. The Theory Center’s first big machines came from the IBM 3090 series of vector computers, but soon Big Blue was persuaded to deploy to Cornell one of the largest and fastest IBM SP (scalable power) parallel computers in the world.

Success of that IBM “beta test” at Cornell persuaded others in the industry to follow, even as the superlative “super” became a moving target. A Dell supercomputer at the Theory Center helped that company make the Top 500 supercomputers list. When the Theory Center pioneered the use of a Windows cluster (more than 2,000 processors), Microsoft decided to enter the high-performance computing marketplace. One of the first Intel Hyercubes powered a Theory Center offshoot, the Advanced Computing Research Institute (ACRI), led by a computer science faculty member, Thomas F. Coleman, who later directed the Theory Center.

Other ACRI members from computer science, including Keshav Pingali, Stephen Vavasis, and Van Loan, collaborated—with engineers and scientists from chemistry to biomechanics to civil and environmental engineering—to apply computer-science expertise in parallel linear algebra methods and advanced optimization techniques. Along with its new name, the Center for Advanced Computing redefined a mission that Theory Center founders had in mind in the first place: to reduce time-to-insight, develop better products faster, and deploy cyber infrastructure to deliver the data that would drive discovery for decades to come.

The Department of Computer Science has always been involved with the basic software that keeps computers running—operating systems, security methods, networking modules, and so forth. On the theoretical side, Joe Halpern was awarded the 1997 Goedel Prize for his work on common knowledge in distributed environments. On the practical side, Ken Birman’s Isis Toolkit has been used in the French air traffic control system, the Swiss Stock Exchange, and the AEGIS warship. And Fred Schneider chaired a National Research Council committee that produced the important study “Trust in Cyberspace,” which received much attention.

Security is the big issue these days, and Cornell leads the way in a number of security areas, from language-based security (Schneider, Andrew Myers, Dexter Kozen) to peer-to-peer systems (Gun Sirer), to operating systems (Birman, Schneider, Sirer). What makes this group so influential is its mix of backgrounds in theory, logic, formal methods, programming languages, and operating systems. In fact, this bridging of areas is a hallmark of computer science at Cornell.

**How Computer Science Melted the Cold War**

Explaining real-world applications of arcane disciplines—matrix computation, for example—can stymie some scientists. But not Charles Van Loan, who claims only half jokingly that “matrix computation brought down the Berlin Wall.”
His reasoning: Matrix computation—solving basic algebra problems with computers—was essential to signal processing and control engineering R&D for America’s Strategic Defense Initiative (SDI or “Star Wars”) anti-missile shield program in the 1980s. The proposed shield depended on real-time signal processing to sense data (incoming missiles), solve equations quickly (thanks to matrix computation), and determine where to aim a counter force (the missile-zapping lasers).

Like the popular film series, America’s Star Wars was more fiction than science. “It was mostly a bluff,” Van Loan said, “but with enough exciting and realistic technology to make it a credible bluff. At the core of the enterprise was real-time matrix-based signal processing, an area that remains important to this day. The current spread of powerful matrix techniques into information science areas is very reminiscent of what went on in these other areas during the 1980s.” Since then, matrix computation has become important in other applications, such as data mining. Van Loan found a use for his research as well. His widely cited text, *Matrix Computations* (with Gene H. Golub) is now in its fourth edition.

**Experiential Learning**

Less concerned with publishing at this stage of their education, Cornell undergraduates readily find tangible applications for their newfound computer-science skills. Across the college, student teams that design and build such projects as race cars, autonomous underwater vehicles, minisatellites, and mine sweepers offer opportunities to put computer science to work.

Interdisciplinary opportunities also extend beyond the Engineering Quad. Computer science undergraduates in GDIAC (the Game Design Initiative at Cornell), launched by computer science lecturer David Schwartz and computer science alumni Ramin Hoetzein and Mohan Rajagopalan, learn to collaborate with student artists and musicians from across campus. As a result, computer games that arise from the GameX platform for collaborative instruction at Cornell are highly regarded for their integration of the best technical, artistic, and cultural aspects of game design.

“It’s called experiential learning—and it’s one of the best things Cornell students have going for them,” said David Gries. He points to the computer-controlled photovoltaic-powered house, the second-place finisher in the 2005 national Solar Decathlon, as proof that Cornell computer sci-
ence students thrive in cross-disciplinary teams. “We even had business students from the Johnson School who helped market the Solar Decathlon house and get the funding. It was a wonderful experiential learning achievement for the whole team.” Gries said.

**Collegiality Space**

The role models for collegial collaboration among students, Gries says, are the faculty members they see each day in the Department of Computer Science, the other schools and departments of the College of Engineering, and in the other colleges across the campus. Gries credits Hartmanis with starting the tradition of collegiality in Cornell computer science—a department that for years preferred daily lunches to formal faculty meetings.

Hartmanis modestly accepts the recognition, but insists, “I just took advice, poured the coffee, and made consensus decisions. We all shared the enthusiasm for a new science that started in the very early ’60s. It was exciting to see a discipline grow and see it defined.”

Inevitably, the Cornell computer science faculty outgrew the Statler Hotel coffee tables (the department now has more formal, less frequent faculty meetings). From Upson Hall’s fourth floor, and a two-story addition on its other wing, plus a connection to Rhodes Hall, computing at Cornell is about to get more space. A $25 million gift from Bill Gates’s Microsoft has provided seed money for such a facility.

Juris Hartmanis’ wish list for the future of computer science at Cornell is short but well considered. It doesn’t include more funding. Computing is pretty well supported at Cornell, both internally and by external sources like the NSF, the Defense Advanced Research Projects Agency (DARPA), the Department of Defense, and more recently, the National Institutes of Health, he observes.

“A few more superstars” on the faculty would be nice, of course, but what the founding chair mainly wants is space for collegiality. He doesn’t mean more Internet bandwidth or faster instant messaging: “No, we computer scientists need physical proximity, in the same building with open stairwells and atriums, to give a feeling of connectivity. We want a building created for interactions.”
Just because parts of the Earth system can be named—the atmosphere, biosphere, hydrosphere, and lithosphere—and studied in the context of traditional disciplines—biology, climatology, geology, meteorology, and oceanography—doesn’t mean there’s not a better way.

Students and faculty members of Cornell’s Department of Earth and Atmospheric Sciences (EAS) have found a way to embrace all the spheres—without overlooking details of any of them and learning a lot about at least one of them—that reveals how they are interrelated. The science of earth systems, they’re finding, can be a portal to the past, an integrative explanation of present-day phenomena, and an enlightened strategy to manage a sustainable future for the planet.

Better yet, students earning a Science of Earth Systems bachelor’s degree or an Atmospheric Sciences bachelor’s degree do it all in four years that begin with a solid grounding in biology, chemistry, mathematics, and physics. Then, after a required introductory course, the world is theirs to explore, with core courses like “Introduction to Biogeochemistry,” “Climate Dynamics,” “Evolution of the Earth System,” and “Interior of the Earth.”

For meteorology students in the atmospheric sciences side of the department, a strong background in mathematics and science prepares them equally well for careers in broadcasting; positions with environmental consulting and weather-forecasting firms, government agencies, or Wall Street firms; or advanced study in related disciplines.

Independent studies of the Earth and of the atmosphere go back to Cornell’s beginnings. Meteorology and astronomy were of interest to Cornell civil engineers through the 1880s and ’90s when Estévan Fuertes led that field, although no formal degree pro-
gram existed for either subject. That changed with the 1904 founding of the New York State College of Agriculture. Meteorology—with a distinctive agricultural focus at first, but broadening its mission in the 1980s to include climatology—has been taught there ever since.

Cornell engineering students could study geology from the day the university opened its doors in 1868, although the Department of Geology was based in the arts college until 1971. That year, administration of the renamed Department of Geological Sciences moved to the College of Engineering. Even though Cornell geologists left their longtime home in McGraw Hall (for temporary quarters in Kimball Hall, until a dedicated facility in Snee Hall was ready), geology continued to be a degree-granting field in both the College of Arts and Sciences and the College of Engineering.

Today, the Department of Earth and Atmospheric Sciences has connections to all three colleges—Engineering, Arts and Sciences, and Agriculture and Life Sciences. These scientists of the Earth and all its spheres have a rather expansive definition of the term “classroom.”

“Back in September”

As if earth scientists ever need a reason to pack a kitbag, tack a “Back in September” note on the office door, and head off to explore the planet, the founding faculty of Cornell’s Department of Geology had a dark and dusty one. Cornell geology’s first headquarters was a single basement room next to the coal cellars in Morrill Hall. So Charles Frederick Hartt, the university’s first professor of geology, dutifully taught classes in the fall and spring semesters, began to assemble a faculty that soon would total four, and plotted a summer getaway.

By June 1870, Hartt had amassed the funding (principally from a university trustee, Col. Edwin P. Morgan) for the first of two geological forays to Brazil, known as the Morgan Expeditions. Nine geology students—together with a Cornell professor of botany who specialized in mycology, Albert N. Prentiss—sailed from New York with Hartt. Their Brazil fieldwork yielded more geological and paleontological samples for the growing collections and botanical specimens for the university’s Wiegand Herbarium. Hartt had been to Brazil once before, with the 1865–66 Thayer Expedition headed by his Harvard mentor, Louis Agassiz (who served as a visiting lecturer at Cornell beginning in 1868). This time around he tried to learn more Indian languages and customs, help with the botanical survey, and discover talent for the next generation of field geologists.

One of Hartt’s talent finds was Orville A. Derby, who earned an 1873 bachelor’s degree and an M.S. in 1874—when the School of Geology was part of Cornell’s College of Natural Science, together with schools of zoology, botany, and physical geography—and who became the chief geologist of Brazil.

For other Hartt students, Brazilian expeditions were stepping-stones to university president’s offices. Theodore B. Comstock earned his B.S. degree (the first awarded in
geology by Cornell) in 1870, was appointed as Cornell’s first assistant professor of applied geology, and subsequently was put in charge of that department in 1875. Comstock earned the only geology D.Sc. ever awarded by Cornell (in 1886), and became the first president of the University of Arizona (in 1894).

John Casper Branner, a Cornell student member of the 1874 expedition that launched the Brazilian Geological Survey, became president of Stanford University in 1913. Branner was the second Cornellian to head the Palo Alto school, having been the first faculty appointee of David Starr Jordan, an ichthyologist who earned a Cornell master’s degree in 1872 and was president of Stanford from 1894 to 1913. (Jordan learned some of his ichthyology from visiting lecturer Agassiz, who questioned Darwin’s theory of evolution [see “Evolving Thought,” page 152].) Branner rose from Stanford’s geology faculty to become vice president, but he was back in Brazil and looking forward to retirement when the Stanford trustees offered him a promotion.

Stanford President Branner is revered to this day for blocking a Board of Trustees attempt to cut salaries and department budgets with this declaration: “If scholars are to be chased away or replaced by cheap instructors, I don’t want anything to do with the outfit!”

**Geologists and the Art of Teaching**

Classroom instruction that prepared the first geology students for the much-anticipated fieldwork emphasized learning to learn by observation—under the watchful eyes of real scholars, not “cheap instructors.” As an 1874 course description made clear: “The early training of geological students consists in the personal, critical examination of specimens. The student [is] required to find out everything for himself, without the consultation of books.” Geology professors set out the specimens for the day, explained “the difference between seeing and observing,” and stepped back. “Only after he has completed his work for himself,” the course description said of the student, “is he allowed to consult authorities, and, by comparing his own work with that of a master, test the accuracy of his own results.”

Cornell geology students could learn about fossils when Frederic W. Simonds was hired to teach paleontology. For a time, beginning in 1874, the department was called the School of Geology and Paleontology. Then, when paleontologist Henry Shaler Williams was geology’s chair (1886–92), the teaching of mineralogy moved from the chemistry department to geology.

Before leaving Cornell in 1879, Comstock organized geology courses for students in architecture and engineering that were among the first of their kind in the country. Another Cornell geologist, Samuel Gardner Williams, became the university’s first professor of the Science and Art of Teaching. For a few months, the department had three professors named “Williams”—until J. Francis Williams, the teacher of practical petrography and optical crystallography, died in 1891. Henry Shaler Williams was among the founders of two organizations that got their start at Cornell: the Society of Sigma Xi and the Geological Society of America (GSA). He was elected treasurer of GSA at its first formal meeting, December 27, 1888, in Sage Hall, and he served as the society’s third president from 1895 to 1901.
Regarded by geological sciences historian William R. Brice as the “intellectual patron of Cornell geology,” Louis Agassiz might not be accorded the same status in departments that teach evolutionary biology. The Harvard zoologist, paleontologist, and geomorphologist was among Cornell’s first roster of distinguished nonresidential professors when the university began classes in 1868. In addition to delivering lectures on natural history to Cornell students, Agassiz freely offered his advice to founding president Andrew Dickson White—including the recommendation to hire Charles Frederick Hartt as a professor of geology:

“Your appointment of a professor of geology is the most important among the physical sciences [because] New York is, as it were, the standard ground of American Geology. You cannot afford to make a mistake in your selection of the man who shall represent that branch of science in the new University.”

But Hartt, while acknowledging that he owed his job to Agassiz, soon had to point out a serious error in the senior scientist’s thinking. Agassiz was one of the foremost proponents, at the time, of the theory of catastrophic glaciation; he maintained that “God’s great plough” in a relatively recent Ice Age—rather than a biblical Great Flood—had wiped out all living species with globe-spanning ice sheets. The provocative Agassiz argued against Charles Darwin’s theory of evolution, espousing instead the so-called “fixity of species,” and he angered geologists who had documented glaciation in the Northern Hemisphere with his claim, following an 1865–66 expedition to Brazil, that scattered boulders there were “glacial erratics,” evidently moved great distances when ice-age glaciers supposedly covered South America.

Hartt followed Agassiz’s footsteps in his 1871 expedition to Brazil, examined some of the same boulders, and determined that they were not glacial erratics at all—just big rocks transported by rushing water. Hesitating at first to contradict the department’s intellectual godfather, Hartt did eventually publish his findings.

Before death in 1873 ended his Cornell visiting professorship, Agassiz was beginning to soften his opposition to the theory of evolution. He said: “Every great scientific truth goes through three stages. First people say it conflicts with the Bible. Next they say it had been discovered before. Lastly, they say they always believed it.”

Cornell’s twentieth-century geologists generally had no problem with evolution. While Oscar D. von Engeln taught glaciology and geomorphology, the university became a center of expertise in paleontology and biostratigraphy (as mollusks and foraminifera, the fossilized microscopic skeletons of single-celled marine organisms became valuable tools for the oil-exploration industry), thanks to the work of Gilbert D. Harris, W. Storrs Cole, and John W. Wells. With the exception of Harris, all served as chairs of the department. Cole advanced a plan that, had it succeeded, might have kept Cornell geologists on the arts quad: he suggested gutting McGraw Hall to its stone exterior, installing a steel frame to squeeze two more floors into the high-ceilinged building, and allocating half of McGraw’s space to geology.

Instead, geology moved to Kimball Hall with its affiliation with the College of Engineering and when Wells retired in 1973, his replacement was paleontologist and stratigrapher John L. Cisne. Known for developing the X-ray technique that reveals parts of fossilized organisms which had been soft tissue, Cisne led Cornell geology students in a long-term study of Ordovician rocks in New York’s Mohawk River valley. Paleontology—and earth sciences in general—at Cornell gained a major public face in 2004, when the Paleontological Research Institution (PRI) under the direction of Warren Allmon affiliated with Cornell. PRI’s Museum of the Earth is now both a major tourist attraction and an effective means of communicating earth science to the public at large.

Agassiz probably had something like that in mind, more than a century before, when he said: “The time has come when scientific truth must cease to be the property of the few—when it must be woven into the common life of the world.”
The lure of far-away places notwithstanding, Cornell geology’s immediate neighborhood offered plenty of interesting rocks and fossils. Local Devonian strata became the research-and-teaching laboratories for Henry Shaler Williams, before he took on the early and late Carboniferous time period.

Oscar D. von Engeln, a member of the Cornell geology community for sixty-one years and department chair from 1944 to 1947, was still a student when he wrote in his 1909 guidebook to the university and its environs: “The story of the hills, the valleys, the streams and the lakes of Central New York . . ., fascinating in themselves, are many times more so, once their historic relations are known.” A shrewd observer of natural phenomena (See “A Geologist Talks about the Weather,” page 155.), von Engeln described for his student readers the effects of post–Ice Age glacial melting on a familiar landscape:

“After thus cutting across its former banks in a rock gorge, a stream once more encountered its drift-filled valley, it swept out this loose material and thus formed a broad, shallow trough, locally known as an amphitheatre, of which the site of Beebe Lake is an illustration.”

Von Engeln picked up those details from the faculty member who followed Williams as department chief, glacial geologist Ralph Stockman Tarr, who brought that specialty to Cornell in 1892. Tarr presided over the division of the department into four fields: Dynamical Geology and Physical Geography, which he headed; Paleontology and Stratigraphic Geology, headed by Gilbert D. Harris; Mineralogy and Petrology, under Adam Capen Gill; and Economic Geology with Heinrich Ries, although Tarr also administered that field until Ries’s death in 1912.

From their beginnings in 1894, those four fields defined geology for the next forty years on the Cornell campus. Fieldwork figured heavily in all of them. Glaciologist Tarr led expeditions to icy places, including Greenland in 1896, and Alaska’s Yakutat Bay in 1905, 1906, and 1909. As much as von Engeln loved Ithaca (he worked for years on the manuscript for *The Finger Lakes Region: Its Origin and Nature*, which was finally published in 1965 when he was eighty-one years old), he joined the Yakutat Bay expeditions, then wrote the book, *An Alaska Wonderplace*.

Harris steered in the opposite direction—partly to get away from Ithaca winters, colleagues suspected—in his dual roles as professor of paleontology at Cornell University in the temperate trimesters in New York, and as the state geologist of Louisiana in the winters. (See his business card, above.) Even as a college professor, Harris’s classrooms were mobile. Beginning with the paddle-wheel gasoline launch *Ianthina* in 1896 and a series of fossil-namesake boats that followed, Harris and his students surveyed riverbanks, lakeshores, and the eastern coast of the United States from water level.

Harris also is credited with bringing more women into geology, by way of paleontology—the one field that was considered to be “respectable” for female scholars of the
A suit-clad Oscar von Engeln taught in Ithaca’s Fall Creek gorge.
A GEOLOGIST TALKS ABOUT THE WEATHER

“Perhaps there will be some among the university community who will feel you should not have been told this.”

O. D. von Engeln, Concerning Cornell (1917)

Before college admissions offices published viewbooks to tout their academic programs and scenic campuses to prospective students, a Cornell geology graduate of the time wrote his own. Oscar D. von Engeln (Ph.D. 1911) was already the author of An Alaskan Wonderplace and On Being Abroad in Winter when he published the first viewbook, At Cornell, in 1909. Its 347 pages were filled with von Engeln’s photographs and lyrical descriptions of the natural history of the campus and its environs (including more regional geology than most students probably cared to know), together with descriptions of Cornell’s classrooms, laboratories, and living quarters; customs and traditions; and “Student Life of Everyday,” as one chapter promised. He was a recently appointed assistant professor of physical geology when his 455-page revised viewbook was published in 1917, under the title, Concerning Cornell. The frontispiece in both editions was a photograph by the author, “In Cornell Precincts,” showing two coat-clad figures passing the geology department’s office in McGraw Hall.

Significantly, it had been raining when the graduate student set up his camera, and von Engeln had more than a few words of warning about Ithaca’s famously dreary weather:

“The Cornell region lies in the average storm track of the west wind belt. As a result practically every weather disturbance that crosses the United States from the west is felt in this region. Overcast skies are common; we normally have frequent rains and usually much snow. Unfortunately, too, the university session beginning with fall and extending through winter and spring comes in the eight months of the year that include both the disagreeable transitional seasons.”

Since the books were not official Cornell publications, the former student was free to discuss turn-of-the-century winters at Cornell: “Fiercely buffeting winds, whistling around corners of buildings and bringing with them blinding flurries of snow that pile up in drifts across the walks, are typical of winter days.”

The campus’s Beebe Lake, a wintertime center of social activity for skating, tobogganing, and cheering Cornell’s hockey team on the home ice, “freezes over readily and smoothly after the first few hours of consecutive cold and then usually remains ice-covered for several months.” In these times of global warming and shorter winters, there are two ways to verify von Engeln’s icy claim: February 1912 was cold enough for an athletic Cornell senior chemistry major, Floyd R. “Flood” Newman, to skate the length of Cayuga Lake. Or you can check with the Northeast Regional Climate Center, the Earth and Atmospheric Sciences unit on the top floor of Bradfield Hall, where historic weather records from all National Weather Service stations, including Ithaca’s, are kept.

The nearest weather station was on campus (in a Central Avenue kiosk that contained a rain gauge, barometer, maximum and minimum thermometers, a thermograph, and other instruments) when von Engeln commented: “It is a great comfort to stop on a frosty morning and observe how low the temperature actually is.”

Wretched weather notwithstanding, Cornell really had some nice days, the geologist admitted, when “the sun shines clear, the air is a sparkling tonic.” He recommended Cornell summer, early fall, late spring, and just about any time when storm clouds parted. Captioning the view shown on the frontispiece of his viewbooks, he wrote:

“The time is late afternoon in early spring; the last clouds from a warm shower have just passed over, and now the sun, still high in the west, makes a reflection of the cerulean blue sky and the flowing lines of the elms in the little pools which fill the hollows of the old, worn walks.”
earth sciences in the early 1900s. By the end of that century, a quarter of all Earth and Atmospheric Sciences–affiliated undergraduates were women, and some were finding jobs as broadcast meteorologists. At present, about 50 percent of Earth and Atmospheric Sciences undergrads are women.

Geology students’ enthusiasm for more distant expeditions was whetted by summer field experiences—first at the Henry Shaler Williams field camps at Spruce Creek, Pennsylvania, and later at the Sierra Madre (Wyoming) field camps run by William Travers. After Williams’s retirement, the Spruce Creek camp was run by the structural geologist (and department chair from 1939 to 1944) Charles Merrick Nevin. Dubbed “Chief What-Are-You-Standing-On,” Nevin was remembered by students as a first-rate teacher but a terrible cook. Bathing and laundry accommodations were the same: the icy waters of Spruce Creek.

Heinrich Ries, the economic geologist and a specialist in clay mineralogy, extended his science across departmental borders to teach engineering geology. Ries’s text, Engineering Geology, went through five editions and was co-authored by Thomas L. Watson, who earned his Cornell Ph.D. in geology the year after joining the 1896 Tarr expedition to Greenland. Ries also developed the country’s first laboratory for testing molding sands at Cornell, and built the university’s collection of ore samples.

Following Harris’s 1936 retirement from Cornell (He had founded the Ithaca-based Paleontological Research Institution in 1932 and continued to publish the scholarly monograph series he started at the university from that Ithaca-based institution), the tradition of research and teaching in paleontology was carried on by W. Storrs Cole and John W. Wells. A 1963 discovery by Wells—that corals can be used as indicators of the number of days per year in the earth’s geological past—confirmed that the rotational speed of the planet is slowing. Before that, both Cole and Wells had witnessed effects of
events that changed the earth (and the atmosphere): the atomic bomb tests at Bikini atoll in the Marshall Islands. They were members of government-commissioned scientific teams that studied the area before and after the blasts. Back in Ithaca, Wells continued the studies of local Devonian strata begun by Henry Shaler Williams, served as department chair from 1962 to 1965, and was the first Cornell geology faculty member elected to the National Academy of Sciences. Cole had preceded Wells as chair, serving from 1947 to 1962.

By the late 1960s, a department with little more to offer than mineralogy, paleontology, petrology, and economic geology was attracting fewer and fewer students each year. Questioning the university’s support of geology, some faculty members left for other opportunities. In the 1970–71 academic year—when no undergraduates earned geology degrees and only one master’s degree candidate and four doctoral candidates did so—the most exciting event was the discovery of a firebomb in the basement of McGraw Hall. The bomb failed to detonate but faculty members and students feared for the well-being of geological collections in the old wood-and-stone building and they volunteered for overnight shifts to watch the building—until a few dollars were found in the department’s meager research budget to pay a security guard.

A university-wide committee debated three possible fates for geology at Cornell: dissolve the department and disperse remaining faculty members to other departments; combine geology with astronomy, a more vigorous department in the College of Arts and Sciences; or move the administration of and responsibility for geology to the College of Engineering. Along with the recommendation to build expertise in an up-and-coming field—the geophysics of plate tectonics—to reinvigorate research and attract more students, the committee recommended that the engineering-based department have faculty appointments in and grant degrees from the arts college. George A. Kiersch retired as the last geology department chair in the arts college, and astronomer Frank Drake served as acting chair until a plate-tectonics specialist arrived.

**A Fair Shake for Planet Earth**

The department had its own seismograph as early as 1907, when an office assistant named Pearl Sheldon kept an eye on the slowly revolving smoked metal drums and alerted the faculty if she thought a scratched squiggle seemed to indicate a tremor. But with the 1971 arrival (from Columbia University’s Lamont–Doherty Observatory) of a newly recruited chair, Jack E. Oliver, Cornell geological sciences was about to do some earth shaking of its own.

Geophysicist Oliver and his colleagues adopted (from the petroleum-exploration industry) and adapted (for basic research) the seismic-reflection profiling technique for mapping structures deep within the continental crust. With substantial funding from the NSF, they leased a fleet of vibrator trucks that moved slowly across the countryside, thumping the ground and collecting the reflected signals on kilometers-long arrays of geophones. Multiple channels of seismic reflection data were recorded on reels of magnetic tape for subsequent analysis.
They called the program COCORP, for Consortium for Continental Reflection Profiling. The fleets of vibrator trucks that inched along public highways inevitably attracted curious passersby. Obligingly, Oliver and colleagues Larry Brown and Sidney Kaufman explained that their technique was like sonar: the vibrators generated acoustic waves that moved at different speeds depending on rock composition. They were particularly interested in the so-called discontinuities, places where the composition or structure of the crust changed abruptly. When the collected data were sent back to Cornell for computer processing, the geophysicists said, they could make three-dimensional maps that extended beneath the surface of the earth. The academic scientists were always careful to credit seismic reflection profiling to the petroleum industry. When passersby politely suggested that the COCORP trucks might be a little off course—that the nearest known oil fields were hundreds of miles away and, in any case, no drill could reach the depths achieved by the acoustic waves—the Cornell geophysicists had a polite response: We’re not oil men; we are earth scientists trying to solve fundamental questions about the composition, structure, and evolution of the continents.

**Breakup and Reassembly of the Continents**

That all began to make sense—to the general public and the scientific community—when 1980s reports of COCORP surveys reached the scholarly literature and the popular news media. Seismic-reflection profiling in areas such as the southern Appalachians and the Basin and Range of the western United States revolutionized geologic thinking about the origin and evolution of mountain belts, rift valleys, and the continents they form.
In the eastern United States, for instance, COCORP studies of the roots of the mountain belts overturned conventional notions of how the Appalachians arose. Colliding continents started the process, the COCORP geophysicists agreed, but they disproved assumptions that had been made from studying rocks on the surface—that the Appalachians must have been formed by lateral accretion of new continental material along steeply inclined “sutures.” Instead, the COCORP profiling showed the overthrusting—for hundreds of miles in a southeast to northwest direction—of relatively thin sheets of rock. The result, they said, was an out-of-order sandwich, with wet sedimentary rocks trapped beneath older metamorphic rocks.

Implications of the rewritten story of the Appalachians would have intrigued Cornell’s first economic geologists: it suggested that the buried strata might still contain economic reserves of hydrocarbons, according to Brown. Or that the water squeezed out of trapped sediments might have migrated through the overlying crystalline rock to deposit significant quantities of ore. Twenty-five years later, a Cornell-educated geologist, Steve Squyres, suggested that certain minerals discovered by the Mars rovers had been deposited in water—water that once might have nurtured life on the Red Planet.

And in the Basin and Range province of western Utah and Nevada, where the present North American continent seems to be pulling apart at the seams, COCORP offered a different perspective. The geophysicists agreed that the characteristic series of mountain ranges and valleys resulted from lateral extension of the surface. But instead of faults believed to extend completely through the crust into the underlying mantle, COCORP surveys found a radically different arrangement: that former low-angle compressional faults, such as those formed during continental collisions, had been reactived to stretch apart the continental crust.

Wherever COCORP’s vibrator trucks roamed, it seemed, new light was shed on earth’s subsurface. In New Mexico and in southern California’s Death Valley, for instance, they found midcrustal magma chambers that no one knew were there. Crossing the Sierra Nevada in northern California, COCORP surveyors found moderately dipping fault zones that extended into the middle and lower crust. The faults, geophysicists said, might have been conduits for the circulating fluids that deposited the minerals that started the California Gold Rush.

**Alternative Introspection**

Even as COCORP and INSTOC (the Cornell-based Institute for the Study of the Continents) prepared to take seismic reflection profiling on the road to Asia and Europe, other Cornell geologists tried alternative ways of looking inward. For William A.
Bassett, John M. Bird, and Maura S. Weathers, their journey-to-the-center-of-the-earth vehicle was a diamond-anvil cell. By squeezing samples between the flat faces of single-crystal diamonds—to simulate deep-earth pressures—and focusing infrared radiation from rapidly pulsed lasers to achieve very high temperatures—they managed to melt not only the sample but also the surface of the diamond. If diamond can be melted at high temperatures and pressures, so can other forms of carbon. Liquid carbon, they said, could even provide the driving mechanism for mantle plumes that produce such features as the Hawaiian volcanoes.

Far north of the Hawaiian Islands, meanwhile, in Alaska's fog-shrouded Aleutian Islands, the team of Robert W. Kay and Suzanne Mahlburg Kay were looking inward. Their research into geodynamics and crustal growth tracked radiogenic isotopes of mantle material through one of the original recycling processes on earth—the subduction of old crust into the mantle and the formation of new crust out of mantle material. When subduction occurs at one edge of an oceanic plate, the Kays observed, everything goes down—continental sediment elements that were dissolved by chemical erosion of the continents and fixed into basaltic oceanic crust by hydrothermal circulation of sea water, along with plenty of water. Millions of years later, they said, the long-missing water has an important role in initiating the rise of mantle material as molten magma, which returns to the surface to make more crust. Since the best places to observe this cycle are volcanic arcs, the Kays zigzagged among the Aleutians, the Philippines, and the Andes. Their immobile gear list was topped with mass spectrometers, electron microprobes, computers, and x-ray and neutron-activation devices—"mobilized" by camping gear, Zodiac pontoon boats, sturdy field boots, compasses, and many sample bags.
Geomorphologist Arthur D. Bloom was to be found on islands in the South Pacific. Presaging by thirty years the twenty-first century “hot topic” of global climate change, Bloom’s team established the age of the most recent “interglacial,” the pause between multiple advances toward the equator of polar ice sheets. Using the islands as “dipsticks,” they measured the magnitude of sea level rises and falls in step with the Ice Ages. Their finding—that sea level was five meters higher during one of the recent interglacials, 120,000 years ago—indicates to policy makers one possible result of this century’s global warming.

Marine geologist Daniel E. Karig traveled to the Japan Arc, but not for the volcanoes. He was interested in the way ocean-bottom sediments are deposited, lithified, and eventually deformed, as rock becomes part of mountain belts. Much of the deformation geologists were observing in mountain belts actually began near the deep-sea trenches that mark converging plate boundaries, he said, explaining that soft sediments are scraped off the descending oceanic plates, to be incorporated into mountain belts. Deep-sea drilling provided much of the evidence for Karig’s lithification and deformation studies, but he did his share of mountain hiking, too.

When Cornell geology took on the Andes for an ongoing study of mountain-building processes—in one of the two places in the world where the effects of the convergence of lithospheric plates are most dramatic (the other is the Himalayas)—it was all hands on deck. Specialists in seismology and tectonics Bryan L. Isacks and Muawia Barazangi got help from Richard W. Allmendinger, who knew about seismic-reflection profiling and young faults. They were joined by Teresa E. Jordan, an expert in basin formation who could help determine the timing of deformation; Arthur L. Bloom, on the topic of landform evolution; Suzanne Kay, with her expertise in chemistry and the timing of volcanism; and numerous graduate students whose thesis research was based on the Cornell Andes Project.

Their ongoing project—the first and most comprehensive regional-scale synthesis of geological, topographic, and geophysical data ever attempted for the Andes—soon found something amiss in the generally accepted story. The conventional model of the underlying processes for mountains like the Andes had the crust thickening primarily by the addition of molten rock that rises from the mantle. Instead, Cornell’s team was finding evidence that the key operational process was a combination of heating and weakening of the continental plate that was followed, they said, by horizontal shortening and vertical thickening of the crust in response to compressional stresses produced by the convergence of lithospheric plates.

The start of Cornell’s Andes Project coincided, in the early 1980s, with some great leaps forward in computing technology that enabled earth scientists to exploit the rapidly expanding satellite and geophysical databases. Funded by the NSF and set up...
in Snee Hall by the Institute for the Study of the Continents, Cornell’s image-processing facility was available to all researchers in the scientific and engineering community. John Bird and David Harding, an NSF graduate fellow, used the facility to interpret LANDSAT data from southwest Oregon, for example. Allan Gibbs processed remote-sensing data for a study of the geology and mineral-resource potential in otherwise-inaccessible parts of the Amazon rainforest.

But it was the Andes Project crew who kept the image-processing facility the busiest. Isacks worked to integrate geophysical data sets—earthquake and topographic data—from the Andes, while Bloom used satellite-radar images of the Argentine Andes to study relatively recent geologic features like active fault scarps, volcanic fields, river terraces, and glacial deposits. LANDSAT images processed in the Snee Hall facility helped Jordan and Allmendinger study the active tectonics of the Andes and draw comparisons to mountain-building processes in the western United States 100 million years ago.

**Geology Comes to Life**

Along with several longtime geological sciences colleagues, Jordan still works in the Andes but a couple of things have changed. Lately she’s become interested in the geologic role of groundwater in a place where there is virtually no surface water, in Chile’s Atacama Desert, one of the driest spots on earth.

And the geologist has an expanded source of scientific collaboration, now that Cornell geology has joined Atmospheric Sciences to form the new Department of Earth and Atmospheric Sciences. The new connection to a college with “life” in its name (Agriculture and Life Sciences) is especially timely given the new global emphasis on “sustainability.” In addition to facilitating cross-disciplinary research, the merger has led to the development of new courses designed to make all Cornell students literate on the hot-button issues of global climate change, critical energy resources, and natural hazards.

Collaborations also extend beyond departmental borders. Inspired in part by the new sense of urgency on environmental issues, EAS scientists are forming new research partnerships with faculty members from chemical engineering, civil and environmental engineering, and materials science, among others, to initiate research on cutting-edge topics such as geothermal energy, carbon sequestration, and clean coal.

New frontiers for EAS research are also being opened by recent additions to the EAS faculty. Whether it is Jason Phipps-Morgan testing his new theory on the origin of the famous Tunguska, Siberia blast of 1908, or Matt Pritchard’s detection of unsuspected magma inflation beneath the Andes, Rowena Lohman’s fresh geodetic insights into earthquake processes at depth, Chris Andronicos’s probes of lower crust in western North America, or Natalie Mahowald’s novel models for distribution of dust particles, EAS is moving boldly into uncharted territory.

Perhaps the geologists’ wanderlust is contagious. More and more earth and atmospheric sciences faculty researchers and their students are going wherever on earth the interesting problems are found. Oceanographer Charles Greene counted zooplank-
ton in the North Atlantic to show the relationship between global climate change and abundance of food eaten by the endangered right whales. Then Greene, the director of Cornell’s Ocean Resources and Ecosystems Program, switched oceans for acoustic studies of the ecological dynamics of pelagic animal populations around Hawaii and the coast of the Pacific Northwest.

David L. Hysell’s radar investigations of plasmas and plasma waves in the ionosphere take him to two observatories run by Cornell, Arecibo in Puerto Rico and Jicamarca in Peru.

One hundred thirty years after the Hartt surveys, another Cornellian went to Brazil. Soil scientist Susan J. Riha documented carbon and nutrient accumulations in secondary forests regenerated from degraded pastures in central Amazonia.

For some EAS students, the department’s emphasis on “learning beyond the classroom” means a summer away from Ithaca, as it has since 1870. EAS 4170, “Field Mapping in Argentina” takes students from Cornell and from the University of Buenos Aires through the Andes’ San Juan and Mendoza provinces, a region of spectacular geology, to the foot of Cerro Aconcagua, the highest peak outside the Himalayas. A semester in Hawaii—designed to help undergraduates understand the relationships among the geosphere, biosphere, atmosphere, and ocean—prompted student Stephen Romaniello to say: “The emphasis is not on a book. It is on the ground, in the trees, the plants, and the rocks.”

Jordan says the department’s teaching and research is carried out at the frontier between the natural world and the human world of technology. When she states that “we benefit greatly from modern technologies to advance our knowledge about the working of Mother Nature,” she’s thinking about students’ and faculty members’ observations of volcano inflation or glacier melt (using satellite-borne synthetic aperture radar), about mapping shallow, subsurface features that are about to channel leachate from a decommissioned landfill into local water supplies (using ground-penetrating radar), or about measuring the chemical flux from hot water springs to a river system (using inductively coupled plasma mass spectrometry).

She thinks that geology’s move to the engineering college thirty-five years ago “could be seen as an omen of the increasingly refined technologies that would enable our current studies of Earth and its atmosphere. At the beginning of a century in which engineers must work to stabilize the relationships of humankind with Earth’s natural systems, the integration of Earth study with engineering has never been more valuable.

“We try,” Jordan says, “to educate our students about the most basic facets of earth processes, the complexly interacting systems of the earth, and the analytical tools necessary to extract information and analyze the system.”

By necessity, that education starts in classrooms. But there’s a whole earth (and atmosphere) out there, waiting to be cataloged.
Electrical and Computer Engineering: Cornell’s First Applied Science

Electrical engineering, the first applied science to emerge in 1885 from the original academic structure of the young university, today encompasses some forty subdisciplines. Many relate to communication and information technology—specialties such as bioelectronics, computer architecture, digital signal processing and information theory, optoelectronics, semiconductors, and visual communication. Studies of electrical phenomena are conducted by Cornell researchers on the largest and the smallest stages—in atmospheric and space plasmas and on the “nano” scale (a nanometer is a billionth of a meter).

Cornell was among the first to teach nanotechnology to undergraduates, who are introduced to the myriad applications of electricity, in required core courses that range from “Circuits for Electrical and Computer Engineering,” “Signals and Information,” and “Electromagnetic Fields and Waves” to “Computer Organization,” “Microelectronics,” and “Networks and Systems.”

Then they get to apply their creativity in what used to be called “laboratory courses”—but now demand much more than ingenuity from the would-be engineers who complete the two required “Culminating Design Experiences.” The students’ laboratory-designed systems must address issues of concern in the real world: economic and environmental sustainability, manufacturability, health and safety, and the ethical, social, and political implications of an engineered product—and, of course, they must work.

Power and Communications

Social considerations were fewer—and so were the uses of electricity—in electrical engineering’s formative years at Cornell. Physicists and mechanical engineers who could envision electricity’s place—in industry and an in everyday life—moved quickly, offering
the first course at Cornell in 1883 and establishing an electrical engineering department in 1889. Even at the university whose birth was founded on one of the more elegant uses of electricity—telegraphy—the first electrical engineers focused on making and transmitting massive quantities of electrical power.

“It was all about power at first—power generation, power transmission, and electrical power distribution,” according to Simpson “Sam” Linke, the emeritus professor and historian for the unit now called the School of Electrical and Computer Engineering (ECE), who began teaching at Cornell in 1946. Although power generation and distribution would continue to be one strength of Cornell’s electrical engineering program,
Linke quickly sensed that the balance was about to shift. His postwar generation of educators and their students would strive to make electrically powered devices smaller and faster for more efficient and powerful communication and information processing. “First power, and then,” Linke said, “communication.”

Students who saw communication as the wave of the future were further encouraged in 1909 when Cornell offered an elective course, “Wireless Telegraphy and Telephony,” and soon they were using radio signals to communicate. Whatever track they chose, power or communications, hands-on learning was the educational foundation of the first Cornell electrical engineering students. Some of the required core courses would send today’s students running to the clean room for refuge. One called “Sand Pounding” sent students to the foundry where they learned to cast molten metal in sand molds.

**Karapetoff’s Concentric Method**

By 1904, Cornell’s electrical engineering program had attracted an assistant professor who went on to write some of the standard texts of the time, share university-based knowledge with industry (just as Lester Eastman did in the second half of the century: see “Talk to Me,” page 169), and develop the so-called “concentric method” of teaching highly technical subjects. During his thirty-five years on the Cornell faculty, Vladimir Karapetoff saw his *Experimental Electrical Engineering* go through four editions, while writing the trilogy *The Electrical Circuit*, *The Magnetic Circuit*, and *Elementary Electrical Testing*, as well as the five-volume *Electrical Applications of High Mathematics*. The multilingual Karapetoff wrote *Polyphase Electric System with Unbalanced Load* in both German and Russian. But his poetry, collected in *Rhythmical Tales of Stormy Years*, was in English.

Karapetoff used his concentric method to teach experimental electrical engineering in three sequential courses—all of which used the same apparatus. As the experiments in each class grew increasingly sophisticated, more was demanded of the students, but they gained “a more mature understanding of the theory . . . in accordance with human nature; we always desire a bird’s-eye view of a subject before we care to go into the details,” Karapetoff explained.

Karapetoff’s teaching style was widely adopted but his “Rational Nomenclature of Electric and Magnetic Quantities” was not (one yrneh, which was Henry spelled backwards, was his unit of magnetic reluctance). Neither was his campaign platform (“Make Ithaca a Seaport”) when he ran for mayor on the Socialist ticket.

The master of electrical theory (and builder of kinematic computing devices) also was an accomplished musician (and inventor of a five-string cello.) Blindness—later in life, due to retinal detachment—did not keep Karapetoff from touring the country to
perform on the piano, violoncello, and double bass and giving lectures on Wagner, Liszt, Chopin, Brahms, and Debussy.

Legends of Karapetoff were all that remained when a young Sam Linke joined the faculty and returning war veterans (among them, Wilson Greatbatch: see “The Heart of the Matter,” page 171) used the GI Bill to study here. Faculty and students alike watched the field of electrical engineering enter an era of profound change. Linke remembers a 1950s symposium, in which Cornell electrical engineers were the first to hear plans to build the planet’s biggest “ear,” the Arecibo Observatory.

The director of the school, Charles Burrows, had established Tuesday afternoon colloquia in the 1950s, a tradition that continues to the present. Graduate students and junior faculty members gathered in the director’s office for refreshments and then adjourned to the auditorium. The colloquium speaker one Tuesday in 1958 was William E. Gordon, an electrical engineering associate professor. Gordon made an astonishing proposal: “Why don’t we find a big hole in the ground, about a thousand feet in diameter, and line it with metal, and set up a radar in the center? If we have this device, we can turn on the radar and direct it at Jupiter, and then go away and have a leisurely lunch—an hour, an hour-and-a-half or so—then return and the signals would be coming back from Jupiter.”

Members of the electrical engineering faculty involved in radio astronomy research offered to join the project. Three Cornell civil engineers (William McGuire, George Winter, and Donald Belcher) helped Gordon scout for likely sites near the equator (where objects in the solar system pass almost directly overhead). The search settled on a natural, bowl-shaped depression in the mountains of Puerto Rico. With support from the DARPA (and later from the NSF), the observatory was built, opening for busi-
In the area of communications alone, one can foresee the simultaneous use of hundreds of television channels because of the greatly increased number of frequencies available. Millions of simultaneous telephone conversations could be transmitted through a single microwave amplifier.

Lester F. Eastman, 1971

In his summer 1971 article in *Engineering: Cornell Quarterly*, titled “Crystals for Microwave Communication,” Cornell professor of electrical engineering Lester F. Eastman made some bold predictions. At that time most Americans were lucky to get three television channels on their rooftop antennas.

Beginning in the early 1960s (after earning all his engineering degrees, including the Ph.D. in 1957, at Cornell), Eastman pioneered the fundamentals of microwave solid-state electronics in the United States, then consulted with corporations such as RCA to help make his prediction of communication breakthroughs become reality. Eastman also took his new knowledge on the road, teaching in-plant courses to engineers at Westinghouse and Sylvania.
mation about plasma waves and turbulence during the interactions of solar storms with the earth’s magnetosphere and ionosphere.

Conducting experiments from other sites, including Arecibo and Cornell’s Jicamarca Radio Observatory in Peru, were faculty members of the Space Plasma Physics group, Donald T. Farley and Tor Hagfors, their research associates, and more than a dozen Ph.D. students. Decades of collaboration with Swedish physicists paid off in 1986 with the launch of *Viking*, Sweden’s first satellite, and the Cornell-designed plasma wave interferometer, also a first of its kind.

“Submicron electronics”—employing devices smaller than a millionth of a meter—was the next frontier for integrated circuit design when engineering dean Edmund Cranch headed west in 1977 for a national meeting of engineering educators in New Mexico. The assembled deans’ reward for mulling administrative details was a weekend ski holiday in Taos. Berkeley’s dean spoke with pride of a major national center he was sure would come to that University of California institution. The self-confident dean let it slip that the deadline for proposals to the NSF had not yet passed. That was all Cranch needed to hear.

“I changed my flights and returned to Ithaca immediately,” Cranch said, recalling that he “holed up in the dean’s office Saturday and Sunday with Connie Dalman and Joe Ballantyne (G. Conrad Dalman, electrical engineering director, and Joseph M. Ballantyne, an electrical engineering professor and future director). We finished the
By his own admission, Wilson Greatbatch (B.E.E. ’50) was not the most promising student in the School of Electrical Engineering. He tested poorly. The GI Bill scholar was distracted from his studies by the several jobs he held to support a growing family. The first application of his Cornell education—hourly work attaching brain-wave electrodes to goats for neurophysiology experiments—was not typical for electrical engineering graduates. Being in the right place at the right time, at a brownbag lunch one sunny summer day in 1951 at the Cornell psychology department’s off-campus animal behavior farm in Varna, New York, led to Greatbatch’s life-saving invention, the implantable cardiac pacemaker.

Greatbatch had installed telephones in western New York before making his way to Ithaca. During World War II, he had been a shipboard radio operator and a tail-gunner, flying off the carrier U.S.S. *Monterey*, where former president Gerald R. Ford was the deck officer. His Navy veteran’s status and a lifelong passion for all things electrical made Greatbatch eligible for the School of Electrical Engineering. There was room in the classroom, but no housing for nonresidential students. Greatbatch was ready to give up when he found a farmhouse for sale in Danby, six miles south of Ithaca.

He commuted to campus in a 1936 Buick, and his one distinction at Cornell, Greatbatch recalled years later, was having more children than most undergraduates (three at the time). He put food on the table by working at the student radio station and soldering parts into prototype equipment that would become part of the Arecibo radio-radar telescope.

His interest in electrophysiology began on the animal-behavior farm, as visiting surgeons discussed with the inquisitive electrical engineer the relationship between the brain’s hypothalamus and the heart. But in the days of vacuum tubes and bulky storage batteries, Greatbatch’s idea for an internal device to control cardiac irregularities was far from practical (the first pacemaker, built by Paul Zoll in 1952, was the size of a table radio and delivered painful shocks).

Greatbatch saw his first transistor in 1953, while working at the Cornell Aeronautical Laboratory in Buffalo. He designed the lab’s first transistorized device, an air-speed computer for helicopters. By the time transistors became commercially available around 1956, Greatbatch had met the Buffalo surgeon, William C. Chardack, who gave the engineer an assignment: build an oscillator with one transistor to record heart sounds. The oscillator design called for a 10-k ohm resistor, but Greatbatch made a serendipitous mistake. He accidentally substituted a 1-k ohm resistor and created a circuit that could drive the heart. The first successful cardiac pacemaker was implanted in a dog by Dr. Chardack on May 7, 1958.

A religious man since a close call over the Pacific in World War II, Greatbatch said he prayed and “was led to quit my jobs and devote my time to the pacemaker.” Working out of a wood-heated shop in a barn with $2,000 in capital, Greatbatch fabricated fifty prototype pacemakers for implantation—first in animals and subsequently in humans. Not all the human patients survived for long. But as pacemaker technology improved (using epoxy sealants instead of electrical tape and lithium–iodine batteries in place of the ones that use toxic plutonium-238), Chardack’s surgical technique improved, too. Cardiac pacemakers are now a routine way of life for hundreds of thousands of people who might otherwise not survive.

With biomedical companies manufacturing the pacemakers and batteries, Greatbatch’s attention turned to other innovations. Some were electrical—like the photovoltaic-powered canoe he sailed on Seneca Lake—while others crossed scientific boundaries, like the strategy to control immunodeficiency virus in cats that he developed with Cornell plant scientist John Sanford, a co-inventor of the Gene Gun. Certain Greatbatch ideas present enormous engineering challenges (mining the Moon for helium to power helium-3 nuclear fusion reactors for interplanetary travel) and some are pure whimsy (a cell-cultured rose called Rosemary Cloney that sports a five-millimeter-wide bud).

“The breadth of background Cornell gave me,” the man with some 200 patents said, “has enabled me to branch out when necessary into nuclear physics, electrochemical polarization of physiological electrodes, battery chemistry, the physics of welding, and countless other things.”
proposal and beat the deadline.” The result was the National Research and Resource Facility for Submicron Structures, or NRRFSS.

In fact, Cranch had already lined up funding from alumnus Lester B. Knight ’29 to help construct a specially outfitted laboratory adjacent to Phillips Hall. While the other deans skied, Cornell’s Cranch scrambled to come up with $1 million in matching funds, a requirement of the federal grant. Knight Laboratory was built to house NRRFSS, a first-of-its-kind “user facility” that attracted scientists from corporations and other universities while educating Cornell electrical engineering students using machines and materials they would encounter in the most advanced levels of industry. NRRFSS, now called the Cornell NanoScale Science and Technology Facility, quickly became one of Cornell’s leading sources of innovation.

Even before micron-sized devices became commonplace, Cornell electrical engineering was working at the nanometer (one-billionth of a meter) scale, leading the way in assembly of these tiny components. An NSF grant contributed to the establishment of the Nanobiotechnology Center at Cornell in 1999. The federal agency responded again in 2001 with funding for Cornell’s Center for Nanoscale Systems, and soon “nano” was cropping up everywhere at Cornell. In 2004, NSF selected Cornell to be the administrative hub and one of thirteen research nodes of NNIN, the National Nanotechnology Infrastructure Network.

Professor Sandip Tiwari, who joined Cornell in 1999, serves as the director of NNIN. Over the course of his career, he has explored microwave devices and circuits, high-speed electronic devices, optoelectronics, small and low-power devices, and their circuits and technology. Over time, his own research interests have gotten “smaller”—in small devices and their circuits, in ideas and technologies that allow continuing evolution of microelectronics in functional integration, and in interesting offshoots of small structures in other areas using silicon technology as a foundation.

Also in 2004, the Kavli Institute at Cornell for Nanoscale Science was established. Robert C. Richardson, the Nobel Prize–winning physicist, vice provost for research, and founding director of the institute, described it as a think tank designed “to engage multidisciplinary groups in exploration of emerging themes in nanoscale science and technology.”

One result of this Cornell nano-activity was the world’s smallest musical instrument, the 1997 nanoguitar. The tiny silicon guitar, about the size of a red blood cell, was built “to demonstrate fabrication techniques” and could not actually be played, but its successor, the 1999 nanoharp, could. By 2003, with the advent of the somewhat larger and highly playable nanoguitar (its silicon strings vibrated seventeen octaves—130,000 times—higher than a real guitar), Cornell nanoscientists had changed their tune: Such fanciful devices, they said, demonstrated their advanced capabilities for materials and device research in nanoelectromechanical systems or NEMS.

Industry insiders speculated that the guitar “strings,” 150-nanometer-wide silicon bars, might someday replace quartz crystals in telephones, taking up much less space and using a fraction of the power. Electrical engineering graduate Jeff Hawkins ’79 had another idea when he addressed the October 2004 grand opening of Cornell’s center of nanotechnology, Duffield Hall, which is named for its principal benefactor,
1962 electrical engineering graduate David Duffield. “We imagine new products that will benefit humankind,” said Hawkins, the father of the PalmPilot. “We imagine new manufacturing processes, a whole new world of the small, and even a hope for discoveries about the nature of life.”

Old Problems, New Solutions

Speculation about faster, more powerful devices from smaller bits of improved materials has some Cornell electrical and computer engineers wondering when Moore’s Law will hit a brick wall. (In 1965, Gordon Moore, the co-founder of Intel, had predicted that data density on integrated circuit chips would double every twelve months. He later revised this to eighteen months.) They know that as electrical engineers, they have been able to ride Moore’s Law. Many problems were solved by improving performance—higher speed, more transistors in a smaller space—and that has solved a lot. The coming problem, they say, is this: maybe performance isn’t the most important issue. Maybe engineers have to start looking at broader issues, social issues. Satellites are taking pictures of everything, all over, all the time. How do we deal with that? How do we digest that data? How do we store it? Or should we store it?

Problems such as data overload are the meat and potatoes of ECE’s highly regarded information theory group, led by Toby Berger, the Irwin and Joan Jacobs Professor of Engineering Emeritus. For the 1985 centennial observance of electrical engineering at Cornell, Berger looked ahead to predict “Communications 2100.” He postulated thousandfold increases—not just in the rate of propagation of messages and bandwidth but thousandfold increases in “the rate at which we are capable of absorbing information sent to us from another organism or mechanism.” Berger talked about biochemically based artificial “gray-matter” storage media, virtual brain transplants, brain-to-brain communication, brain paralleling, and backing up accumulated information by dumping “part or all of the contents of one’s brain into a storage medium, then temporarily inserting contents from another brain.”

For students bewildered by his prophecies, Berger had some good news and some of the other kind for the year 2100. The thousandfold leap in students’ high-speed information implementation capabilities would compress the 1,800 hours of class time required for a Cornell engineering bachelor’s degree to one hour and forty-eight minutes. But by then, Berger counseled, “undergraduates may be expected to learn one-thousand times as much material.”

The next breakthroughs from ECE might be closer than 2100. For example, Amit Lal is working on an atomic powered microchip. A small amount of a radioactive element—the same as in a smoke alarm but on a microchip—produces enough radioactivity to energize a motion-lever arm, and the arm generates electricity for hundreds of years.

Rajit Manohar is making computers that run without a clock. These computers operate only when data are present, so they need very little power. A typical computer today, running at 1.5 gigahertz, is always on, like leaving the motor of a car running. Instead of an energy-consuming 200-watt machine, a computer without a clock would run on about one watt.
Energy conservation is the object of Richard Shealy’s attempt to make a light emitting diode (LED) that produces white light—not the ersatz combination of red, blue, and green LEDs, but full-spectrum white light that faithfully renders all colors. His LED is based on unique semiconducting materials that are grown with nanodimensional control. At a time when a third of this country’s energy bill goes into lighting, illumination with full-spectrum LEDs could be ten times as efficient.

Michael Spencer is conducting research focused on the epitaxial and bulk growth of large bandgap semiconductors, which will be critical for power electronics. Applications for this technology will likely include electric cars and DC-to-DC conversions for the national power grid.

A Wealth of Inventions

Of all of Cornell engineering’s inventive units, electrical engineering must keep the U.S. Patent Office the busiest. Dozens of electrical inventions with an Ithaca origin have come from electrical engineering faculty members.

Harris J. Ryan, the Class of 1887 graduate who succeeded Professor William A. Anthony as the head of the Department of Electrical Engineering in 1889, built one of America’s first high-voltage transformers in Ithaca. (The device, a key to long-distance transmission of electrical power, awaits restoration in the basement of Phillips Hall.) Two other Ryan inventions had a profound impact on electrical technology. On August 1, 1893, he was awarded U.S. Patent 502,384 for the “Dynamo-Electric Machine or Motor,” which overcame a major defect in the operation of DC (direct-current) machinery—sparking at the brushes. In 1905, Ryan developed his “Electric Wave Form Tracer.” By inserting and energizing horizontal and vertical plates around the electron beam of a cathode-ray tube, Ryan showed how the beam’s spot on a fluorescent screen could move in accordance with the voltage waveforms applied to the plates. He could not have imagined the applications that followed: the versatile monitors of modern cathode-ray oscilloscopes, television sets, radar, and computers.

A 1923 electrical engineering graduate who taught and experimented here from 1947 to 1956, Malcolm S. McIlroy was responsible for the “Electric Analyzer for Fluid Distribution Systems” (U.S. Patent 2,509,042, May 23, 1950), a device whose tungsten lamps lit up with varying degrees of intensity to indicate changes in fluid pressure of municipal gas or water pipe systems. Although the analyzer was built by the Standard Electric Time Company and sold to cities throughout the United States, McIlroy predicted that computers would someday surpass his invention.

Today’s computers run thousands of times faster—and the millions of transistors on each chip keep the signals from getting tangled—thanks, in part to the instruction-sorting developments of Hwa C. Torng, who earned a Cornell Ph.D. in 1960 and began teaching that same year. Some of Intel’s benchmark-setting Pentium chips were based on Torng’s innovations, which enabled processors to read, evaluate, and execute instructions.

Charles A. Lee and fellow Bell Laboratories scientist William Shockley were awarded the patent for the diffused-base transistor, the first demonstration of the feasibility of microwave transistor operation. Shockley received the 1956 Nobel Prize in Physics
(along with John Bardeen and Walter Brattain), for demonstrating the transistor effect, and Lee got a good job at Cornell. Joining the electrical engineering faculty in 1967, Lee and other Cornell engineers (including G. Conrad Dalman and John Silcox) patented more than a dozen semiconductor devices and manufacturing techniques. Some of Lee’s novel ultrathin devices went beyond the standard silicon to employ gallium arsenide and other semiconductor materials, and he pushed the envelope in field-effect transistors. Lee worked with fellow electrical engineering faculty member Jeffrey Frey and several of the school’s students to design and build the first ion-implantation machine, making ion-beam lithography a hallmark of the university’s Submicron Facility, which is now the Cornell NanoScale Science and Technology Facility (CNF).

Potential to “revolutionize the industry” was the way the New York Times hailed Yu-Hwa Lo’s patent for a compliant universal substrate for growing pure, single crystals of almost any semiconductor material. Other Lo patents covered quantum well lasers and optomechanical terabit data-storage systems, the latter with electrical engineering faculty member Noel MacDonald. MacDonald, the director of the CNF from 1996 to 1998 and school director from 1989 to 1994, was awarded more than two dozen patents. MEMS (microelectromechanical systems) were the focus of MacDonald’s research group at Cornell, although he is also credited with helping to combine Auger electron spectroscopy with scanning electron microscopy to further the capabilities of scanning Auger microscopy.

If electrical engineers were superheroes, Chung L. Tang would be the “femtosecond flash.” After joining the electrical engineering faculty in 1964, Tang was made the Spencer T. Olin Professor of Engineering, in part for his accelerating research in new optical materials and processes. The holder of some twenty patents, Tang is known for developing broadly tunable lasers that pulse in the femtosecond range—and for helping people appreciate how fast things change. (At 10^{-15} seconds, a femtosecond is even briefer than a nanosecond. The term used to measure the speed of some chemical reactions comes from the word “femto,” which means “fifteen” in Danish.) Another electrical engineering laser specialist with a penchant for speed is Clifford R. Pollock, the Ilda and Charles Lee Professor in Engineering. Some of Pollock’s patents are based on tunable infrared lasers, and optical fiber transmission.

Edward D. Wolf, the Hughes Aircraft scientist who joined the electrical engineering faculty in 1978, will be forever linked to an invention that, although it had little to do with electrical engineering, changed biotechnology in a big way. The biolistic particle-delivery system popularly called the Gene Gun grew out of the Submicron Facility (now CNF), where Wolf was the director in the 1980s. Cornell plant scientist John Sanford wanted to coat extremely small “pellets” with DNA and needed a better delivery system than the pellet gun he was using. With facility staff member Nelson Allen, Wolf
THE PRIDE OF CORNELL ENGINEERING

COOL STUFF FROM THE PODFATHER

If Cornell students had anything white in their ears during the summer of 2001—when the School of Electrical and Computer Engineering named Jonathan J. Rubinstein as one of its four outstanding living alumni—it was excess sunscreen lotion.

Rubinstein was cited in the school’s alumni newsletter, Connections, for changing Apple Computers’ money-losing ways of the late ’90s. He had brought to market such modestly successful products as the iMac desktop computer and the PowerBook and iBook laptops. But in 2001, Cornell (and other college) students were more likely to carry McIntosh apples from dining halls than Apple products from the Cupertino, California, company.

Unbeknownst to Connections Editor Sam Linke, the Apple vice president was leading a top-secret engineering team that—in an industry-record eight months—would bring to market the iPod in November 2001. By the next summer, the distinctive white earbuds of iPods were on the hippest heads on campus—the early adopters of a device that would sell 100 million within six years.

Here’s what Rubinstein told Linke about his Cornell education:

“When I entered Cornell, my only goal was to graduate and get a chance to build stuff. At that point in my life, I didn’t really appreciate the education I was receiving nor did I understand the impact technology and engineering would have on our economy and our lives.

With the perspective that time gives you, I can say unequivocally that the engineering education I received was top-notch. This opinion is reinforced by observing my coworkers and associates in the industry. It is clear that as an engineering school, Cornell does an outstanding job.

Engineering as a discipline is a balance of art and science, but science is required to allow those products to be manufactured in volume while being reliable and useful. . . . With the excellent education I received, I have achieved my original goal to build really cool stuff.”

Returning the compliment, the Cornell engineering professor who taught operating systems to Rubinstein in the mid-1970s, Fred B. Schneider, offered a 2005 opinion on making technology “transparent” to the user: “What Rubinstein taught me [is that a computer is] no different than a vacuum cleaner. It has to be that easy to use, from the first time you open the box.”

By 2005, tens of millions of people had opened an unpretentious box containing an iPod (Rubinstein reportedly kept jazz, reggae, and ’70s rock on his) and the man they called the Podfather was preparing to retire from Apple. He told an interviewer for Cornell Engineering magazine about the Podfather’s role with the iPod development team: “It’s a real pleasure to be able to work through a large team of people and create lots of products because at the end of the day, I’m really a product guy, and by leveraging my skills with the capabilities of the team, we can make lots and lots of great products.”

After Rubinstein left Apple, some of his iPod team stayed to work on a device that was hailed, when it was released in 2007, as an example of the “convergence” of wireless communication, personal computers, and digital entertainment into a single device: the iPhone.

In a related kind of convergence, the other three alums on electrical engineering’s 2001 “outstanding” list were Wilson Greatbatch ’50, Jeffrey Hawkins ’79, and Irwin Jacobs ’56, inventors of the cardiac pacemaker, Palm personal computers, and the CDMA encoding system for cell phones, respectively. Speaking to a campus audience in 2006, Jacobs included Greatbatch in the electronics convergence when he predicted that multipurpose cell phones might someday include heart monitors that can dial 911. Jacobs also gave the most generous educational gift, to date, in the history of the College of Engineering. (See “Applying Theory to Cell Phones,” page 52.)

While most Cornell students don’t need pacemakers yet, they make good use of technologies from the other three ECE alums. Even a 200-year-old Cornellian was sporting white earbuds.
designed and built the Gene Gun and provided the minuscule particles. When the biolistics technology was sold to DuPont in 1990, it generated the largest single royalty payment ever made to the university—and the inventors profited, too. Wolf made important contributions to the world of integrated circuit design and manufacturing, but only the Gene Gun went on display at the Smithsonian Institution and Disney’s Epcot Center.

ECE alumni haven’t done so badly either. (See “Cool Stuff from the Podfather,” previous page.)

Computers, Microelectronics, and Other Things Electric

Among the faculty members conducting research and teaching about computer architecture are David Albonesi, Adam W. Bojanczyk, Jose F. Martinez, Sally A. McKee, and G. Edward Suh. Albonesi’s work spans single and multiple processors with a particular focus on adaptive, power-efficient, and reliability-aware computer architectures. Bojanczyk concentrates his research on the design of parallel algorithms and architectures for signal processing, while Martinez addresses problems in reconfigurable and self-optimizing architectures and the architectural impact of disruptive technologies. McKee focuses her research on analyzing application memory behavior, as well as on designing more efficient memory systems and software to exploit them. Suh works to combine architectural techniques with low-level software to enhance performance, security, and reliability.

Very large-scale integration, or VLSI, is of particular interest to three ECE faculty members: Ehsan Afshari, Alyssa Apsel, and Rajit Manohar. Afshari blends multiple disciplines within the fields of electrical engineering, applied physics, and mathematics to apply theory of wave propagation to high-performance circuit design. A specialist in the class of integrated circuits called CMOS (complementary metal-oxide semiconductors), Apsel works to develop low-power CMOS systems that utilize the speed and computational benefits of optical processing and communication. Manohar concentrates on asynchronous VLSI design and architectures, and is one of the maintainers of Magic, the open-source VLSI layout tool.

In the field of communication and sensor networks, Zygmunt J. Haas works to allow ubiquitous, multimedia access to information and services by mobile and wireless systems users. Sergio Servetto, a popular teacher among undergraduates for his course, “Digital Communications over Packet-Switched Networks,” was about to publish a book on the topic when he died in a plane crash, July 24, 2007, in Upstate New York. Lang Tong conducts research in the general area of statistical signal processing, communication systems and networks, and information theory.

In addition to Toby Berger, at least three other faculty members work in the area of information theory and communications. Terrence Fine examines issues in the foundations of probability. Aaron B. Wagner studies the connections between information
theory and queuing theory, as well as the role of feedback in communications and applications of information theory to computational linguistics. Stephen Wicker is a specialist in telecommunications networks information theory and coding.

Among ECE faculty members working in the field of signal and image processing are Peter C. Doerschuk, biological and medical systems; Sheila Hemami, communication of visual information; Charles R. Johnson Jr., signal processing algorithms for painting analysis; Thomas Parks, signal theory and digital signal processing; Anthony Reeves, computer methods for analyzing biomedical images; and Anna Scaglione, signal processing for communication systems. Johnson’s development of a mathematical process called “stylometry”—to determine the “visual signature” in authenticated Van Gogh paintings, for example—helps museums detect fakes by artists’ imitators.

Carrying forward Cornell’s six-decade tradition of research in space plasma physics is the atmospheric science group consisting of Donald Farley, Michael Kelley, Paul Kintner, and Charles Seyler Jr. While his ECE colleagues study plasmas in the “outdoor laboratory” of space, David A. Hammer explores the interactions between intense ion beams and plasmas for possible applications to magnetic confinement fusion.

Control, power, and complex systems—another long-standing focus in Cornell electrical engineering—reaches from the highly theoretical to the practical applications that keep lights burning at Cornell and across the country. Emeritus professor James Thorp, who earned all his degrees at Cornell and spent 42 years on ECE’s faculty, shared electrical engineering’s “Oscar” for lifetime achievements—the Benjamin Franklin Medal in Electrical Engineering—with colleague Arun Phadke of Virginia Tech. In the words of the Franklin Institute, these researchers made “pioneering contributions to the development and application of microprocessor controllers in electric power systems. These devices make synchronized measurements to monitor and protect components throughout the power grid, playing a key role in diminishing the frequency and impact of blackouts.”

Hsiao-Dong Chiang also contributes to the improvement of power systems; he seeks to apply nonlinear systems theory to improve power-system stability and control, security assessment, and enhancement. David Delchamps works with feedback control systems that have complicated dynamical properties. An engineering faculty member since 1973, Robert Thomas has a long record of government service in the areas of industry deregulation and power system stability—including participation in the fed-
eral Department of Energy’s investigation into the widespread blackout on August 14, 2003.

MEMS are the special focus of Sunil Bhave, Edwin C. Kan, and Amit Lal. Before joining the Cornell engineering faculty in 2007, Alyosha Molnar worked as a deckhand on a fishing boat, helped design the first-generation GSM (global system mobile) transceiver, and broached the realm of science fiction with his ultra-low power transceiver for “smart dust.” Now he tries to understand the neuronal code of the mammalian retina while tracing the neural circuitry that underlies vision—with two possible applications: low-power, wireless implants in the eye to process data from microelectrode arrays as well as silicon circuitry that is inspired by enhanced understanding of biological circuits.

From VLSI to FSPI

With all that good work, it’s not surprising that Cornell electrical and computer engineering regularly ranks at the top of FSPI, the prestigious Faculty Scholarly Productivity Index. Generally regarded as more scientific than rankings like those in *U.S. News & World Report*, the index tallies the number of book and journal articles published by the faculties of research institutions, then factors in the number of times each publication is cited by other published scholars, and also accounts for the number of awards, honors, and grants received by faculty members.

Besides electrical and computer engineering (which are ranked separately in the FSPI survey of more than 7,200 doctoral programs in the United States), Cornell usually has two other fields at the top: information science (studied, at Cornell, in the Department of Computer Science and the School of Operations Research and Information Engineering) and food science (a department in Cornell’s College of Agriculture and Life Sciences).

Staying Agile

Sam Linke, who has seen a lifetime of breakthroughs and intriguing promises at Cornell electrical engineering, advises up-and-coming engineers to stay open-minded, versatile, and agile. His role model for agility was Malcolm McIlroy, the distinguished Cornell researcher who spent years developing the pipeline analyzer. “He was interested in flow problems,” Linke said, “and his system could analyze and predict water flow, traffic flow, virtually anything that flowed. Someone asked him, ‘Do you recognize the application of your method to computing?’”

McIlroy had already pitted his pipeline analyzer against a computer. The finest pipeline analyzer in the world and the primitive (by today’s standards) computer produced the same results, Linke reported. “McIlroy predicted that his own device would be obsolete in short order, and he understood why.” McIlroy recommended that Cornell electrical engineering focus on computer research. Leaders of the school took his advice.
Materials Science and Engineering Builds a Team

Just as modern materials science encompasses ceramics, polymers, semiconductors, metals, and glasses in various combinations—and new technologies demand more than mechanical strength from materials that must have useful electrical, optical, or magnetic properties—materials science and engineering (MSE) graduates are complex, multi-talented, and high-performing individuals who are well prepared for advanced study and for leadership roles in technical fields.

Cornell-educated materials scientists begin with a core competence across the spectrum of basic and applied sciences, followed by a broad education in scientific and engineering disciplines that enables them to create novel solutions to materials problems in engineering systems. They must be professionals, and possess ethical attitudes and effective communication and teamwork skills and the ability to place science and engineering issues within a broader societal context. These attributes are melded in a learning environment that fosters commitments to excellence and innovation, leadership, and a lifelong curiosity.

Core competency is built with courses such as “Internal Structure of Materials,” “Thermodynamics,” “Thermodynamics of Condensed Systems,” and “Electronic Materials for the Information Age.” Career options are broadened with the study of materials-science applications in a variety of fields (biotechnology and life sciences, energy and environmental technology, nanotechnology, and information and communications technology) with courses such as “Molecular Principles of Biomedical Engineering,” “Organic Optoelectronics,” and “Microchemical and Microfluidic Systems.”

Infused with an understanding of technology management and ethics—and enthused after laboratory-research opportunities that begin as early as the freshman
year—the would-be materials science engineers are ready for the performance test: Can they demonstrate an ability to apply knowledge of mathematics, science, and engineering to challenging materials issues? Have they acquired the ability to design and conduct experiments, to critically analyze and interpret data, and to design a process or materials system to meet specific requirements? Are they sufficiently conversant in the language of other fields to work effectively in multidisciplinary teams—and to provide leadership of teams by identifying, formulating, and solving engineering problems? Can they communicate effectively? Do they have an in-depth understanding of professional and ethical responsibilities, the contemporary issues in engineering and society, and the global impacts of the technologies they have learned to implement? Have their years of study at Cornell honed an ability to use modern techniques, skills, and engineering tools—and the recognition of the need for lifelong learning?

It’s not a multiple-choice test. Cornell faculty members who design high-performance materials and teach about them expect the best. They get that and more every time they award diplomas to a class of materials science engineers.

The Department Metals Built

From its start as an applied-laboratory subject in the original College of the Mechanic Arts to its present-day form as the Department of Materials Science and Engineering, one of twelve units in the College of Engineering, the study of materials has moved from unit to unit around Cornell University.

With each stop the field recruited more kinds of educators—physical scientists at first, and later life scientists—and discovered more engineering applications for the science of materials. The list of types of materials keeps growing, as well.
Although the research and teaching taking place in the Sibley College of the Mechanic Arts in the 1870s emphasized wooden materials and metals, materials science was never just about metals and natural polymers. By 1885, that college’s cast-metals laboratory was regarded as a model for teaching materials engineering in universities nationwide.

The Sibley College gradually de-emphasized wood as an industrial material, although another natural polymeric material—leather, for the heavy-duty belts that connected the wheels of industrial machinery—remained important into the early twentieth century when Cornell boasted the only leather-beling laboratory in the country. Metals, and steel in particular, were the focus of the Sibley College’s mechanics and materials department—as were steel and concrete in a materials section of the civil engineering college.

In 1904, mechanical engineering graduated Francis N. Bard, who prospered in the metals industry—enough so that in 1946 Bard was able to begin a series of gifts that laid the foundation for a world-class program in materials science and engineering at the university. Francis Bard’s first gift to Cornell endowed a professorship in applied metallurgy. The unit that would lead to a materials-related field of study was established at the end of World War II.

The School of Engineering Physics had roots in both the engineering and arts colleges, metallurgists and solid-state physicists on its faculty, and a brief existence as the School of Engineering Physics and Materials Science from 1962 to 1965. The Department of Materials Science and Engineering, formed in 1965, took up residence in the newly opened (1963) Bard Hall, another gift from the man who learned about metals in mechanical engineering. In the meantime, Cornell’s Materials Science Center (MSC), begun in 1960, was becoming a collaborative crossroads for physical scientists and engineers of all kinds. Today that program’s successor, the Cornell Center for Materials Research (CCMR), has some 100 faculty participants from ten departments around the university, including the Department of Materials Science and Engineering.

**No More Stone Age**

The formal study of materials at Cornell was more than a century old when the newborn Department of Materials Science and Engineering’s assistant director and director, Malcolm S. Burton and Walter S. Owen, respectively, took a look backward and tried to predict the future.

Burton recalled that, despite the attention to Cornell’s nineteenth-century metals-engineering laboratories, they had been little more than foundries and forges where students learned to apply the lessons from engineering classroom lectures. The scientific study of the behavior of materials, Burton said, had not been possible anywhere until technology caught up in the second quarter of the twentieth century. When it did, Cornell again was among the leaders in education. He cited Clyde W. Mason, for example, a Cornell chemist who brought then-state-of-
the-art microscopy techniques to the School of Chemical and Metallurgical Engineering. Mason advanced the materials-science discipline with his microstructural approach to the study of materials’ properties. Mason’s metallographic courses developed the concept that properties of materials are, in fact, related to and controlled by their structure. His microstructural approach formed the nucleus from which modern instruction and research in materials grew.

The department chair, Owen, spoke ruefully to his students of how materials science was losing a chance to name another historical epoch for materials critical to the advancement of human culture and society. No more Stone Age, Bronze Age, or Iron Age, said the professor who taught his specialty, the mechanical properties and physical metallurgy of steel.

Take heart, the metallurgist told his students: In the Space Age and the Atomic Age, skills of materials-science engineers would be needed more than ever. Owen offered two examples. First, the engineering concept of the gas turbine preceded man’s ability to make the hardware; gas turbines remained an interesting but academic exercise until “the concerted effort of a large number of materials scientists” produced alloys with the necessary creep-resistance at elevated temperatures for the manufacture of turbine blades.

Owen’s second example concerned a sporting application of materials science. Modern steel had relegated wooden-shafted golf clubs to museums, he observed. If his Class of ’66 students doubted that application’s relevance to the Space
Age, it became apparent in 1971 when Apollo 14 astronaut Alan Shepherd became the first golfer on the moon—with a one-handed, 400-yard slice with a six iron.

The metals-centric scientist could not have predicted the next epoch around the corner, the Information Age, when computer builders would look to materials engineers for help in fabricating and packaging their semiconductor-based integrated circuits. But he had the materials-vision part right. While physical metallurgy had been one of the “parents of modern materials science,” Owen told his students, “the science and technology of ceramics, glass, polymers, and aggregates (composites) with or without metals” were the way of the future.

Strategically, the new department that sought to apply science to materials engineering (just in case future historians proposed the Ceramics–Polymers–Composites Age) was adding intellectual resources and new investigative technologies to further the science behind the materials. The 1965 collaboration of Cornell materials science’s Ulrich Bonse and Michael Hart made it possible, for the first time, to perform X-ray interferometry. The Materials Science Center became the campus’s centralized home for advanced equipment such as the Bonse–Hart multiple-reflection X-ray diffractometer.

The Materials Science Center and Its Successor

Dating back to 1960, when Cornell’s Materials Science Center was one of the first three Interdisciplinary Laboratory Program centers established nationwide (among thirty-five applicants) by DARPA, the Materials Science Center’s record of achievement impressed NSF, which took over federal funding in 1972. The name was changed in 1998 to the Cornell Center for Materials Research (CCMR). As interdisciplinary as its research center predecessor, CCMR expanded its educational outreach to the general public (See “Materials Scientists Don’t Bite,” page 186), as well as to college students.

The university’s X-ray diffraction facilities were coordinated through the original Materials Science Center and supervised by Boris W. Batterman, who studied changes in structure of superconducting compounds when they were chilled to extremely low temperatures. Also keeping electrical and electronic applications in mind, Arthur L. Ruoff confessed to “modern-day alchemy” in his attempts to make pressure-induced superconductors become metastable—remaining in metallic form after the pressure necessary to produce them was released. Ruoff’s laboratory group succeeded in making metallic xenon and then turned sulfur, one of the best electric insulators, into a metal that was later shown to be a superconductor.

During the 1960s, the university’s central electron microscope facility was run by the Materials Science Center, and investigators learned to apply tensile stresses to materials by heating or cooling a specimen while it was still in the electron microscope. At the same time, Cornell found itself in the forefront of field-ion microscopy as Thor N. Rhodin refined the technique to look for single-atom defects, such as a vacancy in a crystal lattice. David N. Seidman, a student of Professor Robert W. Baluffi, led a group to build a field-ion microscopy laboratory to study point defects in solids.
SO THEY SAID

MATERIALS SCIENTISTS DON’T BITE

“How do you make a rock into a metal or crystal?”

Cristian Zaloj, Grade 2, Northeast Elementary School, Ithaca, New York

Of all the educational outreach activities of the Cornell Center for Materials Research, the “Ask a Scientist” feature, which appears in the Ithaca Journal and on the CCMR web site, is the most visible. One requirement of CCMR’s funding contract with the National Science Foundation is the mandate to spend a percentage of federal support on educational outreach. Most of the center’s numerous efforts—like summer institutes for high school teachers and graduate student visits to school classrooms—operate in the background.

But when a second grader got up the nerve to ask a question that most adults couldn’t answer, the CCMR educators scrambled to find a grown-up with the right information and a knack for explaining things to nonscientists. (Since few of the questions involve materials science, CCMR educators draw on the expertise of faculty and graduate students in departments throughout Cornell.) Here’s the answer to Cristian Zaloj’s question, from professor of materials science and engineering Stephen L. Sass:

After our ancestors found the answer to your question six thousand years ago, they were able to replace their stone tools and weapons with much better ones made from metals. If that hadn’t happened then, there would be no skyscrapers and jet aircraft today.

Folks in the Near East knew of metals because they found little pieces of copper at the bottom of streams. Artisans hammered and melted this copper to form beads and jewelry, but they didn’t have enough for useful tools such as axes and plows. Early workers had to learn how to extract copper from copper-containing stones, called ores.

In most such ores, copper atoms are tightly bound to oxygen atoms. To free the copper, its ore must be heated with something that binds oxygen even more strongly than copper. This is called a reduction reaction, in which two different atoms compete for oxygen, with the more reactive one winning by binding to it. Carbon, such as the charcoal in our backyard grill, is more reactive than copper, so that it can reduce copper back to its metallic state. The oxygen binds to the carbon and goes off in the form of carbon dioxide gas, leaving behind copper metal. No one is sure how this first happened. It may have occurred when a potter fashioning a pot decorated it with malachite, a beautiful green copper-rich stone. When the clay pot was fired in a wood-fueled kiln, perhaps the malachite fell to the bottom into the partially burnt wood (charcoal), which bound to the oxygen, releasing metallic copper. Imagine the joy of our potter when, raking out the ashes from the kiln, he or she came upon a chunk of copper. This revolutionary discovery led to the Bronze Age beginning 5,000 years ago and the Iron Age 3,000 years ago. Learning to extract metals from rocks using charcoal was a crucial step toward establishing our modern industrial world.

When Sass isn’t answering questions from the curious public, he heads a research group that studies grain-boundary structure, as well as fabrication and application of nanoscale periodic templates.

Herbert H. Johnson (1931–89), a metallurgist who probed the thermodynamics of solids and corrosion while chairing the department (1970–74) and directing the Materials Science Center (1974–84), won international recognition for his research in hydrogen embrittlement and delayed failure, as well as hydrogen diffusion and trapping in iron-base alloys. Johnson also studied crack tips with nanometer radii before the field of nanoscience was founded. Faculty member Edward W. Hart (1918–2004) was acclaimed as a brilliant theoretician and superb experimentalist for his studies of the inelastic behavior of metals. His “Hart’s Equations” managed what existing equations-of-state could not, by incorporating time dependence into the analysis of deformation processes in a materials-specific way.
The Science of Art Materials

Twenty-three years after Walter Owen explained the difference between materials science and materials engineering, the director of Cornell’s Microscience and Technology Program, James Mayer, connected materials science to the arts. Owen, in 1966, had asked students to imagine the dispersion of small particles in a liquid matrix encountered when fabricating potentially improved materials with thermal and mechanical treatments. Whereas the materials scientist is called on to determine the optimum form of dispersion, Burton said, “the materials engineer needs to find out how to produce and control the dispersion consistently in a commercial process.”

Mayer, a physicist who had joined the engineering faculty in 1980 as a Francis Norwood Bard Professor when the school began to focus on semiconductor materials, was an authority on thin-film reactions, ion implantation in silicon, and ion-beam analysis. He was at the Louvre in Paris—lecturing to art conservators about ion-beam analysis of paint pigments and the ink in rare books—when he got the idea for a multidisciplinary course at Cornell.

Returning to Ithaca, Mayer recruited an art professor (W. Stanley Taft) and an English professor who knew about rare books (Donald D. Eddy). Then Mayer persuaded a geologist-turned-university-president (Frank H. T. Rhodes, an engineering college faculty member, who had just launched the President’s Fund for Education Initiatives) to support a costly course.

“Art, Isotopes, and Analysis” (offered first in the 1990 spring semester as MSE 285 and cross-listed as an archaeology, engineering, or physics course) took a team to teach it (including two archaeologists, John S. Henderson and Thomas P. Volman; a professor of physics and nuclear studies, Albert Silverman; as well as Eddy, Taft, and
Mayer), but students from across the campus were enthralled. Art students learned how to identify pigment materials from the radiation emitted in electronic transitions. Archaeologists-to-be discovered how the ratio of isotopes can clarify the age and geographical origin of ancient artifacts—or newfound fakes. The students of materials science and engineering—who already knew how infrared and x-ray examinations provide insight into physical properties—learned a lot about art.

Cornell Engineering’s “Primary Product”

In the same year (1989) that Mayer built a multidisciplinary team to teach undergraduates, the Samuel B. Eckert Professor of Materials Science and Engineering, Edward J. Kramer, gathered graduate students and faculty members from across the campus into a collaboration he called the Polymers and Polymer Composites Study Group. The traditional “single-investigator” approach, still favored at the time by the NSF, was inadequate for the complex problems facing materials science and engineering, Kramer said, and he named one such: the study of the effects of reinforcing two-phase polymer blends with block copolymers.

“My students and I, in materials science and engineering, can measure the concentrations of deuterium-labeled block copolymers at interfaces, using forward recoil spectrometry and neutron reflectometry,” Kramer proposed. But he still needed Chung-Yuen Hui and his students in theoretical and applied mechanics (TAM) to collaborate and measure the fracture properties of interfaces stitched with known concentrations of block copolymers. Before the TAM researchers could construct micromechanical models to understand the fracture processes of molecularly reinforced interfaces, an industry collaborator (Hugh Brown at IBM’s Almaden Research Laboratory) helped develop both the fracture methods and some fundamentals of micromechanical modeling, Kramer noted. Cooperative research—with interdisciplinary collaboration within the university and extramural links to industry—would benefit all parties, Kramer predicted: “The university researchers benefit from the insights, ‘real world’ knowledge, and points of view that their counterparts in industry provide.” In return, companies get access to what Kramer called “the primary Cornell product,” engineering graduates who have learned to work in interdisciplinary teams.

Recyclable Computers and Organic Semiconductors

Another member of MSE’s first polymer team (along with Kramer and David Grubb), Christopher Ober, watched in the 1990s as discarded desktop computers piled up on loading docks across campus and throughout the land, and he wondered: Is landfill
dumping the appropriate fate for machines containing precious metals, toxic materials, and reusable parts?

Nearby in Endicott, New York, where IBM had begun as the Computing-Tabulating-Recording Machine Company long before “Big Blue” made little PCs, the so-called PC Paradox was troubling Mark D. Poliks as the millennium approached. “Computers don’t break down when we want them to,” said Poliks, who in 2000 was the manager of material development for IBM’s microelectronics division. “Long after you have moved on to a more powerful machine, your old machine continues to contain components and materials that could be recycled and reused” if only the epoxy adhesives that held components together would let go.

That’s what Cornell’s Ober was waiting to hear. Ober had invented a thermoset epoxy called Alpha-Terp that was nearly indestructible—until enough heat was applied. Ober formed a research team that included an MSE graduate student, John Jir-Shyr Chen, and Poliks. Chen used a variety of analysis techniques, including NMR (nuclear magnetic resonance) spectroscopy to study the performance of Alpha-Terp. He found that the epoxy breaks down at 190 °C (374 °F), allowing common industrial solvents to wash away the glue and free computer components for reuse or recycling. The Cornell–IBM team announced the development at the August 2000 meeting of the American Chemical Society in Washington, D.C., as “Reworkable Thermosets: Enabling Disassembly of Microelectronic Components.”

Within five years, Cornell materials scientists were turning their backs on the traditional semiconductor material, silicon, to focus on the Cornell Laboratory for Organic Electronics. There, George Malliaras and a campus-wide team of engineers and physical scientists work with semiconducting organic molecules. They are making improvements in electroluminescence devices—and lasers and single-molecule switches—that can be manufactured at minimal cost by “wet chemistry” rather than the more expensive nanofabrication procedures.

A member of the materials science and engineering faculty since 2002, Robert Bruce Van Dover spent twenty-two years at Bell Laboratories pursuing basic-research questions in superconducting, magnetic, and dielectric materials. His scientific publications from Bell
labs and Cornell have been cited more than 9,000 times by authors of other publications, ranking Van Dover twenty-ninth among the most-cited physical scientists worldwide. At Cornell, the engineer with more than fifty patents issued or pending leads a research group that is studying thin-film devices and the properties of magnetic and superconducting ceramics.

The research group led by Rüdiger Dieckmann, a faculty member since 1987, examines the high-temperature physical chemistry of solids, such as metal-ceramic microstructures. Jack M. Blakely, a faculty member since 1963, leads a surface-science laboratory that studies semiconductor surfaces, corrosion, and insulator and photographic materials. Shefford P. Baker, who came to the Cornell faculty from Stuttgart’s Max Planck Institute for Metallurgy, produces films in ultra-high vacuum environments as part of his study of the mechanical properties of materials at the nanoscale.

An Education in Materials Science and Engineering

A materials-chemistry lab led by Emmanuel P. Giannelis studies polymer–ceramic nanocomposites, thin ceramic films, nano-crystalline materials, and high-temperature composites. Those subjects dip into at least two of the three thematic focus areas of Cornell materials science and engineering—nanotechnology, energy and environmental technology, and biotechnology and life sciences—according to Giannelis, who notes: “All three areas offer scientific problems of interest for new generations of materials-engineering students.”

With that in mind, the department revised the undergraduate curriculum for students graduating in 2008 or later. Adding a fifth year to the usual four required for a bachelor’s degree can lead to a master of engineering (M.Eng.) degree in materials science, an industry-oriented program that requires a design project while allowing students to develop a depth and breadth of knowledge in a particular area. Many M.S. and Ph.D. students take advantage of one of two industry-collaboration programs. The Industrial Partnership at the Cornell Center for Materials Research involves graduate students in joint projects, often in polymer science, with CCMR researchers, and with engineers from large or small companies in the region. The Coop-Ph.D. program sends students to industrial R&D labs for six months to a year. The perspective of application-driven research—at IBM, Intel, Kodak, or Lucent Bell Laboratories, for example—complements the more fundamentals-driven research that students engage in at Cornell, according to Giannelis.
Not Your Grandfather’s Materials Science Lab

The foundry that served Cornell materials science in the early years of the university still stands, although now it accommodates art students who cast sculptures in metals and other materials. Bard Hall—the first dedicated home for Cornell materials science and engineering—has been renovated and refitted several times to keep pace with changing needs for experimentation and teaching. Today, students and faculty researchers have their choice of facilities for Auger spectroscopy, deep-level transient spectroscopy, differential scanning calorimetry, diamond anvil high-pressure cells, electron-beam induced current microscopy, high-energy ion-beam acceleration, infrared and Raman spectroscopy, laser melting, and low-energy electron diffraction. Not to mention mass spectroscopy, scanning tunneling microscopy, and secondary electron spectroscopy, mechanical testing at high temperatures and pressures, optical and interference microscopy, reactive ion-beam etching, and Rutherford backscattering spectroscopy.

The NSF–supported Cornell Center for Materials Research has even more specialized equipment—electron microscopes equipped with liquid-helium stages, high-
temperature stages, and tensile-straining stages, for example—and so does the Cornell NanoScale Facility in nearby Duffield Hall’s Knight Laboratory, also with NSF support. Also nearby is the Cornell Center for Advanced Computing, offering advanced research computing resources and consulting services; the Cornell High Energy Synchrotron Source, which provides extremely high-intensity x-rays for scattering and diffraction experiments; and the SRC (Semiconductor Research Corporation) Program in Microscience and Technology.

A major research university—with so many specialized facilities supported by industry, the federal government, foundations, philanthropists, and the university itself—also becomes a good place for state government to invest in technology transfer and economic development. One such program in CCMR is called JumpStart, where the New York State Office of Science, Technology, and Academic Research (NYSTAR) helps small businesses that lack in-house R&D capabilities pay for research in Cornell labs.

**Sputnik, Spit, and the Age of Team Building**

Remembering where he was when everything changed, department historian Arthur Ruoff recalls flying over the Grand Canyon on his way to a conference when the pilot announced tough news for the Yankees of New York and some challenging news for the yankees of the United States of America: Lew Burdette, a suspected hurler of spitballs, had pitched a shutout, clinching the 1957 World Series on October 10 for the Milwaukee Braves. Meanwhile, President Dwight D. Eisenhower was distracted from baseball game broadcasts by beeping sounds that ham radio operators were hearing from Sputnik, launched into orbit that October 4 by the Soviet Union.

The rocket that put Sputnik into orbit was essentially an intercontinental ballistic missile, an ICBM, the president had just learned in a briefing by the National Security Council. If the Soviets had ICBMs, they could hurl nuclear weapons anywhere in America. Eisenhower took this as a challenge, which he vowed the nation would answer.

For an increasingly insecure nation, the rocketman of the hour was Werner von Braun, the expatriate German physicist-turned-designer of ballistic missiles for the U.S. Army. Von Braun chastised Americans for fixating on baseball teams. Assemble the world’s best scientists and engineers to develop the technology for an American space program, he demanded. DARPA, the Department of Defense’s Advanced Research Projects Agency, was launched in February of 1958. It solicited proposals for an array of university-based materials science centers.
Two Cornell physicists (Robert Sproull and dean of engineering Dale Corson) teamed with Henri Sack (in engineering physics), Chester Spencer (chemical and metallurgical engineering) and Ruoff (a physical chemist working in mechanics and materials) to make an interdisciplinary pitch for a DARPA–funded materials science center, the result of which was the establishment of the Materials Science Center, now called the Cornell Center for Materials Research.

Cornell’s demonstrated success in materials-science teamwork was subsequently noted by the federal government when it came to siting two more national centers, according to Ruoff: the National Research and Resource Facility for Submicron Structures (awarded to Cornell instead of Berkeley, in part because biological scientists could work with engineers and physical scientists in the proposed structure here) and CHESS, the Cornell High Energy Synchrotron Source (still a mainstay of this university’s Life Sciences Initiative, as well as an adaptable tool for physical scientists and engineers).

As it turned out, the radio beeps that mocked Americans from the orbiting *Sputnik* were an experiment to study the ionosphere, or so the Soviets said. Cornell’s answer to that was to study the ionosphere from the ground, by building the Arecibo Observatory, supported initially by DARPA and now administered by the National Astronomy and Ionosphere Center, an NSF–funded unit at Cornell (for details on that interdisciplinary team project, see pages 57, 124, and 170).

While many American scientists looked to the skies, Ruoff looked inward for inspiration—to the center of the earth. Pressures there (an estimated 3.6 megabars, or 3.6 million times atmospheric pressure at the surface) were small steps in Ruoff’s progressive attempts to squeeze materials to unimaginable extremes.

The experimentalist had successes and disappointments. The diamond-surfaced pressure devices did turn nonmetallic elements such as sulfur, xenon, and oxygen into...
metals—albeit in minute quantities and not for long. But the holy grail for diamond-anvil alchemists, metallic hydrogen, managed to elude Ruoff. “Hydrogen tends to dissolve in diamond and causes problems,” he said, noting that his work is at pressures a hundred times greater than those needed to make synthetic diamond. “I know it looks like I’m just having fun,” he said, but the experiments with phase changes under pressure provide information that theoretical physicists can’t get, even with today’s superfast computers.

Along the way, Ruoff had the satisfaction of heading the department (1977–87) when the enrollment of Ph.D. students rose to an all-time high (105) and important faculty hires burnished Cornell’s national reputation. Fifty years in Cornell materials science affords Ruoff a vision for future contributions by his field; he predicts that materials’ future is in energy security. Wind turbines, he believes, need lighter, stronger materials (blades on the big turbines now weigh several tons apiece, and that puts bearing-busting strain on mechanical parts). The photovoltaic panels (and solar collectors that focus rays to make steam) would benefit from better materials. Technology for storage batteries is holding back electric-powered transportation (Ruoff is betting on zinc-oxide batteries, which received some research attention in the United States before China took up the challenge). Materials science can help nuclear energy make a comeback in America, he says: “The planet’s proven reserves of uranium and thorium, if used in breeder reactors, would provide electric power for a global population of nine billion for the next 15,000 years.” Not surprisingly, he is writing a book about the role of materials research in energy security. Ruoff notes that materials scientists at Cornell are working on some of the technology challenges he outlines.

But retirement from teaching needn’t stop a die-hard experimentalist. The failure to make metallic hydrogen leaves other interesting gases to squeeze—methane, for instance, and its silicon analog, silane, await the ministrations of the diamond anvil. Ruoff and his team have already made methane behave like a semiconductor. The same for cesium hydride—again, a very little bit became crystalline for a short while, at 253 gigapascals. That’s 253 billion atmospheric pressures.

And suppose that one day the exotic experiments do make a little of the next big thing in superconducting materials. Then what? How will Ruoff scale up production to make commercial quantities?

No problem, he says. “We’ll just add a genius to the team.”
As might be expected from an educational institution that values well-crafted systems, the Sibley School of Mechanical and Aerospace Engineering designs a curriculum and teaches a group of students that, upon graduation, collectively can meet society’s expectations of Cornell-trained mechanical engineers in the twenty-first century. They are expected to conceive, design, and realize useful products, services, and systems—while respecting economic, environmental, cultural, life-safety, and ethical standards. Graduates of Cornell’s mechanical engineering program will discover and apply new knowledge, and develop new tools for the practice of engineering. They will be valued in their careers, whether for the mastery of the disciplines central to mechanical engineering or for the broader analytical and creative abilities fostered by their education at Cornell.

They will go on to complete programs of graduate or professional studies and continue to learn throughout their lives. They will assume leadership positions in technology-based industries—and engage with their communities, profession, and the world. If that sounds like a lot for a lifetime, look at the record: Cornell mechanical engineers fulfill many of these expectations within three or four years of graduation. That record of achievement owes a lot to a curriculum designed to provide a broad background in the fundamentals of mechanical engineering while introducing students to more focused technical and professional areas, called “streams.”

One stream—mechanical systems (including structural analysis, dynamics, and control) and materials processing—is concerned with the design, analysis, testing, and manufacture of devices, machinery, robotics, and vehicles. Students following this stream are encouraged to choose one or more areas of concentration, such as biomechanics,
mechanical systems, vehicle engineering, or materials processing and precision engineering. Among other topics covered in the mechanical systems stream are computer-aided design, control systems, dynamics, and vibrations.

The other stream—energy, fluids, and heat-transfer systems—attracts students who are interested in the experimental and theoretical aspects of fluid flow and heat transfer as they follow in the footsteps of two 1800s predecessors. (See “Mechanic Arts Paints a Skyline,” below.) The sciences of thermodynamics and combustion hold a fascination for some of these students. They have the chance to concentrate specifically on fluids and aerospace engineering, thermal systems engineering, or vehicle engineering.

SO THEY SAID

MECHANIC ARTS PAINTS A SKYLINE

“There are mixed feelings in the neighborhood . . . the artists, they tend to be preservationists.”

A Queens, N.Y., resident’s comment on demolition of the 95-year-old Pennsylvania Railroad powerhouse smokestacks, 2005.

An object of nostalgia in the twenty-first century, the four smokestacks atop the Pennsylvania Railroad powerhouse were symbols of the next big thing when two Sibley College of Mechanic Arts–trained engineers designed the 1909 Queens borough landmark. Henry Herman Westinghouse left Cornell after only one year (1871–72) to help his older brother, George Westinghouse, put air brakes on trains and electric motors in locomotives. Walter Craig Kerr graduated in 1879 with a mechanical engineering degree and then joined the Westinghouse brothers’ Pittsburgh-based operation.

The two Cornellians subsequently established Westinghouse, Church, Kerr & Company, the New York City arm of George Westinghouse’s expansion into the electric power-generation and railroad industries. The electrification of the Pennsylvania Railroad marked a turning point, not only for the industry but for the Westinghouse brothers, who had made early marks in steam engineering. Smoke-belching steam locomotives were not suitable for the next generation of service to Manhattan, where trains to the new Pennsylvania Station would pass through tunnels under the East and Hudson rivers. Electric-powered trains were the wave of the future.

Westinghouse, Church, Kerr & Company engineered the mechanical and electrical infrastructure for Penn Station, which was designed by architects McKim, Mead, and White. Amid all the acclaim for Penn Station in its 1910 grand opening, the architects tacitly received credit for the industrial elegance of the powerhouse, where coal-burning steam turbines made the electricity that kept Penn Station’s concourses and interior free of soot.

Manhattanites soon adopted the four ebony-colored towers, atop the granite powerhouse with its arched windows, as a cherished part of their skyline to the east. The powerhouse towers are prominently featured in period photos. When wrecking balls threatened the powerhouse smokestacks in 2005, architectural historians acknowledged who really designed the landmark—not architects but the same Cornell engineers who made the insides.

Before heading west to paint skulls and big flowers, Georgia O’Keeffe’s “East River from the 30th Story of the Shelton Hotel” showed the mark left on the New York skyline by two Cornell engineers, the four stacks of the Pennsylvania Railroad powerhouse in Queens.
Then the fun begins: Whichever stream they’ve chosen, mechanical engineering students soon find that their talents are much in demand in the school’s famous (and prize-winning) project teams.

**Ezra’s Engineers**

Mechanical engineering was dear to the heart of university founder Ezra Cornell, practical tinkerer–inventor–improver that he was. Clearly the field was important to federal lawmakers when they passed the Morrill Act in 1862 and ordered land-grant colleges like the new (1868) Cornell University to teach “the mechanic arts.”

It was the first engineering discipline at Cornell University to get its own building, when Hiram Sibley funded his namesake hall in 1870. No respectable university could provide science-based education in the mechanic arts without proper teaching tools, or so the university’s founding president Andrew Dickson White figured when he acquired one of Cornell’s core collections (the Reuleaux Collection of Kinematic Mechanisms) in 1882.

America’s revolution in engineering education started here with Robert H. Thurston (and with his colleagues in teaching scientific fundamentals, such as John H. Barr, Rolla C. Carpenter, William F. Durand, George R. McDermott, and Albert W. Smith). At least two other engineering fields at Cornell, materials science and electrical engineering, got their start in mechanical engineering. So did the Cornell University Press, one of the oldest academic publishers in the land, because printers needed mechanical engineers to handle the steam-operated presses of the 1870s. A decade later, mechanical engineers came to the aid of a thirsty university (See “Why There’s No Lake Morris Here,” page 200.), although their advice wasn’t always heeded.

When machines needed to fly, Cornell mechanical engineers stepped forward to teach the science and art of the aeroplane—initially to Cornell students, then to the U.S. Army’s student pilots during World War I, and again to civilian engineers during
WHY THERE'S NO “LAKE MORRIS” HERE

“. . . several privies, which could easily be moved.”

John L. Morris, report to university trustees, May 30, 1886

A rapidly growing university needed more potable water in 1888. Three Cornell engineers had a plan for the larger of the two water sources that cross the campus, Fall Creek. John Lewis Morris, who helped run Sibley College until mechanical engineer Robert H. Thurston took over in 1885, and Estevan Antonio Fuertes, Cornell’s patriarch of civil engineering for nearly thirty years, surveyed the winding course of Fall Creek as it approached the campus from the east.

The creekside hamlet of Forest Home was also the site of nineteenth-century mills and other enterprises that took advantage of Fall Creek both to power their machinery and, in some instances, to carry away their waste. The three engineers found much to dislike about the community’s industries: Woolen mills, a slaughterhouse, and “several privies which could easily be moved” lined the banks of the waterway. Then there was a certain Empire Mills, discovered to be draining wastes into the creek and maintaining “a very filthy pig pen” on its premises.

The engineers did not suggest shutting down the mills and other businesses—they were a vital part of Ithaca’s thriving industrial base—and remediation was not part of the engineers’ vocabulary in a May 30, 1886 report to university trustees. But they had some recommendations.

Besides moving privies away from the water source, they were ready to approach the proprietor of the slaughterhouse to “buy all putrescible for fertilizer,” presumably to apply to the university’s farm fields, then build a dam upstream to impound Fall Creek. A six-inch pipeline from the dam would bypass the mills and other pollution sources, and provide the campus with relatively clean water. An appropriation of $4,000 should be enough to build the dam and connecting water lines, they told the trustees, without estimating the cost of privately owned land that the proposed reservoir would flood. As a bonus, impounding all that water for a year-round supply would provide enough “head” for more mills at the base of the dam.

Morris, who despite his position in mechanical engineering was a civil engineer by training, insisted on one caveat in an otherwise optimistic report. He noted that several miles upstream (and beyond the site of the proposed reservoir, where the other engineers agreed “on the entire suitableness of this supply for domestic purposes”) was the village of Dryden with a healthcare facility called the Dryden Sanitarium. Morris worried about “pollution of the water by excretae of patients affected by cholera and equally virulent zymotic diseases.”

Whether the trustees were spooked by the price tag or by the threat of zymotic [contagious] disease, the project was never approved.
World War II. In fact, in October 1903, when Samuel Langley’s “aerodrome” made an unsuccessful attempt at manned flight—two months ahead of the Wright brothers—Charles Manley, a Sibley College grad, was at the controls.

Innovators in the mold of Ezra Cornell, students of mechanical engineering made fundamental contributions to aviation (Leroy Grumman and Leon Swirbul), air conditioning (Willis Carrier), 3-D movies and electronic music (Laurens Hammond), and the manufacturing of gears and bearings (Kate Gleason and Francis Bard, respectively). Now that the home of mechanic arts at Cornell has morphed into the Sibley School of Mechanical and Aerospace Engineering, artful students and scientific faculty members work everywhere on the planet—the skies above and water below, and in cyberspace.

The Power and the Heat

If Cornell mechanical engineering is among the world’s best in what it does today, that’s because it’s had plenty of practice, according to Sidney Leibovich and David Caughey, both faculty members who have been directors of the school. Whether it comes to cramming more components into computers or improving the efficiency of combustion, it’s all about heat and power—one of the first departments of the Sibley School.

“Heat transfer is the limiting factor in computer speed and memory, and heat transfer is a mechanical engineering problem,” Leibovich notes. “When the program began nearly 150 years ago, the focus was on railroads and engines and machines for industry during the Industrial Revolution,” Caughey observes. “They were just learning to use machines for power produced by people, rather than power from animals, and the best power at the time came from heating water to make steam.”

Two of Cornell’s first mechanical engineering faculty members, John Edson Sweet (1832–1916) and Robert H. Thurston (1839–1903), knew the power of steam. Sweet was an architect who caught the inventing “bug” while working at the international patent office in London during the American Civil War. He devised a typesetting machine that is regarded as a forerunner of the Linotype, a nail-making machine that made the hand-forging of nails obsolete, and the Straight-Line steam engine. He manufactured the last of these in Syracuse after teaching at Cornell for six years, beginning in 1872. Ezra Cornell found Sweet supervising construction of a bridge on the new campus, asked his opinion on shop instruction in the newly opened Sibley College, and hired him to be director of the college’s machine shops. While at Cornell, Sweet built the first micrometer caliper for making tools in the United States (1873) and pioneered production of standard surface plates for reference in machine-tool shops. When he broke for lunch, discussions with colleagues and students continued at the nearby Sibley Dog. (See “Complaints from the ‘Overall Brigade’,” page 64.)
Thurston was about to join his father’s Providence (Rhode Island) Steam Engine Company when a high school science teacher persuaded him to try college (Brown University) first. A naval engineer for the Union during the Civil War, Thurston served on the steam gunboat *U.S.S. Unadilla* and other ships that enforced the blockades of southern ports. Thurston taught at the U.S. Naval Academy and Stevens Institute of Technology before being named director of Sibley College in 1885. At Cornell, Thurston established the Department of Experimental Engineering, taught courses in thermodynamics and steam engineering, and published a multivolume series of manuals on the strength of materials, friction and energetics, and steam boilers and engines. He held patents for two laboratory devices, the autographic testing machine (now in Thurston Hall) for material in torsion and a machine that tested lubricants.

Thurston was the first president (1880–82) of the American Society of Mechanical Engineers and he used his professional connections to invite distinguished engineers to lecture at Cornell—with mixed results. (See “Letters of Regret,” page 205.) Sweet was the organization’s third president (1884–85). One such visitor in 1897 was Octave Chanute, a designer of gliders and a colleague of other aircraft pioneers, including Samuel Langley, the Wright brothers, and Glenn Curtiss. Chanute lectured on the “Progress of Manned Flight.”

One Cornell student who thrived in Thurston’s experimental engineering program was George Burr Upton (1881–1942), who got a teaching appointment there after earning his master’s degree in 1905. Upton was a specialist in materials (he wrote the book *Materials of Engineering* and was the co-inventor of the Upton–Lewis Fatigue Testing Machine) as well as the internal combustion engine and its applications to transporta-
John Edson Sweet served six years as a professor of the mechanic arts, master mechanic, and director of the university’s machine shops before retiring to build steam engines in Syracuse.

Robert H. Thurston, seen in this bas-relief in his namesake hall, served on a steam-powered gunboat during the Civil War and taught at two other institutions before settling at Cornell in 1885.

Upton guided the development of aircraft engines when he served, during World War I, on the National Advisory Committee for Aeronautics, and consulted for the Curtiss Airplane Company in Hammondsport, New York. Upton was the founding director (1936) of the university’s Department of Automotive and Aeronautic Engineering.

Another student of Thurston’s, S. C. Thomas Sze, now has his name on the directorship of the school. Sze was one of Cornell’s first Chinese students and a 1905 graduate.
of mechanical engineering, who worked his way up from locomotive superintendent of the Peking Mukden Railway to become a major force in the building of China’s national railroad system. He also was director of China’s Northwest Highway Administration, both the Cha-Pei Electric and the Shanghai Power Companies, three banking corporations, and several shipping companies.

The Transition to Internal Combustion

Steam power attracted William Nicholas Barnard (1875–1947) to Cornell, where he studied thermodynamics with Thurston and steam engine design with Barr. Barnard taught steam engineering, from 1903 to 1915, when his professorial title changed to heat and power engineering. The lighter, more versatile internal combustion engines were proliferating at Cornell when Barnard was named director of the U.S. Army School of Military Aeronautics, the ground school for flight cadets in Barton Hall. He was the co-author, with C. F. Hirshfeld, of the 1926 text, *Heat-Power Engineering*, and of subsequent volumes that were published in 1933.

By the time 1889 mechanical engineering graduate John Wilkinson (inset, in his senior photo) was honored by the Society of Automotive Engineers for establishing “the sound fundamentals for future growth of the automotive industry,” he had designed the forerunner of the Franklin automobile (his 1898 Pilot, with Wilkinson at the controls, and a four-cylinder air-cooled engine under the seat). From 1902 to 1924, he led the Syracuse-based Franklin company to race victories and dozens of automotive firsts in engine and chassis design. The fast and luxurious air-cooled machines earned a reputation for reliability and efficiency (32.8 miles per gallon, coast to coast, in 1914). But when franchised dealers demanded a fake radiator—to make Franklins look like competing models at the time—Wilkinson resigned in protest.

In 1909, two years before Cornell’s first formal course in aerial engineering—and decades before student-project teams and their machines competed against other institutions—some 80 students formed the Cornell Aero Club to design and build gliders, fly the engineless craft, and “promote the investigation and study, from a theoretical and practical standpoint, of the science of aeronautics.” After testing a series of biplane and monoplane gliders from the high and relatively treeless Kite Hill, Cornell engineers flew in intercollegiate competition against student aviators from Harvard, Tufts, and Dartmouth.
Barnard’s co-author on the 1933 heat-power books was Frank Oakes Ellenwood (1878–1947), another faculty member who previously trained World War I aviators, as head of the engine department in the School of Military Aeronautics. Spanning two wars, and leading the Department of Experimental Engineering in between, Adam Clark Davis (1889–1942) taught Army aviators during World War I and was the founding director of the U.S. Navy’s Diesel Engine Training Program at the start of World War II. A man of multiple careers, Millard Clayton Ernsberger (1862–1940) was a practicing lawyer, photography editor of the *New York Tribune*, draftsman for a steam engine company (where he tried to make improvements to the rotary steam engine), a quick-study midlife student (completing his Cornell degree in mechanical engineering in two years), and ultimately the head of the heat-power department at Cornell until 1930. Students

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**SO THEY SAID**

**LETTERS OF REGRET**

“My gift of gab unfortunately is limited.”

Washington A. Roebling, August 9, 1887

Not that the College of the Mechanic Arts of the mid-1880s lacked for erudite faculty, but the director, Robert H. Thurston, wanted his students to hear from distinguished, real-world experts. Letters of invitation to visit Cornell and deliver a lecture or two were posted regularly from Thurston’s Sibley Hall office; more often than not, letters of regret returned.

“I could not be of any use talking to the young men upon either of the two subjects you mention,” Andrew Carnegie wrote in 1888. “I am neither mechanic nor engineer, nor am I a scientist. The fact is I don’t amount to anything in any industrial department. I seem to have a knack of utilizing those that do know better than myself.” Carnegie, whose nephew was about to attend Cornell, eventually changed his mind. (See “The Wizard, the Prince, the Carrier, and the Builder,” page 61.)

Brooklyn Bridge builder Washington A. Roebling offered an excuse that might have lingered from an 1872 bout of caisson disease (decompression sickness) when he wrote back to Thurston in 1887: “My gift of gab unfortunately is limited, and in place of seeking opportunities to display my eloquence, I try to avoid them. Owing to an old case of pleurisy my voice gives out after a few minutes and I cannot at any time talk very loud.”

Other invitees seemed to confess a fear of public speaking. The president of the Naval War College, Admiral Stephen B. Luce, wrote in 1889: “I have read one or two lectures to the class at the War College on purely professional subjects; so I would not venture as yet, up before such an audience as you speak of under any circumstances.” Massachusetts Institute of Technology’s third president (1881–97), Francis Amasa Walker, a noted economist but a reluctant orator, declined the Cornell invitation in 1886 by writing: “These ‘occasional’ engagements, no matter how simple or informal the duty, worry & harass me far beyond most men. I cannot take them easily or perform them lightly.” The designer of ironclad ships, Edward S. Renwick, preferred to stay at the drafting table in 1886, writing: “I have never had occasion to deliver a lecture. I would probably fail in any attempt to either lecture or talk to an audience of either boys or men.”

Some pleaded previous commitments. The naval engineer Benjamin F. Isherwood, a noted designer of steamship propellers, found himself “receiving daily so much additional work that I have, with many thanks, to decline your kind offer.” Traveling to Cornell by train would take a day in each direction, Isherwood observed. Statue of Liberty sculptor Frederic Auguste Barthold wrote from New York City in 1886: “... the time of the French Delegation & of my own has been disposed in such a way as to make a visit to Ithaca impossible.”

Thurston’s persistence paid off when Alexander Graham Bell consented in 1889, telling Thurston: “I would propose to make this simply the first test of a discursive address designed to interest the students and stimulate them to original research.” Bell’s lecture was titled “Disturbances Upon Electrical Circuits.”
who learned the laws of thermodynamics from professor of heat-power engineering Roy Edwards Clark (1889–1970) returned for engineering college reunions and looked up the man they called “Entropy Clark.”

**Dean for a Year, a Coach for All Seasons**

The shortest tenure in the Cornell Engineering deanship belongs to Herman Diederichs (1876–1937). His 42-year association with the university—as a Class of 1897 mechanical engineering graduate, instructor, director of the Sibley College Mechanical Laboratory, the first John Edson Sweet Professor of Engineering, director of the Sibley School for ten years, and college dean beginning July 1, 1936—ended with his death from a misdiagnosed illness.

Colleagues eulogized Diederichs as a world-class experimentalist in engineering materials (everything from coal to cold-rolled steel), the writer of three standard textbooks and numerous scientific papers as well as extension bulletins from the Engineering Experiment Station at Cornell (“Flame Propagation in Closed Cylinders,” for instance). He was the one engineer called upon by the Ward Line in 1906 to test the power plant of the first *Morro Castle* (forerunner to the second *Morro Castle*, a luxury liner that burned at sea in 1934), and he was an expert in the industrial uses of oxygen.

Students in engineering and across the university remembered the gruff-but-kindly professor whom the Class of 1935 had elected Cornell’s “Man of the Year.” He was also remembered as the director of the Cornell Athletic Association who went to bat for the student athlete. As the Cornell representative to the National Collegiate Athletic Association, he horrified other institutions by calling for athletic scholarships.

Diederichs was the one who saw “no reason why a boy who had character and brains and was at the same time an athlete should not be accorded aid by a university on the same footing with students who do not possess athletic abilities.” He helped raise money for athletic scholarships at Cornell, long before that practice was banned in the Ivy League.

Diederichs had attended Cornell on the state scholarship that he won in a competitive exam, which he took after hiking 15 miles to Herkimer, New York, from Dolgeville, where the German-immigrant family with seven children had settled two years after the founding of Cornell University. He worked his way through Cornell (and subsequently won a Sibley fellowship and completed a year of graduate studies) by waiting tables and “rustling customers” at Mrs. Patch’s boarding house on Aurora Street. Participation in track (he medaled in discus and shotput) convinced Diederichs that engineers could be athletes as well as students. (His academic side was certified by winning the Melville Medal of the American Society of Mechanical Engineers for “a thesis of exceptional merit.”)

Most of Diederichs’ truncated deanship was spent in hospitals, beginning with John Harvey Kellogg’s notorious Battle Creek (Michigan) sanitarium. By the time his illness was diagnosed, as a rare form of anemia, Diederichs was in another sanitarium in Upstate New York (Dr. Henry Foster’s in Clifton Springs) and in desperate need of daily blood transfusions. The engineering faculty donated countless pints of blood. Diederichs underwent an unsuccessful operation. He died on August 31, 1937, at age 63.
Cornell’s athletic manager at the time when Diederichs headed the Athletic Association (and later the Athletic Policy Board), Romeyn Berry, was an editorialist for *The New Yorker* when he told *Time* magazine:

*I have worked with Herman Diederichs 20 years. Half the time I would have died for him and the other half I wanted to kill him. He did a thousand kindly acts in my behalf and never gave me a kind word anytime. He was a big soft-hearted Dutch sentimentalist who studied to be gruff so people wouldn’t find him out. I’m still mad at him and this telegraph blank is wet with tears because he won’t bawl me out any more.*
A former student and long-time colleague (C. F. Hirshfeld, a 1905 master of mechanical engineering who taught heat-and-power classes in Sibley College) was the chief of research at Detroit Edison Company when he told what happened to miscreants who were summoned before the professor:

Many of the weak, the lame, and the mischievous who appeared before Professor Diederichs . . . by special though not sought-after invitation, discovered that in back of the severe manner of strict disciplinarian there dwelt a kindly, understanding, and human soul.

A Class of ’37 student (Jira Payne Thayer) remembered the professor of engineering materials’ forbidding facade (See photograph, page 207.) this way: “Diederichs had a countenance that would stampede buffalo.” Those who didn’t turn tail and run, Thayer said, discovered another side to the stern teacher—maybe not sympathetic, but certainly supportive and willing to grant a second chance. More like a good coach, actually.

Let’s Design and Build Something!

“Mechanical engineering at Cornell is tough—academically—but students can put in a lot of time designing and building things, so they come away with confidence that they can actually use the knowledge,” said Francis C. “Frank” Moon, an engineering faculty member since 1975 and historian–curator of the teaching tools in the Reuleaux Collection. Machine design was one of the Sibley School’s original strengths, Moon said, harkening to the 1870s when Albert William Smith (1856–1942) studied and subsequently taught here, and to the 1950s when Howard N. McManus Jr. (1921–74) engineered a reemphasis on machine design in the curriculum.

Smith earned two Cornell degrees in mechanical engineering (and trophies as an oarsman on the first of the university’s famous crews); taught machine design at Cornell, the University of Wisconsin, and Stanford (where he chaired the Department of Mechanical Engineering); and returned to Cornell in 1904 as dean of Sibley College. Smith also served as acting president of the university for eighteen months (1920–21). He also wrote biographies (of John Edson Sweet, Walter Craig Kerr, and Ezra Cornell), several volumes of his own poetry, and the words to the Cornell Hymn (“Lo, at her feet the valley lies.”).

The author of Machine Design Drawing Room Problems (first through fourth editions, 1923–51), Calvin Dodge Albert (1876–1959) co-authored the 1931 book, Kinematics of Machinery. Albert taught machine design at Cornell from 1906 to 1944 and headed the department for twenty-five years—only taking a leave of absence during World War I to supervise the U.S. Shipping Board’s wood-and-steel ships programs.

Albert’s collaborator on the kinematics book was another machine design professor, Edgar Harper Wood (1872–1961), who also wrote A Textbook of Mechanics and...
co-wrote, with Cornell’s John H. Barr, *Strength of Materials*. The holder of two Cornell degrees in mechanical engineering, he was one of the university’s first “faculty brats.” His father, William H. Wood, was foreman of the Sibley College wood shop.

However, by the 1950s—by Frank Moon’s account—the curriculum in the United States had shifted to what he calls “cookbook engineering.” It took the Soviet Union’s launch of *Sputnik* in 1957 to return science and mathematics to engineering education, according to Moon, and by 1966 McManus had begun to return engineering design to its former prominence. Teaching colleagues recalled that McManus had experienced his own conversion—starting as a professor of thermal engineering and conducting research in heat transfer, combustion, and fluid mechanics—until he realized the importance of design among the fundamental engineering skills that Cornell students were acquiring.

McManus got his chance to change engineering education at Cornell with his 1966 appointment as chair of a faculty committee on long-term needs in instruction, laboratory work, and research. The committee’s recommendation was clear: reintroduce the design function into engineering programs at Cornell. McManus lost no time in launching new courses, serving as chair of the Sibley School’s mechanical design department, heading an experimental engineering-design program at the doctoral level with funding from NASA, and advocating at engineering-design education conferences around the country.

Not surprisingly, student engineers who were learning all that math and science and theory of machine design in the classroom were itching to put it into practice and build things. That’s how mechanical and aerospace engineering’s award-winning project teams started—at first with urging from faculty members like Albert R. George, then with students starting to take the initiative, Moon recalls. Soon the trophy cases in Upson Hall filled with prizes won by the student teams.
Mechanical engineering students applied their skills on land and sea, and in space, in national and international competitions. Student design–build–compete teams formed up for everything from the Solar Decathlon houses and the Autonomous Underwater Vehicle minisubmarines to the DARPA Grand Challenge (full-sized vehicles turned loose to find their way through deserts and urban environments) and the smaller Mini Baja off-road vehicles (running through rough terrain and water). Teams also entered competitions involving human-powered vehicles for NASA’s Great Moonbuggy Race, ICE Cube satellites (to launch into space), bio-inspired Snake Arm robots, and untethered imagination-inspired things like the Hopping Gyroscope Rover. The longest string of wins came to Formula SAE, the student-designed, -built, and -driven race cars, and RoboCup, the soccer-playing robots.

Simply designing, building, and driving (or writing computer code that drives) prize-winning machines is not enough, according to Moon, who says students must “sell” their product. “Students in the project teams learn to manage people, money, and time. And they learn how to communicate and sell, in required presentations at the competitions, because the product cannot speak for itself.”

Student project teams, such as the Cornell crew that won the sixth annual Autonomous Underwater Vehicle competition in 2003, also learn to plan for the unexpected. Their two-meter-long minisub worked perfectly in the crystal clear waters of Teagle Hall’s indoor pool—navigating a predetermined course under computer control, reading the underwater arrows, and dropping markers right on target. But at the competition in San Diego, the team from Cornell discovered two challenges to their entry’s digital vision-processing system—murky water and bright California sunlight. Back to the laptops they went for a total rework of the sub’s vision code—just in time for clouds to dim the sunlight. Next the Cornell machine’s propulsion system failed, and the students scrambled to swap components, with fifteen minutes to spare before the competition, which they won.

The reward for the Cornell Autonomous Underwater Vehicle team, besides a cash prize and the satisfaction of beating archrival MIT and every other team in the country, was a discovery: The people lurking in the Cornell tent weren’t scholastic spies. They were representatives of companies—potential employers, in fact—curious to learn how student engineers from landlocked Ithaca designed and built the best swimming robot in the land.

All This Fun, and Course Credit Too?

Undergraduates might show up for project team practice just for the heck of it, but classes like MAE 4250, “FSAE Automotive Design Project” or MAE 4291, “Supervised Senior Design Experience” are also handy ways to earn credit for being team players. Likewise, signing up for an undergraduate research opportunity puts students in touch with faculty researchers who work at the frontiers of mechanical and aerospace engineering. Those are faculty members such as Elizabeth M. Fisher, who welcomes undergraduates to a project called “Destruction of Weapons of Mass Destruction.” Fisher’s research focus is combustion chemistry related to the practical problems of hazardous waste incineration and fire suppression. Typically, for most interdisciplinary research in
Built in Ithaca (top right) but destroyed when a Russian rocket crashed soon after launch on July 26, 2006, near the Kazakhstan–Uzbekistan border, Cornell engineering’s ICE Cube satellite was still considered a successful learning exercise. The students’ next effort was the CU Sat nanosatellite (top left), which won the U.S. Air Force’s 2007 University NanoSat Flight Competition Review. After numerous RoboCup victories (center left), Cornell students were co-authors of a chapter, “Real-time Motion Planning and Control in the 2005 Cornell RoboCup System,” in a 2006 textbook. A DARPA Grand Challenge vehicle (center right) competes in a desert environment.

World champions in nine out of 19 annual competitions, the team behind the spectacularly successful 2005 Formula SAE race car posed after the series of challenges at Michigan’s Pontiac Silverdome. A total of 140 teams from around the world participated that year. Standing at left is the Cornell FSAE team’s longtime advisor, MAE Professor Al George.
the College of Engineering, MAE students on the mechanical insect project also work with a physicist in the Department of Theoretical and Applied Mechanics, Jane Wang, who makes mathematical models of the aerodynamics of insect flight.

Students who join Hod Lipson’s Self-Replicating Machines Project must accept his challenge: Design and construct a machine that can construct a working copy of itself. Other student opportunities in the Lipson lab include self-organizing cellular micro-robots (which share information with their neighbors and the environment to self-organize into macrostructures by repairing and reconfiguring themselves) and something Lipson calls the Santa Clause Machine (a rapid prototyping 3-D printer that constructs shapes by depositing material layer by layer).

In 2006, a three-legged mechanical creature limped out of the Lipson lab to wow the world of robotics—in part because the thing had begun “life” with four legs, lost one, and figured out how to cope. Lipson, working with postdoctoral researcher Josh Bongard and graduate student Viktor Zykov, had not preprogrammed the robot to walk; rather, they had programmed it to explore itself and learn to use its limbs to move. When Bongard removed a leg, the robot self-assessed the problem, tested alternative solutions, and taught itself to walk again. It was almost as if the robot had a primitive kind of consciousness, Bongard claimed, after building a device that asks itself, essentially: What would happen if I do this?

Meanwhile, students with a knack for gaming are attracted to Lipson’s Evolutionary Robotics Project. The professor and his students try to develop robots not by designing them directly, the traditional way, but by allowing robots to compete and cooperate under the rules of natural selection. “After many generations we get interesting new kinds of machines and controllers,” Lipson says. “This is where AI (artificial intelligence) meets engineering design, to make the future of design automation.”

If bio-inspired flight and robotic evolution aren’t biological enough for students, there’s lots of life sciences–related work to be done. Mingming Wu, a specialist in bio-
fluid dynamics, has a project she calls “Tracking the Social Behavior of \textit{E. coli}.” Students are invited to help Wu figure out how the single-celled organisms “swim smartly,” rather than at random, and why they relate so sociably to their neighboring \textit{E. coli}.

An internationally recognized pioneer in bone-implant systems and total-joint replacements, Donald L. Bartel, works with the top orthopedic specialists at New York’s Hospital for Special Surgery and Weill Cornell Medical College. Bartel also works with interested undergraduates in his Cornell–Ithaca lab to plan new designs for minimal size knee replacements and shoulder joint replacements.

**Mechanobiology and Beyond**

Among other faculty members who merge mechanical engineering with medicine is Marjolein van der Meulen. She has refocused the traditional biomechanics approach to studying living tissue in its normal and diseased state. Instead, van der Meulen tries to understand how mechanical forces influence skeletal structure, a new approach called mechanobiology that emphasizes the modulation of biological processes by mechanical stimuli.

Larry Bonassar, a faculty member in mechanical and aerospace engineering and in the college’s newest department, biomedical engineering, studies the regeneration of musculoskeletal tissues, including bone and cartilage, in the spine, skull, and trachea. Bonassar recruits students to help with several futuristic projects, including one called “Tissue Injection Molding Using Mesenchymal Stem Cells.”

Between 40 and 50 percent of undergraduate mechanical engineering majors take advantage of the opportunity to participate in projects—the faculty calls it experiential education—and those opportunities, plus the strong emphasis on mathematics and en-
Beginning in the first semester of her freshman year, MAE’s Stephanie Gil worked on the Mars Exploration Rover project, including stints at Langley Research Center and (shown here) at the Jet Propulsion Lab in Pasadena, California.

Bill Nye, a 1977 MAE graduate and television’s “Science Guy,” demonstrates smoke vortices in an Upson Hall lab, one of his duties as the Frank H. T. Rhodes Class of ’56 Professor.
gineering science, are what distinguish Cornell’s mechanical and aerospace engineering program from those in other colleges, according to veteran faculty members Moon, Leibovich, and Caughey. By engineering science they mean courses like ENGRD 2020, “Mechanics of Solids,” which requires a solid background in physics and mathematics and is usually taken in the sophomore year. But as early as the freshman year, prospective MAE majors can get a foretaste of the field in classes such as ENGR 1110, “Nanotechnology” (Cornell was among the first engineering schools to offer a hands-on course that lets undergraduates design and build nanotech devices) or MAE 1270, “Introduction to Entrepreneurship and Enterprise Engineering” (more graduates these days want to start their own companies, according to Leibovich).

**Heat Transfer and Tech Transfer**

While the Sibley School’s early leaders—Thurston, for instance—would still recognize some of the original fields in the mechanic arts, Caughey thinks they would be surprised about some modern-day applications. How could they have guessed, Caughey says, that theoretical studies of heat transfer by Kenneth E. Torrance would produce a revolutionary “reflectance model” for computer graphics? Torrance’s studies of spectral energy distribution enabled the animation company, Pixar, to render metallic and plastic surfaces with startling clarity in the breakthrough film *Toy Story* (1996) and to surpass the technological achievements in 2006 with *Cars*.

Real cars and the environmental problems they cause were not foremost in the minds of Cornell’s nineteenth-century practitioners of the mechanic arts, but they became a real focus in the twentieth century. Edwin L. Resler worked to apply thermodynamic principles to automotive pollution controls and engine design. A director of the Graduate School of Aerospace Engineering (1963–72), Resler was the first director when that graduate program merged and the Sibley School took off into mechanical and aerospace engineering; Resler took off subsequently with studies of magneto-hydrodynamics for shockwave propulsion systems.

With an interest in all kinds of machines that burn fuel, Zellman Warhaft examines the role of turbulence in combustion and pollution. Another specialist in turbulence physics, Lance R. Collins (the Sibley School’s S. C. Thomas Sze Director, beginning in 2006) performs numerical simulations and probability density function modeling to study combustion.

Together with his former Cornell mentor, William R. Sears (1913–2002), Edwin L. Resler Jr. named the field they pioneered: magneto-hydrodynamics. Resler went on to lead the Graduate School of Aerospace Engineering and become the founding director of the merged Sibley School of Mechanical and Aerospace Engineering—while applying thermodynamic principles to automotive engine design and pollution controls.
Combustion, for the first Sibley School engineers, meant burning of coal, wood, gas and oil, and petroleum distillates. It still does, and today the Sibley engineers have added other fuels to the mix. For example, the incineration of chemical warfare agents is studied at Cornell by Frederick C. Gouldin (as well as by Elizabeth Fisher and her project undergraduates) with high-tech methods such as color-center lasers for infrared combustion spectroscopy and stereo-particle image velocimetry.

**Delayed Gratification**

A very low-tech fuel, methane, was burned in Stephen B. Pope’s landmark study of probability density function methods for tracking turbulent combustion. “Steve Pope’s work in the early 1980s wasn’t adopted by industry and built into commercial codes for twenty-five years,” Caughey notes, “and methods he’s working on now probably won’t be practicable for another ten or fifteen years. That kind of beyond-the-horizon research is only possible in an academic setting.”

Both Caughey and Leibovich, who between them have more than seventy years’ experience at Cornell, know about aeronautical researchers’ delayed gratification. Their computational fluid dynamics work on problems, such as the shockwaves forming at subsonic speeds over aircraft wings, led to computer-based tools for aircraft designers who, in turn, managed to increase the fuel economy and range of big planes like the Boeing 777 and the Airbus.

Jet planes are less likely to fall from the sky thanks to earlier work by another long-time member of the Sibley School faculty, Franklin K. Moore. He tackled the problem of rotating stall—and more importantly, recovery from stall—in turbojet engines.
One of the last living links to the Cornell Aeronautical Laboratory, Moore was the director of the Aerosciences Division of that Buffalo, New York, facility before joining the Sibley School faculty in 1965 as head of the Department of Thermal Engineering.

Moore worked toward a modern theory of nonlinear vibration (along with computational methods to make theory applicable to real engines), a theory that also is of interest to Moon in his studies of nonlinear and chaotic dynamics in machines. A former director of the Sibley School (1987–92), Moon says mechanical engineers are well equipped to move fluidly among the macro-, micro-, and nanoscale worlds.

He points to Sibley researcher Brian J. Kirby, director of the micro/nanofluidics laboratory, who builds miniaturized devices for biochemical analysis, studies nanoscale fluid transport, and works on laser microfabrication. “People thought there was a paradigm shift in the 1980s and ’90s and everything was going to be microtechnology,” Moon said. “We forgot about the macrotechnology world, which is where we live, a world where micro things control large-scale devices. That’s where mechanical engineers have done best in the past—machines and the control of machines—and where we will continue to excel in the future.”
Cornell students of operations research and information engineering (ORIE) are characteristically enthusiastic about their major, one of the most popular in the College of Engineering. When they convey that enthusiasm to other Cornell students, they often encounter expressions of skepticism rooted in unfamiliarity with operations research and its pervasive applicability. Responses like “operations research methods can be used to optimize organizational and system performance” usually don’t close the deal.

Now they can respond with a ready example of how OR tools have improved Cornell, by solving a scheduling problem that baffled administrators for decades and caused nightmares for students: “We devised a method for scheduling final exams university wide (with a little help from Professors Bob Bland and David Shmoys and Ph.D. student Dmitriy Levchenkov) that reduced by 85 percent the number of students facing three exams in a day. The number of students with back-to-back finals was reduced by 65 percent. Eighteen thousand students at Cornell and more than four thousand courses—you do the math if you can—but we did the optimization. The number of possible exam schedules? More than 50,000,000,000,000,000,000. And we get the best one. Any other questions?”

Cornell undergraduate students can develop a basic mastery of the core methods of OR and learn how to apply them in industry with a bachelor’s degree in either operations research and engineering or information science, systems, and technology. Master of engineering students receive a deeper immersion in the requisite math, scientific, computational, and engineering skills and apply them in team-based design projects for real clients in finance, information technology, manufacturing, marketing, operations management, or systems engineering. Ph.D. students enter a rigorous academic program
that demands independent investigation and achievement and original scholarly work of the highest caliber—their preparation for academic teaching and research positions or careers in the private sector. In the ten academic years from fall 1996 through spring 2006, Cornell’s OR programs have awarded 1,085 B.S. degrees, 721 M.Eng. degrees, and 52 Ph.D. degrees.

In the two undergraduate options, students get a broad education in the technical and modeling concepts used to analyze and design complex systems and to operate them efficiently. Their foundations include basic skills in computing, optimization, probability, and statistics, plus required courses in managerial accounting, simulation, and systems analysis. They have the opportunity to explore in greater depth areas such as data mining, finance, game theory, and manufacturing systems design, information technology, as well as the foundational areas. The new major in information science, systems, and technology offered by the ORIE faculty in collaboration with the university’s Faculty of Computing and Information Science allows a further specialization in management science. Students learn the design and management of complex information systems as well as methods for quantitative decision-making. (See “Optimizing Education for the Information Industry,” above.)

**Roll Up Your Sleeves, Watch Your Fingers, Use Your Head**

Cornell was a pioneer in industrial engineering education. It was among the first universities to offer courses in IE more than 100 years ago and awarded the first Ph.D. in IE in
1933. The current School of Operations Research and Information Engineering traces its roots to the beginnings of industrial engineering. There have been vast changes in both the areas of application and the methodological tools, but even in the early twentieth century, when industrial engineering implied noisy workplaces filled with heavy machinery, Cornell graduates didn’t expect to stay on the factory floor for long. They rolled up their sleeves, learned to watch their fingers, and looked for opportunities to make the system work better for all concerned. That can-do approach and the future-oriented training to match has been the hallmark of industrial engineering at Cornell, although the name of the program changed several times along the way. (See “What’s in a Name?” page 224.)

ONLY IN ITHACA

THE MAN WHO MINDED THERBLIGS

“Movement: R. H. moves from center of fixture to right and to the front, about 8 inches, grasps the knob of the fixture lever and swings it back around fixture in clockwise direction about 200 degrees on a radius of 8 inches.”

“Practical and Theoretical Aspects of Micromotion Study,” Ralph Mosser Barnes, 1933.

A woman named “R. H.” was making inch-long connector links for Corona typewriters when a Cornell professor of industrial engineering set up his movie camera in the L. C. Smith & Corona Typewriters Company factory in Groton, New York. Professor Ralph Mosser Barnes had already parlayed his Cornell M.S. degree in mechanical engineering into several Rochester-based jobs, including service as a time-study engineer at the Gleason Works gear-machinery factory and as an industrial engineer at Eastman Kodak.

Barnes’s 1931 book, Industrial Engineering and Management, was a modest success, but a best seller was in the works—if only he could find a suitable factory for research. Working on his Ph.D. while teaching industrial engineering at Cornell, he went to the typewriter factory to discover the optimum means of studying time and motion in assembly-line tasks.

Time-study pioneers Frank and Lillian Gilbreth previously laid the new profession’s foundation, helping factory managers teach workers the “one best way” to perform their repetitive tasks. Indeed, Barnes credited the Gilbreths with the concept of therbligs—their term for micromotions—by rearranging the letters of the family name.

Barnes’s plan was to analyze each typewriter factory therblig—inch by inch, second by second—by filming workers’ hands, then analyzing their micromotions with a special movie projector. He pilot-tested his study method while women folded napkins in the company cafeteria. The therbligs he filmed—while workers built Corona portable typewriters—were documented in great detail for his doctoral dissertation: “Practical and Theoretical Aspects of Micromotion Study,” which the practical man retooled into the 1937 text that sold 300,000 copies: Motion and Time: Design and Measurement in Work.
Dexter Kimball: Machinist and Educator

The first courses in industrial engineering were taught in Sibley College of the Mechanic Arts by Dexter Kimball, who later became the first dean of the newly consolidated College of Engineering in 1921.

Kimball was twenty-eight years old and a first-class machinist at San Francisco’s Union Iron Works when he quit his job and enrolled in the recently opened (1891) Stanford University. At first, the Stanford freshman felt he had “made a great mistake in wasting those years working in shops.” Subsequently he came to recognize that shop work was an essential part of his education.

In 1904 Kimball, then a full professor in Sibley College, put together a new course he intended to call “Economics of Production.” When his dean objected that this was “too high-brow,” Kimball changed the name to “Works Administration” and taught about the economics of production for the first time at an American university. In 1913, Kimball turned his lectures from “Works Administration” into the textbook, *Principles of Industrial Organization.*

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**THE PRIDE OF CORNELL ENGINEERING**

**THE PRINCIPLES OF SCIENTIFIC MANAGEMENT**

In the 1890s, Frederick Taylor introduced ideas for improving the efficiency of labor by breaking down the steps required for a task and designing “the one best method” for all steps and the task they comprise. Taylor expounded on this scientific management approach, as an invited lecturer at many engineering schools and business schools, and as a consultant in industry.

When Taylor presented a paper, “Shop Management,” at the 1903 meeting of the American Society of Mechanical Engineers, Dexter Kimball, then works manager at Stanley Electric Manufacturing Company, was in the audience. Taylor’s approach received widespread attention beyond the management and engineering communities when, in 1910, Louis Brandeis invoked it successfully in a case before the Interstate Commerce Commission. The future Supreme Court justice argued that railroads could raise wages without raising fares, if they operated more efficiently by employing scientific management.

Indeed, it has been reported that this was the first known use of the term “scientific management,” although it is not clear whether Brandeis coined the term or it was suggested to him by some of Taylor’s collaborators. In 1911, Taylor published a book entitled *The Principles of Scientific Management.* Lillian and Frank Gilbreth further developed the application of what they called “time and motion study” to efficiency in the workplace. The Gilbreths were passionate about efficiency in their home as well as in the work place; two of their twelve children wrote about these experiences in the book *Cheaper by the Dozen.*

In 1913, Kimball wrote in *Principles of Industrial Organization,* “the application of these well-known methods . . . has become known as efficiency engineering, industrial engineering, or scientific management.” Since the time of Taylor and the Gilbreths, many other terms have been linked to the discipline(s) that grew from their ideas: *administrative engineering, administrative science, engineering management, management engineering, management science, operations management, operations research, systems analysis,* and *systems engineering.*

One could debate whether these terms are all variations on a theme, or whether they represent distinct descendants of a common ancestor. Their standard short definitions are very similar—application of *scientific methods to systems* in order to design and operate them *efficiently.*
Andrew Schultz Jr.: Cornell to Colonel and Back

In 1914, the Sibley College created a Department of Industrial Engineering, and, a year later, introduced an option in industrial engineering for seniors. In 1931, ten years after Sibley College was absorbed into the consolidated College of Engineering as the Sibley School of Mechanical Engineering, a bachelor of science in administrative engineering curriculum was introduced in both mechanical engineering and electrical engineering. In 1935, civil engineering followed suit. For the time being, the title “administrative engineering” had replaced “industrial engineering,” but the titles were roughly synonymous. In 1936, Kimball’s last year as dean, one of the recipients of the B.S. in administrative engineering from the Sibley School was Andrew S. Schultz Jr.

Like Kimball, Schultz was to have a profound impact on the development of Cornell’s engineering college, and, especially on the development of operations research as an academic discipline in the United States and as a strong academic unit at Cornell. He received his Ph.D. at Cornell in 1941 and returned in 1946 as an assistant professor. He served as head of the Department of Industrial Engineering and Administration from 1951 to 1963, when he became dean of the College of Engineering.

Between the completion of his Ph.D. in 1941 and his appointment as a faculty member in 1946, Schultz served in the U.S. Army as chief of section in the Industrial Service, Ammunition Division, Office of the Chief of Ordnance, rising to the rank of lieutenant colonel.

In England during World War II, military planners worked with civilians from a variety of disciplines, including mathematics and engineering, and, interestingly, law, to tackle the challenges imposed by the logistical support of massive military operations. Operations analysis (or, operational analysis, in British English) was the name that was
initially associated with their systematic approach to planning and the collection of mathematical tools employed. Over time it came to be called operations research. After the conclusion of the war, the military services continued to support the development of OR tools, and private industry quickly recognized their value as well.

By the time he returned to Cornell in 1946 to join the faculty, Schultz had a firm appreciation of the potential of OR. He saw the basically descriptive or qualitative discipline of industrial/administrative engineering that he had studied being transformed into a powerful, more mathematical field. He also saw a major obstacle to exploiting the new tools: large-scale application required substantial computational effort.

The Emergence of Operations Research

During the early 1950s, as head of the Department of Industrial Engineering and Administration, Schultz took several important steps that accelerated Cornell’s commitment and contributions to OR. He added two new faculty members, Robert Bechhofer...
and Lionel Weiss, who were trained as mathematical statisticians. They played key roles in making applications of statistics part of the core of OR and in leading the school beyond traditional industrial engineering to a broader discipline, more sophisticated mathematically, and better suited to the rapidly evolving needs of industry. In 1953, Schultz was instrumental in bringing the first computer to Cornell, and he continued to promote computers as vital tools in research and education. (In 1965, as dean of engineering, Schultz created the Department of Computer Science.) By the end of the 1950s, Schultz had also identified two young Cornell Ph.D.s, Richard Conway and William Maxwell, who would lead a transformation to the new era uniting computing with a mathematically rigorous approach to solving production-planning problems.

The 1967 book, *Theory of Scheduling*, by Conway, Maxwell, and Louis Miller is regarded as a landmark in the timeline of operations research (and was so named by INFORMS, the Institute for Operations Research and the Management Sciences). It placed on a formal foundation the study of the entire area of production scheduling. Conway and Maxwell each taught at Cornell for almost forty years. Conway was one of the founding members of the computer science department; Maxwell spent his entire academic career in OR and was the first Andrew Schultz Jr. Professor of Industrial Engineering. Their roles in the development of OR over several decades at Cornell constitute a metaphor for the evolution of the field of OR in general and the Cornell program in particular.

When they first joined the faculty, Conway and Maxwell must have appeared to many of the incumbent IE faculty members to be wild-eyed young theoreticians. They were developing notation, nomenclature, and theory for a broad, abstract class of optimization problems; they certainly were not at the center of 1950s IE. Long before they retired from the faculty, Conway and Maxwell were viewed, correctly, as among the faculty members most focused on applications, rather than theory. They achieved tremendous success in moving the field: what had been theoretical, relative to the prevailing norms early in their careers, later became, in part due to their efforts, part of the practitioner’s tool kit.

Throughout the 1960s the curriculum and research activities in OR continued to expand with the hiring of faculty members in applied probability, game theory, and optimization. N. U. (Uma) Prabhu joined the faculty in 1965. His 1965 book, *Queues and Inventories, a Study of Their Basic Stochastic Processes*, also recognized by INFORMS as a major contribution to the development of OR, and his journal publications brought unity to the treatment of a variety of important applications and solidified the role of probabilistic models and methods in OR.

Louis Billera joined the faculty in the late 1960s, followed by William Lucas. Together they made Cornell one of three world centers, along with Hebrew University in
Jerusalem and Leningrad State University, for graduate study in game theory, the mathematical analysis of conflict and cooperation. Many influential game theorists of the next generation studied at Cornell in the 1970s and 1980s. By 1970, OR at Cornell had hired several faculty members in optimization, and, in 1971, D. R. Fulkerson left the RAND Corporation to join the Cornell faculty. He was already a legendary figure for his research in network flows and in large-scale optimization. He and L. R. Ford Jr. had developed the theory of network flows, which had had an enormous impact on the practice of OR.

Fulkerson had also co-authored work that introduced several of the cornerstones of large-scale optimization: cutting planes and branch-and-bound (in work on the traveling salesman problem with George Dantzig and Selmer Johnson); column generation (with Ford); and the primal–dual method (with Dantzig and Ford). These contributions were considered among the most important in the field at that time. Over the decades that have passed since, they have become even more important in the practical application of large-scale optimization in industry. Fulkerson’s death in 1976 was a painful blow for Cornell and for the OR community worldwide; however, in his five years at Cornell, he set a standard for excellence that continues to serve well.

Continued Excellence and New Directions

The hiring of Bechhofer and Weiss in the early 1950s began a tradition of excellence in statistical research. Bruce Turnbull, David Ruppert, and Dawn Woodward carry on that tradition and are also leading the school to new application areas, including data mining and biomedicine and public health. For example, Ruppert has studied high-dimensional models in genomics. Turnbull’s research concerns the interim monitoring of clinical trials, statistical evaluation of diagnostic procedures, survival analysis, and the monitoring of spatial patterns of disease incidence. Woodward’s areas of expertise include spatial statistics and the computational complexity of approximating statistical estimators. Another faculty member with expertise in data mining is Paat Rusmevichientong, who helps Amazon and other organizations make effective use of massive web log and point-of-sale data sets.

There are also other contributors to work on biomedical and public-health applications. Shmoys applies discrete optimization to problems in genomics. Shane Henderson’s research is concerned with discrete-event simulation, and he applies structured simulation optimization to radiation treatment planning. Christine Shoemaker, whose primary appointment is in civil and environmental engineering, is an authority in ecosystems management, water-resources systems analysis, and groundwater protection. Jack Muckstadt works in collaboration with faculty at the Weill Cornell Medical College on response logistics for mass casualty events.
Supply chain management, Muckstadt’s principal area, represents a natural continuation of Conway and Maxwell’s production planning activities, but it extends beyond the manufacturing and distribution activities of a single organization to the flow of products, information, and money through the entire supply chain, including corporate partners.

Peter Jackson, Robin Roundy, Huseyin Topaloglu, Mark Lewis, Rusmevichientong, and Shmoys are also major contributors to the supply chain activities. Jackson has also

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SO THEY SAID

HOW CLOSE IS MANHATTAN?

The placement success “clearly attests to the academic strength and recognition Cornell’s Financial Engineering enjoys among Wall Street firms.”

Victoria Averbukh, head of Cornell Financial Engineering Manhattan

The first academic meeting in financial engineering took place at Cornell on May 29, 1989, bringing together many of the most prominent national and international researchers in the field of computational finance. As a result, Cornell’s program in financial engineering was born, establishing Cornell as a pioneering leader in a young and emerging field.

Together, Robert Jarrow and David Heath advised students for several years before formalizing the program in 1995, making Cornell one of the very first universities to have a graduate program in financial engineering, and arguably the oldest such program in the world.

Cornell continues to retain its leadership in the maturing field of financial engineering. Today, a highly active research group in mathematical finance and financial engineering spans the campus. Cornell’s strong tradition of interdisciplinary study plays an important role in financial engineering and includes members of ORIE, the Johnson School, the Department of Economics, and the Department of Applied Economics and Management.

In December 2005, ORIE opened offices at 55 Broad Street, in the heart of the Wall Street financial district, across from the New York Stock Exchange. Programs and activities in Manhattan have become increasingly vibrant, leading to an extension of Ithaca-based financial engineering programs through ORIE’s “Wall Street Campus.” Cornell Financial Engineering Manhattan.

CFEM serves as a bridge between Ithaca’s financial engineering program and the financial industry. Its offerings include practitioner-taught academic programs, projects, research, and seminar series. Particularly successful is the Wall Street outreach program for Cornell financial engineering M.Eng. students. The financial industry was a challenging sector in which to seek employment in 2008. Sector layoffs, which totaled 153,000 in 2007, were predicted to be even higher in 2008. Nonetheless, all of the 2008 ORIE M.Eng. students in the financial engineering concentration had internships and gained valuable experience at financial firms over the summer.
been very influential for his innovations in educational software for manufacturing systems design.

Prabhu brought applied probability methods and applications into OR, and although officially professor emeritus, he still remains active in the area. Like Prabhu, Lewis works on queuing models, and he applies them to dynamic resource allocation in parallel systems. Applied probabilists Sidney Resnick and Gennady Samorodnitsky study heavy-tailed phenomena, and have examined applications to communications networks and finance.

Financial engineering, a vigorous new area for application of OR methods, is a specialty of applied probabilists Philip Protter, Alex Schied, and Stefan Weber. They play a major role at ORIE’s Manhattan office. (See “How Close Is Manhattan,” page 227.) David Ruppert also contributes to financial engineering and has written a book titled *Statistics and Finance*. Robert Jarrow, whose primary appointment is in the Johnson Graduate School of Management, is a major contributor, and internationally visible figure in financial engineering.

Billera and Lucas gave ORIE a very high profile in game theory during the 1970s and 1980s, when the primary applications were in economics. With the rapid growth of the World Wide Web and electronic commerce, game theory has become a very hot application area. Eric Friedman’s research is at the intersection of computer science, game theory, and operations research—constructing robust and effective ranking and reputation systems, designing fair and efficient web-serving algorithms, and allocating bandwidth in wireless systems. Eva Tardos, whose primary appointment is in computer science, works on algorithmic game theory, an emerging new area of designing systems and algorithms for communities of self-interested users. The work of Tardos and Friedman is useful in analyzing communication networks. Henderson, Resnick, Shmoys, Leslie Trotter Jr., and David Williamson also work on infotech modeling.

Since Ray Fulkerson’s arrival in 1971, ORIE has had a leadership role in optimization. There have been many important new developments in optimization (some of them derivative of Fulkerson’s work). Current faculty members in ORIE have been at the center of many of these: fast interior-point methods for linear programming and convex optimization, semidefinite programming, and applications to approximation algorithms (Michael Todd, James Renegar, and Williamson); very fast network flow algorithms (Tardos); approximation algorithms based on linear programming (Shmoys, Tardos,
According to Albert R. George, Cornell's J. F. Carr Professor of Mechanical Engineering and the founding director of the Systems Engineering Program, the very development of the program was an exercise in applied systems engineering. An interdisciplinary team formed in 1997 moved quickly from need to product while engaging “customers” to help focus the project direction. The customers—besides potential students, of course—were industry leaders on an advisory council of companies that need broadly educated systems engineers. In the next academic year, 27 students enrolled in the first course in applied systems engineering; within four years, 205 students were enrolled in a growing roster of classes.

Today, Cornell offers a Systems Engineering Program of unprecedented strength. Five engineering departments collectively own the program: Operations Research and Information Engineering, Electrical and Computer Engineering, Civil and Environmental Engineering, Mechanical and Aerospace Engineering, and Computer Science. Together, they cultivate collaborations that extend to other engineering fields and many additional areas of study across the university. Says Peter L. Jackson, program director, “We strive to equip engineers and managers with tools that work and reward right away and convey to them a habit of asking the right questions, seeing the open possibilities, and planning the best path—and to do all this when the situation is still fluid.”

The Systems Engineering Program offers two courses of study: a Master of Engineering degree and a minor in systems engineering. Reflecting the principles of flexibility and ingenuity, the program now offers a master's degree via distance learning. Through core courses, the degree program emphasizes applied systems engineering, systems architecture, behavior and optimization, and project management. Students then customize their program drawing from a large roster of electives.

The other core component is a hands-on, team-based project, in which students from various disciplines use one another’s knowledge and expertise to solve problems. Says Linda Nozick, professor of civil and environmental engineering, “At Cornell, systems engineering is about the real world—the complicated and messy real world.” Indeed, team projects incorporate a wide range of complicated, messy, real-world challenges including designing a futuristic, fuel-efficient car for the Automotive X Prize Competition; building a robotic soccer team (and winning the Robot World Cup [RoboCup]; helping to design, build, and launch CUSat, an autonomous in-orbit inspection satellite system; and designing future energy systems.

Lockheed Martin is partnering with the College of Engineering to put high-potential employees through the Systems Engineering master's program as an integral part of their leadership development. In 2008, this team of 19 young engineers broke the world amateur high-altitude balloon record in a recent near-space flight that exceeded 125,000 feet—5,000 feet higher than the previous record.

As with so many other Cornell engineering initiatives, Systems Engineering remains fast-evolving, creative, responsive to emerging needs, and highly collaborative.

and Williamson); practical large-scale mixed-integer programming software (Trotter); a new calculus for optimization of nonsmooth functions, with applications to automatic feedback control and the stability of systems (Adrian Lewis); and new foundations for understanding duality in linear programming (Bland).

The current ORIE faculty has carried forward the strong traditions established by an earlier generation, building more powerful mathematical foundations, developing
faster more robust methods, and expanding greatly the scope of applications. OR is a multidisciplinary field. A natural outcome of initiatives in data mining, information technology, financial engineering, and supply-chain management has been a trend toward work that brings together faculty teams with diverse areas of expertise.

What Information Engineers Do

In teaching, as in research, ORIE at Cornell has put a premium on mathematical rigor, pushing the envelope, not merely knowing what works and what doesn’t, but also understanding why. Armed with such training, graduates of the ORIE degree programs are typically able to make broader, more fundamental contributions to the practice of OR. They are able to adapt to the ever more rapidly changing workplace, where tools that work today may be based on assumptions that won’t hold tomorrow.

Almost all ORIE graduates are very successful, and many have notable achievements. For example, Sherri Koenig Stuewer, B.S. 1973, M.S 1975, was the first woman in the world to manage a major oil refinery, Exxon’s Baytown refinery in Texas. Robert Bixby, Ph.D. 1972, is one of the most influential figures in the world in the application of linear and integer–linear optimization methodologies to business. Moreover, Bixby attributes his success in this arena, in part, to the highly rigorous mathematical training he received in OR at Cornell. The success of Bland, Levchenkov, and Shmoys in scheduling final exams derives from developing a model susceptible to the new, high-powered mixed-integer programming machinery that Bixby has pioneered.
If it were necessary for all of the 150–200 academic units that award degrees in OR–related fields in the United States to follow the same curricular model, Cornell’s highly mathematical approach would not be the right one. Of course, you would not want this one-size-fits-all approach to OR education, any more than you would want every employee of a large enterprise to have exactly the same skills, background, and perspective. The great majority of those programs are less mathematical, with greater emphasis than Cornell on such traditional IE subjects as ergonomics, work measurement, and human factors. They are much more like each other than they are like OR at Cornell. There is an important need for practitioners well trained in those subjects. There is also a tremendous value to providing training like that offered in OR at Cornell, and there are very few institutions that have the right faculty and students to do it well.

One of the skills that students learn in OR courses is how to calculate and interpret the marginal value of scarce resources. The degree programs in OR at Cornell have very high marginal values, indeed.
Teaching and research in Cornell’s Department of Theoretical and Applied Mechanics covers a broad range of scales: from nano to celestial. Faculty members in this department strive to create and disseminate knowledge in mechanics and applied mathematics for all present and emerging engineering disciplines.

A Cornell engineering department without an undergraduate major, theoretical and applied mechanics offers a broad selection of undergraduate-level courses that engage majors in other fields. The department also administers advanced studies for master’s or Ph.D. candidates in theoretical and applied mechanics. Whether it’s the inner workings of a popular entertainment device (“Design Integration: A Portable CD Player”) or Saturn’s rings (“Mechanics of the Solar System”), TAM courses are aimed at those with a passion for mathematics (“Advanced Engineering Analysis”) or a curiosity about dynamics (“Nonlinear Vibrations”) or continuum mechanics (“Nonlinear Elasticity”).

The founders who hoped the new university could apply science to problems in nineteenth-century agriculture and industry might be surprised to learn where the strides were made in search for interesting mechanical problems: MEMS and biomolecular structures, insect wings and shape-memory solids, earthquake faults and aster-

In the Biorobotics and Locomotion Lab, TAM Professor Andy Ruina and a student prepare the four-legged robot named Cornell Ranger for what turned out to be a record-breaking walk: 5.6 miles on one battery charge, April 3, 2008, in Barton Hall.
Moving to the Forefront

The mechanical engineer generally credited with incorporating science, mathematics, and theory into nineteenth-century engineering education in America, Robert H. Thurston, dean of the Sibley College of Mechanical Engineering and Mechanic Arts from 1885 to 1903, would be pleased with the way TAM evolved. So says a twenty-first-century educator who headed both that department and the Sibley School, Francis “Frank” Moon:

> By 1900 this [university] was producing 20 percent of the mechanical engineers in the United States. Cornell was right at the forefront of changing the way people designed technology and machines. Thanks to the jump-start Thurston gave us—and the inspired efforts of Cornell mechanical engineers who followed—we are still in the forefront.

Well before 1965, when the College of Engineering settled on the current name for the Department of Theoretical and Applied Mechanics, Cornell engineers were do-

so they said

THERMAL EXPANSION AND WESTWARD EXPANSION

“They could have covered it with 18 gauge for a lot less money.”

P. P. Bijlaard, Cornell professor of theoretical and applied mechanics, 1965

For one Cornell expert in elastic stability, there was a hidden meaning in the formal name of the Gateway Arch in St. Louis.

A native of the Netherlands, P. P. (for Paul Pieter) Bijlaard (1898–1967) was building bridges for the Dutch East Indies State Railway company when the Japanese occupied the archipelago now called Indonesia during World War II. Bijlaard already had achieved an international reputation for pioneering achievements in the basic theory of plasticity of materials (and a knighthood in the Order of the Netherlands Lions, bestowed by Queen Wilhelmina for his government service), but the Japanese threw him into an island prison with meager rations and daily chores of sawing logs. At night, Bijlaard applied his plasticity theories to geophysical problems and later claimed to have laid the groundwork for the modern understanding of plate tectonics. That claim was hard to prove because Bijlaard had burned his handwritten notes, to keep the calculations from falling into the hands of the enemy, before escaping from the concentration camp.

Soon after reaching the United States in 1948, Bijlaard joined the mechanics faculty in the School of Civil Engineering at Cornell. In collaboration with George Winter, he performed experiments “to extend the theory of plasticity in determination of the buckling strength of plates and columns beyond the elastic limit. “Buckling of Trusses and Rigid Frames” (Cornell University Engineering Experiment Station Bulletin No. 36) became a best seller. Other
ing both kinds of mechanics—and writing books to show others how. Edgar H. Wood (1872–1961), the son of a Sibley College shop foreman and recipient of two Cornell degrees (in 1892 and 1893), returned as a professor of machine design and taught for the next thirty years. He wrote *A Textbook of Mechanics* and co-authored *Kinematics of Machinery* and *Strength of Materials* with other Cornell mechanical engineers.

A forty-year faculty member in mechanical engineering, Harold C. Perkins (1891–1986), caught the attention of fellow engineers worldwide, in 1953, when he was the first researcher to extend photoelastic measurements from the static into the dynamic range. Perkins also investigated helical springs, high-velocity impact, welding design, and the distribution of loads on the threads of screws. A firm believer that the simplest experiments were the best (Perkins said the perfect liquid to support his dynamic-loading specimens was a popular brand of hair-setting lotion), he also was skilled at classroom chalkboard lectures. Students who learned their trigonometry and vector forces from his easy-to-grasp free-body diagrams dubbed the professor “Free Body Perkins.”

A co-author of *Theory of Elasticity* (1951) and *Elasticity and Plasticity* (1953), James N. Goodier (1905–69) also was known for his lucid style of lecturing—even to general audiences. Goodier conducted research in continuous media, linear and nonlinear elasticity, wave propagation, static and dynamic instabilities, explosive loading, and hypervelocity impact.

Research into thick and thin shells found applications in the design of pressure vessels for steam generators, chemical reactors, and nuclear reactor vessels. Bijlaard’s analysis of stresses in so-called “sandwich plates” (two metallic sheets held apart by filler material) enabled the aerospace industry to design rigid, smooth skins for supersonic aircraft.

But the Finnish architect and furniture designer, Eero Saarinen, ignored the advice of Bijlaard, who served as a consultant to an ambitious project at the Jefferson National Expansion Memorial. The Saarinen-designed Gateway Arch, which marks the spot where the Lewis and Clark Expedition headed west, was nearing completion in 1965 when sidewalk superintendents noted an apparent flaw in the stainless-steel skin that covered the upper reaches of the sixty-story-tall structure. For the first 300 feet above ground level, reinforced concrete formed the core of the arch. But above that level, the architect had specified a carbon-steel frame. Bijlaard warned Saarinen that stainless steel over carbon steel would wrinkle—because stainless has a coefficient of thermal expansion approximately 50 percent greater than carbon steel—but the distinguished engineer from Cornell was dismissed as an eccentric old man.

Lawrence J. Wolf was a young professor of mechanical engineering at St. Louis Community College in 1965 with an after-hours consulting job at the Nooter Boiler Company designing support lugs on pressure vessels. When Wolf wrote a computer program for his assigned task, he used an analysis developed by Bijlaard and published by the Pressure Vessel Research Council—but the boiler company had its doubts. Double-check your assumptions with the esteemed Professor Bijlaard, the community college engineer was told.

Because Bijlaard declined to fly to St. Louis, Wolf and a senior engineer at the boiler company came to Ithaca. They brought a full-page newspaper story about the latest engineering scandal of St. Louis: Steel plates that were perfectly flat on the ground became visibly wrinkled atop the Gateway Arch. Wolf and his superior, George Conlee, were greeted in the TAM professor’s dining room by a shaky, elderly man and a gracious, comparatively young woman, Claire Radjen Ajoe Radjainten of Bandoeng, whom Bijlaard married in 1931.

“Does it really look this bad?” Bijlaard asked of Wolf, who had driven past the arch earlier that day. When Wolf told Bijlaard that contractors were blaming the steel suppliers for exceeding the flatness tolerance—and that suppliers were blaming the designers and everyone was blaming the politicians—Bijlaard laughed with glee: “Thermal expansion! I told them! I told them!”

The first time the sun warmed the newly placed skin panels, which were secured to the carbon steel inner shell, the quarter-inch-thick outer panels buckled. “It’s only a cosmetic effect,” Bijlaard told his visitors. “But if they wanted it to wrinkle, they could have covered it with 18-gauge for a lot less money!”

The old engineer turned out to be right about the pressure vessel support lugs, too, according to Wolf.
Henry D. Block (1920–78), the author of *Introduction to Tensor Analysis* (1962), found applications for mathematics everywhere, from artificial intelligence and self-reproducing machines to the economics of financial markets and the structure of aircraft. Block’s World War II service, as a flight-test engineer for an American aircraft manufacturer, left him with a lifelong distrust of airplanes. After the war, his flights were more fanciful—and were limited to the footnotes of scholarly papers, in which he cited friends’ children as authorities and included references to fairy godmothers, dismal swamps, and baby robots. In collaboration with Frank Rosenblatt, the Cornell electrical engineer and neurobiologist who built a self-organizing learning machine called the Perceptron, Block derived mathematical statements to analyze machine behavior and proved theorems about the convergence of learning algorithms. Block taught one of Cornell’s first courses on bionics and robots, although he never managed to build a robot himself.

If architects had listened to P. P. Bijlaard, the surface of St. Louis’s Gateway Arch would be less wrinkled. (See “Thermal Expansion and Westward Expansion,” page 234.) Another wrinkled surface, the Wyoming landscape seen from an airplane window, inspired the engineer who built Cornell’s reputation in nonlinear dynamics to write a poem about apparently random motion of turbulent fluids. Philip Holmes, a TAM professor from 1977 to 1994 (and subsequently a member of the faculty of Princeton University) was enjoying a smooth ride through clear skies and billowing clouds—until the plane dropped suddenly—and inspired him to write the second and third verses of his 1986 poem, “Clear Air Turbulence.”

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and up here seconds count as the wingtips dip
and bounce, breaking sight of the wrinkled face
below, the snow blown southward off ridges.
This air we’re turned and bucked in sweeps
and fills huge cells over those ranges
which now shrug again and pull straight.

Unseen, the patterns stagger and break up;
what we would impose on them breaks up.
How can the air’s heated, turning chaos be seen
as a fit end to its local order? And even granting this,
I still know that, in flight, volumes and pressures
far less properly described keep us alive.
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Holmes noted that spilled drinks in passengers’ laps are just one result of physical systems exhibiting complex dynamic behavior. Vibrating structures, electrical circuits, and magnetic devices also can behave in complicated ways. For simplicity, Holmes said, he preferred to use mathematical models that were in the form of ordinary differential equations. The engineer who also served as director of Cornell’s Center for Applied
Mathematics said he had come to feel that some ordinary differential equations were almost as poetic as their literary equivalents.

Holmes was the co-author (with Cornell TAM and mathematics faculty member John Guckenheimer) of the influential 1983 book, Nonlinear Oscillations, Dynamical Systems, and Bifurcations of Vector Fields. He subsequently pondered “beautiful problems in mathematics and mechanics” such as nonlinear modes in optical waveguides, the dynamics of legged motion in cockroaches, and human cognitive processes.

More Beautiful Problems

Nonlinear dynamics continues to be an important theme at Cornell, according to previous TAM chair Timothy J. Healey, a member of the faculty for more than twenty years, but research interests of today’s faculty members are even broader. Healey himself joined the TAM faculty in 1985 and now conducts research at the interface between the mechanics of nonlinearily elastic structures and solids, partial differential equations, nonlinear analysis, and bifurcation theory—as applied to flexible engineering structures and biological structures such as DNA molecules and giant unilamellar vesicles.

Holmes’s “replacement” in 1994, Steven H. Strogatz (a researcher whom Healey calls “an applied mathematician and a closet physicist”), is the author of two popular books that track his changing interests (Nonlinear Dynamics and Chaos: With Applications to Physics, Biology, Chemistry and Engineering [1994] and Sync: The Emerging Science of Spontaneous Order [2003]). In his first years at Cornell, Strogatz applied his studies of nonlinear dynamics to problems in coupled oscillators, such as lasers, superconducting Josephson junctions, and crickets that chirp in unison. The theorist invariably collaborated with experimentalists in his coupled oscillator studies, just as Holmes had with Frank Moon, who built machines to test the mathematician’s ideas. Then Strogatz branched out to new areas, noting that his students often led the way, and tackled parametric resonance in MEMS and the so-called “small-world” phenomenon in social networks.

One of the first graduates of the renamed Department of Theoretical and Applied Mechanics, Joseph A. Burns (Ph.D. ’66), returned to Cornell for a joint professorial appointment in TAM and astronomy. A celestial mechanician who uses classical physics to understand the current structure of the solar system, Burns led a group through a remote
numerical modeling exercise: They explained how perturbations by nearby moons influenced the narrow, clumpy, braided ringlets that the Voyager spacecraft found around Saturn. More recent studies, by Burns and his collaborators, of the orbital histories of particles in the inner solar system might explain the sources and evolution of meteorites that land on Earth.

K. Bingham Cady was a professor of nuclear engineering when that program was active at Cornell as well as an administrator in the College of Engineering. His current research into the theory of response can be equally well applied to modeling engineering systems or business investments.

A TAM faculty member since 1981 and Engineering Professor of the Year in 2005 (by acclaim of the college’s undergraduates who vote on the Tau Beta Pi Teaching Award), Chung-Yuen Hui conducts research that connects mechanics and materials. His work in fracture mechanics and adhesion has applications in the ceramics, electronic-packaging, and aircraft industries.

James T. Jenkins, a faculty member since 1971, runs a research program aimed at determining the relationship between stress and deformation in the two important regimes of granular motion, slow and rapid deformation.

After earning his Ph.D. from TAM in 1972, S. Leigh Phoenix worked for two years at the Fabric Research Laboratories. He joined MAE in 1974, then moved to TAM in 1989. Phoenix is renowned for his work on the statistical theory of failure of fiber-reinforced composite materials and structures. His work has been adopted in industry for the design and life prediction of composite pressure vessels, rocket-motor casings, centrifuges, and flywheels. He consults regularly for NASA concerning composite overwrapped pressure vessels used on the Space Shuttle and under development for Constellation, NASA’s next-generation manned space program.

Subrata Mukherjee joined the faculty in 1974 and began a research program in linear and nonlinear computational mechanics; his current research focuses on simulations of MEMS and nanoelectromechanical systems (NEMS) as well as the dynamical behavior of carbon nanotubes.

Another NEMS researcher and TAM faculty member since 1967, Richard H. Rand, also leads lab groups that are studying the effects of biorhythms on retinal dynamics, cardiac arrhythmias, and the ecology of plant communities. Rand is the au-

The heir to Bijlaard’s interest in geophysics and Block’s fascination with robots, Andy Ruina set aside his study of the laws of friction in the context of earthquake slip to run Cornell’s Robotics and Human Power Lab in Kimball Hall. In 2005, Ruina and a former undergraduate in his lab, Steve Collins, unveiled an energy-efficient robot that walked with humanlike strides—an elegantly simple machine that consumed one-tenth the power of the most advanced robots of the time. Before that, Ruina demonstrated his faith in human power and simple mechanical things when he helped start RIBS (Recycle Ithaca’s Bicycles), a sweat-equity program that enabled youngsters to earn bikes by repairing them.

Longtime faculty member (since 1970) Wolfgang H. Sachse earned teaching awards for developing engaging laboratory courses, such as “Sensors and Actuators” and “Design Integration” (the latter focused on the once-ubiquitous portable CD players, before every student had an iPod). A recent research project in the Sachse lab used microscale point-source/point-receiver techniques to nondestructively measure the spatial distribution of material properties. Among his patented (1990) inventions is an adaptive neural-based signal processor.

A more recent recruit to the TAM faculty (1999), Z. Jane Wang studies unsteady aerodynamics in a broad range of physical and biological systems, including insect flight. By 2000, Wang had disproved a long-held myth—that the bumblebee violates the principles of conventional aerodynamics when it flies—with her computer simulation of rapidly oscillating wings and the complex motion of fluids. But Wang’s calculations might provide more than cocktail-hour chitchat at physics meetings; if insects can hover (and they can), wing-flapping microrobots can’t be far behind.

Alan T. Zehnder, a Cornell faculty member since 1988, studies fracture mechanics and the dynamic mechanical properties of nanoscale materials and systems. In keeping with the TAM spirit, much of Zehnder’s research is cross-disciplinary and has involved collaborations with colleagues from applied and engineering physics, chemistry, civil and environmental engineering, earth and atmospheric sciences, and physics, to perform both experimental and theoretical studies over length scales from tens of kilometers to hundreds of nanometers.
Mathematicians in Engineeringland

TAM’s Healey, educated both as a civil engineer and as a mathematician, says the department owes its mathematical strength to Edmund Cranch, who led both the Department of Engineering Mechanics and Materials, beginning in 1956, and the reorganized Department of Theoretical and Applied Mechanics in 1964 (before becoming dean of engineering at Cornell and president of Worcester Polytechnic Institute, then returning to retire in Ithaca and reclaim an emeritus professorship in TAM). “Cranch recruited applied mathematicians,” Healey said, “and that has been our tradition for forty years. That’s what distinguishes Cornell from most other engineering schools—to have a department like ours, with a strong applied math component, inside engineering.”

Several small departments, each staffed with specialists in a range of disciplines, is another mark of distinction for Cornell engineering, according to Healey, who calls this institution idiosyncratic. “Since the beginning of the university, we were an elite institution, so we share the luster of the Ivy League, but at the same time we are a landgrant school and we’re trying our best to behave like a Michigan or an Illinois. That’s very hard to pull off, but we do with great success. We do it with rather large traditional departments and with small, unconventional units that deal with fields such as operations research, geological sciences, materials science, engineering physics, and theoretical and applied mechanics.”

Cornell TAM is a good place for graduate students to learn to teach and find a place in academia, as about half the doctoral candidates do (others find work in industry and government labs), Healey notes. All those undergraduate-level “service” courses, taught from TAM to engineering students from other fields, require plenty of teaching assistantships that are filled by the department’s grad students. But TAM in the twenty-first century is not an ideal place for faculty members to exercise one professorial perquisite—lucrative consulting work for industry. “More and more of us are applied mathematicians or physicists,” says Healey, noting that the last two faculty members to arrive at TAM, Strogatz and Wang, have not a single engineering degree between them. “We are not practical engineers and we don’t pretend to be. It’s not an accident that engineering is not in the name of the department.”

Those theoretical physicists and applied mathematicians in TAM will have plenty of research work in the future that Healey foresees: the mechanics of the small, biomaterials and nanomechanics. “They still need us to do mathematical modeling and predict outcomes so they don’t have to run an experiment every time. We’re just naturally poised to do that.”

A FOOTNOTE TO HISTORY

On January 1, 2009, the Department of Theoretical and Applied Mechanics was merged into the Sibley School of Mechanical and Aerospace Engineering, where the combination of intellectual overlap and complementary skills created an educational and research program of the highest caliber.
As Cornell was preparing to celebrate 100 years of engineering education in 1970, two editors of Engineering: Cornell Quarterly grew curious about the century ahead. Gladys McConkey and Donald Berth knew that the next generation of leaders in American engineering would come from the ranks of students who were crossing the quadrangle just outside the window of their Carpenter Hall office. How these students felt about their futures, and the futures of the profession and the nation, was bound to have an impact on the directions engineering would take. So McConkey and Berth interviewed a cross-section of engineering students, and used those interviews as the basis for an article in the Autumn 1970 issue, “The New Breed: Conversations with Cornell Students,” which told their stories.

The students interviewed for the “New Breed” article ranged from freshmen to graduate students, from would-be civil engineers and engineering physicists to some who weren’t quite sure in 1970. All were academically successful and enthusiastic, and their responses were used first in a recruiting publication, Engineering at Cornell, which was prepared for secondary school students who had a potential interest in the university.

Tracked down and interviewed thirty-five years later, some still treasured that issue of the Engineering Quarterly among their Cornell keepsakes. Not all had parlayed their engineering degrees into careers in the field, but none had regrets about the time they had spent at Cornell. Here’s what seven of Cornell engineering’s “New Breed” said in 1970 . . . and when the interviewer asked them how their careers had developed since then.
Master of Engineering candidate William A. Bruno was the geotechnical specialist on an eleven-person team—supervised by civil engineering’s Donald Belcher—that in 1970 tried to forestall urban sprawl by siting and designing a new city somewhere in the Ithaca–Elmira–Binghamton area. Their initial study of soil characteristics for the hypothetical city of 30,000 came up with eight possible sites. When they started investigating water resources and access to other cities, the list of feasible sites had shrunk by half. Field investigations at each of the four sites eliminated all but one. Their chosen place had good access to Binghamton and Elmira, enough land to build the city, and plenty of nearby hills and rivers to give aesthetically pleasing variety to the landscape.

The city of rivers and hills never materialized, of course, but other projects followed in Bruno’s career in environmental and geotechnical consulting—power plants, earthen dams, and major buildings arose on the basis of Bruno’s geotechnical field investigations and foundation design work. His very first assignment after Cornell (a B.S. in civil engineering in 1969 and a master of engineering in 1971) took him north, where he was the URS Corporation’s resident geotechnical engineer for construction of the Trans Alaska Pipeline terminal in Valdez.

After five years in Alaska, Palo Alto, California, beckoned and Bruno earned a Stanford University M.B.A. (1977) with an emphasis on finance and decision analysis.

Even before his work with oil pipelines, Bruno said three decades later, he had been fascinated with energy policy issues, “... especially the sustainable development and use of fossil fuels.” His program at Cornell had allowed enough freedom for elective courses and he had roamed across the campus to study environmental law in the law school, meteorology and soil science in the ag college, and psychology and sociology in the arts college.

“Since the three pillars of sustainable development framework are economic development, the environment, and social welfare—little did I know,” he said, “that I was developing my own curriculum that a few decades later would be called ‘sustainable development.’”

All the while, as it turns out, Bruno has been thinking about energy. “My interest in the energy industry was stimulated by an issue of Cornell: Engineering Quarterly (Vol. 9, No. 1, Spring 1974) that came out after the OPEC oil embargo in 1973. I referred back to that issue during the 2004 CEAA [Cornell Engineering Alumni Association] Conference on Energy and the Environment. We were able to bring back retired professor Sam Linke, who was a leader in Cornell’s research into the future of energy development in the 1970s.”

Linke’s article in the Engineering Quarterly—“The Hydrogen Economy: Solution to the Energy Problem?”—compared the costs and efficiencies of various hydrogen production methods, as they were understood in 1974, before predicting that “hydrogen could become the ideal, pollution-free synthetic fuel for transportation, space heating, and industrial processing.”

Bruno took that prophecy to heart and has become an outspoken advocate for research and development of the decarbonization process to produce hydrogen fuel from
coal, this country’s most abundant fossil energy resource. Until more efficient processes are perfected to make hydrogen by other means, Bruno believes, decarbonized fuel from coal satisfies “both sides of the aisle,” national energy security and environmental concerns.

While looking to the future of engineering, Bruno takes inspiration from the past. He and his wife are restoring to its original condition the Martha’s Vineyard home of George Washington Goethals, chief civil engineer for the Panama Canal.

In Pursuit of “Any Study”

A junior at the time, Dennis P. Carroll was one of the first to sign up for the newly instituted College Program that gave upperclassmen the opportunity to develop individual, interdisciplinary courses of study beyond the more defined field programs. He was thinking about research in biomaterials—perhaps to create artificial organs—so Carroll assembled a curriculum with chemistry, materials science, and one field of study Ezra Cornell probably hadn’t anticipated, neurobiology.

When he wasn’t in the laboratory, Carroll developed an appreciation for the natural surroundings of the College of Engineering, by canoeing, horseback riding, and turning a hobbyist’s interest in horticulture and landscaping into summer jobs planting trees.

Dennis Carroll, 1969: “I saw the statement old Ezra made, ‘I would found an institution where any person can find instruction in any study.’ Everything’s here. If you have a spark flickering, you can pursue it.”
His B.S. in materials engineering took Carroll to Johns Hopkins University, where he completed a Ph.D. in chemistry in 1979, intending to become a college professor. But teaching jobs were scarce at the time, and Carroll was glad he had continued to pursue Ezra Cornell’s “any study” dictum. “My graduate work in theoretical chemistry provided me significant expertise in computing and modeling,” Carroll said, “in addition to the analytical skills acquired as an engineering student and a physical-science graduate student. So I embarked on a career in the field of operations analysis.”

Carroll began at the Center for Naval Analyses, the federally funded program in Alexandria, Virginia, that provides analytical support to U.S. Navy and Marine Corps decision-makers. Then he joined the operations analysis team at Metron Incorporated, the scientific consulting company in Reston, Virginia, that uses advanced mathematical methods to solve challenging problems in the national defense. The company’s philosophy on professional development, he realized, could have been written by Ezra Cornell himself: “We believe that employees should combine their innate talent with a willingness to work on challenging problems and to extend their knowledge to other disciplines.”

Testing models of dynamic command structures for military decision-makers leaves Carroll little time for regrets about studies he never pursued. He has never, for example, created artificial organs out of biomaterials.

However, one hobby has not changed. “I infected my wife with an interest in gardening,” Carroll said, “and now gardening has become more ‘fashionable.’ Together we have landscaped each house in which we lived.”

Undoubtedly, Ezra, the scientific farmer and would-be engineer, would approve.

**Probably Not as Simple as ABC**

A career in urban planning seemed probable for Gary Cokins, a junior in operations research and engineering. The Big Red football linebacker (and teammate with Ed Marinaro, the rushing-record tailback) had just spent a summer in the Chicago Transit Authority’s research department. His “most valuable” class so far had been “Highways and Airports—Planning and Design.” He had grown up in Riverside, Illinois, the planned community designed in 1860 by landscape architect Frederick Law Olmsted, and figured that graduate study in environmental systems engineering would launch his career in urban planning.
By then Cokins knew more than most engineering students about probability and statistics. While still in high school he turned an analytical hobby into “Dice Baseball,” an accurate predictor of the performance of individual batters in the major leagues. In professor of theoretical and applied mechanics Henry R. Block’s course, “Bionics and Robots,” Cokins discovered how to foretell—with considerable success—how teams would finish the season on the basis of each player’s batting average and the pitcher’s earned-run average.

While Marinaro went on to pro football and Hollywood, Cokins earned a 1974 M.B.A. at Northwestern’s Kellogg Graduate School of Management, and pursued a successful career in the field of corporate performance management. In his current work with SAS, the leading international vendor of business analytics software, Cokins lectures in dozens of countries each year and has authored such market-leader books as Performance Management: Finding the Missing Pieces (to Close the Intelligence Gap), Activity-Based Cost Management: Making it Work, and An ABC Manager’s Primer.

Thirty-five years after telling a Cornell interviewer, “I like people-oriented activities,” the management expert said he’s happy not to manage people. “Friends envy me since I have no employees who report to me for supervision. Yet I have hundreds of co-workers and corporate partners of SAS, usually management consultants, whom I coach, counsel, and mentor.”

But one aspect of human nature, people’s tendency to play politics, dissuaded Cokins from his interest in urban transportation planning. “I always valued optimization and maximization concepts, to get the best outcome using the least resources. I realized back then that in the environment of public-sector government, politics plays a very influential role. So I shifted my career interest to the corporate world where the profit motive is a strong force for rational decision-making.”

Cokins is encouraged by a recent trend, he said, noting: a “convergence of public sector and commercial businesses in the adoption of modern managerial methodologies.” If he’s right, another Cokins book, Activity-Based Cost Management in Government, could become a bestseller.

**Toymaker to the Stars**

Cornell seemed overwhelming, at first, to the boy from Edgemont, South Dakota. George Gull looked around and discovered that the College of Engineering had more students than his entire hometown had residents. One way to rise above the crowd was on top of the unicycle he had built in high school and brought along to Ithaca.

Gull’s academic work went well enough to land him on the dean’s list and he began looking for a part-time job through the university’s work–study program. For some students, work–study meant shelving library books or washing laboratory glassware. Gull’s aptitude for mathematics and physics caught the attention of a young assistant professor who had just joined the faculty of the Department of Astronomy. James Houck put the engineering student to work analyzing data from the Orion nebula collected at the Kitt Peak National Observatory.

Gull had been attracted to engineering by a passion to create and build things. When he graduated in 1972 with a bachelor’s degree in mechanical engineering, a job
George Gull, 1969: “I wondered if I could do it. You soon learn how to manage your time when you have a part-time job.”
offer in Europe was enticing enough, but a twist of fate—and a chance to build the instruments to gather the data he had been analyzing—kept him at Cornell. Still in the same research group with Houck, who now is Cornell’s Kenneth A. Wallace Professor of Astronomy and principal investigator for a series of NASA–funded infrared astronomy projects, Gull designs and builds telescopes.

“Officially my title is Research Support Specialist, but the sign on my door reads ‘Toymaker,’” Gull said. “And it’s true: the bigger the boys, the bigger the toys.”

Gull builds “toys” like FORCAST, the $7.5 million Faint Object Infrared Camera for the airborne telescope, SOFIA (Stratospheric Observatory for Infrared Astronomy). Flying above 98 percent of the water vapor in the atmosphere to get an unobstructed view of celestial objects, the instruments are cooled to cryogenic temperatures—around 4° Kelvin—far colder than a South Dakota winter’s night.

The engineer who stayed in Ithaca does his share of traveling—to Chile and New Zealand and other sites of infrared telescope projects for Cornell astronomers, to every place in between as an advisor to the globetrotting Cornell Glee Club, and sometimes nearly straight up to the stratosphere in NASA’s Boeing 747 airborne observatory.

**Problem-Solving Skills**

Terry Hartmann had just returned from a junior year exchange program at the University of Poitiers in France. The College Program senior with a major in mechanical engineering and a minor in business admitted to having some doubts before he left: “I wasn’t sure that I could cope with engineering instruction in French, and wondered whether there would be serious discrepancies in course work between the two schools.”

Hartmann need not have worried. His language skills served him well (although the French lecturers “seemed somewhat more theoretical”) and the snow on the Olympic slopes of Grenoble was as good as he expected. But in the fall of 1970 there were career plans to make. Hartmann was looking ahead to graduate work in the international aspects of business, and hoping, ultimately, to combine engineering with management.

Indeed, he has. After earning an M.B.A. (1971) at the University of Chicago, Hartmann started in engineering finance at Xerox and he has been there ever since, “entirely in the finance community, although with many different and interesting assignments.” Thirty-five years after studying engineering and business at Cornell, Hartmann is Xerox’s director of financial services for North American units, with overall responsibility for payroll, cash disbursements, general ledger, and fixed assets. Before that, he saw both sides of the Pacific as CFO of a Xerox/Fuji Xerox joint venture.

Thinking back, Hartmann said he realizes now that his experience at Poitiers “finalized my intentions to go to business school and not to become a practicing engineer. It also influenced my choice of majors at Chicago. A ‘broadening experience’ descriptor seems to fit.”

Even with his start in engineering finance, Hartmann said, having an engineering degree probably was not critical. “But it was very helpful, both in succeeding with an analytical M.B.A. and in my first few jobs. Beyond that, engineering discipline and practice,” he said, “provide a good basis for logical problem solving.”
Not to mention, “occasionally practicing my problem-solving skills maintaining a 1973 Porsche.”

**The Miracle of Engineering and Technology**

Robert E. Kingan had a Cornell bachelor’s degree in electrical engineering (1969) to his credit and was partway through the Master of Engineering program—designing accelerators in Cornell’s Electric Vehicle Laboratory—when he expressed his frustration with all things theoretical. “When I was a kid, I was fascinated with how things worked,” he recalled in 1969. “I took motors and watches apart and built things out of wood.”

KINGAN’s first job after Cornell was hands-on, all right, although it hardly used the skills he had cultivated. “Jobs were scarce for engineers in 1970. I had one job offer from Bell Labs, but my fiancée and I did not want to live in New Jersey. So in September 1970 we came to Boston, neither one of us having a job. Of course this drove our parents crazy. After several months of unsuccessful job searching, we were running low on money, so I took a temporary job installing burglar alarms.”

Finally, in November 1971, Kingan landed a job at Raytheon, working on Navy shipboard fire-control radar, and he’s been there ever since. Today, he is a manager and software architect for Raytheon’s Ballistic Missile Defense System X-band Radar program, a key component of the United States’ homeland security program.

But the threat of missile attack was not the only insecurity Kingan felt, back in 1969. The future emphasis in engineering ought to be on “saving the planet,” he remembers telling an interviewer, and thirty-five years later he told the rest of the story. “At the time I believed there was a small but finite possibility that I would not see the end of my natural life, due to some environmental disaster. A good example is Lake Erie. I grew up in Angola, New York, a small town on the lake south of Buffalo. I spent my summers on the lakeshore, and watched it get more and more polluted. In summers of 1965 and 1966, I was a lifeguard at Evangola State Park and each morning we had to rake up the dead fish that littered the shoreline. In the early ’70s, many of the beaches had to be closed.”
Then came the big push, in the ’70s and ’80s, to clean up the environment in the United States, and Kingan takes pride in knowing that engineers “played a huge role in this effort. In 1998, at a Kingan family reunion, we had breakfast at a park on the lake. The water was as clean and clear as I remembered it when I was ten.”

KINGAN says his core values and concern for the environment have not changed since his days at Cornell. Still calling himself an environmentalist, he says what changed was his belief “in the miracles of engineering and technology. In 1969, I did not believe anything could undo the damage that had been done to our environment. Today I have a strong belief in man’s ability to engineer solutions to problems through technology. Cornell professors like Thomas O’Rourke helped reinforce my belief that engineering and technology can help overcome environmental challenges.”

The Raytheon systems engineer acknowledges “there is no environmental aspect to my work,” but he says his Cornell education helps him every day, making his company “the premier producer of missile defense phased-array radar in the world.” His background in electrical engineering, Kingan says, “has been very valuable in my work. The highly mathematics-oriented Cornell electrical engineering program has been instrumental in my success in the software and systems engineering of Raytheon’s radar systems.”

**Faces and Film in Black and White**

The Willard Straight takeover—and the emblematic photograph of bandoliered Afro-American Society members exiting the student union on April 20, 1969—remained a raw memory at Cornell the following year when mechanical engineering senior Otis W. Sprow contemplated his role as a member of a “minority” in higher education.

Sprow had not been “on the inside” at the Straight and hadn’t been a member of the Black Liberation Front, although he said at the time that the organization served a useful purpose, by giving “the black on campus a sense of identity.” As president of the Chi Psi fraternity, Sprow grew concerned as confrontations between students and the
university administrators escalated. “There were rumors of people with guns walking around campus,” he recalled three decades later, and he worked with other fraternity presidents to collect student-owned firearms and get them off campus.

Volunteering during class breaks to teach at inner-city elementary schools in his native Baltimore, Sprow reached one conclusion: “Only through more and better schooling can the black poor rise in our society.” Integration, he said at the time, was “the only effective means of increasing communication between blacks and whites.”

Sprow’s advocacy of education continued after Cornell. From 1985 to 2001 he served on the board of directors of the National Black M.B.A. Association (he had earned his M.B.A. in 1976 from George Washington University, following a Cornell master of engineering degree in 1971) and he said he came to believe that support of education “is a critical thing that we are all here to do, that we have to do.”

While still in the College of Engineering—at a time when the engineering profession was blamed for putting technology ahead of environmental concerns—Sprow worried about one societal perception: that air pollution resulted from inefficient mechanical devices designed by “the dirty people,” the mechanical engineers. He made his career goal the design of cleaner, more environmentally friendly propulsion systems.

Nuclear energy was Sprow’s initial focus, first as a Navy officer and engineer after leaving Cornell, then in a civilian position in research-and-development programs run by Admiral Hyman Rickover, the “father of naval nuclear power.” When Sprow subsequently went to work at the Ford Motor Company’s Research and Engineering Division, the Stirling engine’s external combustion system seemed—at first—to be the automotive industry’s solution to problems with internal combustion engines. But just six months into Ford’s Stirling engine project, management realized that “there were too many technical problems, and we really couldn’t keep a handle on them all.”

As a structural analyst at Ford, Sprow was one of the first engineers to use supercomputers and component-mode synthesis to design automobiles. Ford was facing bankruptcy in the early 1980s, Sprow recalled, and corporate executives decided to reorganize the company from “from the bottom up. They formed six teams of employees from various parts of the company. Ford wanted a view from the troops about how to run the company.”

Sprow was the captain of one of the employee teams, and the company liked what it heard. He was put in charge of design for the car that became the Ford Taurus. The sleekly aerodynamic Taurus marked a risky departure from the big, boxy cars that dominated the marketplace at the time. Between December 1985, when the Taurus was introduced, and 1989, Americans bought a million of the midsized cars that have been credited with saving Ford from bankruptcy.

When a healthier Ford bought the ailing British carmaker, Jaguar, Sprow had an even more challenging assignment: to make luxury cars smaller, lighter, and more fuel-efficient. Throughout his career at Ford, Sprow said, he always thought about how his car designs would have an impact on the environment, and he took the luxury car assignment with some reservations. The result of his work with lightweight metals and state-of-the-art plastics are two Ford-built models with quite different appearances, but under-the-skin similarities, the Lincoln LS and the Jaguar S-Type.
Most industry critics applauded the S-Type’s retro look (it recalled the 1963 S-Type and the earlier Mark II), but by then Sprow was reaching even further back. What began as a hobby increasingly found the automotive engineer rising at 5:30 a.m. to catch the first light on nature scenes he was capturing with large-format field cameras loaded with 8 × 10 inch, black-and-white film. His inspiration was Ansel Adams. As the hobby turned to a passion he began taking month-long photography treks through the national parks.

The engineer who vowed to battle air pollution reached the Great Smoky Mountains too late. The natural haze that once tempered Ansel Adams’s crisp blacks and whites was compounded by dirty gray murk from fossil-fuel–burning power plants, factories, and automobiles. Sprow recorded the scenes anyhow.

Then he returned to Michigan, and retired from the auto industry to take an artist-in-residence position at the Smithsonian Institution. Sprow’s black-and-white-and-gray images are in the permanent collections of museums worldwide.

From Quantum Physics to Biomedicine

Paul Wozney was a sophomore from Schenectady, New York, who had a passion for engineering physics, a fascination that had been triggered by a memorable class in quantum physics. “The professor,” he said in 1970, “left you wondering after each class what the electron was going to do tomorrow.”

At the time, Wozney thought that his tomorrows would take him to graduate school in electrical engineering. But he surprised himself by going to medical school, selecting from among several that accepted a prospective physician with a Cornell bach-
Paul Wozney (third from right) lined up to see “Easy Rider” at State Street’s Ithaca Theater. “The engineer, contrary to what some people think, is essentially creative, applying theory to reality,” Wozney said in 1969. “There is a beauty to a perfectly functioning device.”
elor’s degree in engineering physics. He graduated from medical school in the usual four years, but no residency offer appealed to him. But he figured his combined background in medicine and physics must have prepared him for something. “I shopped my CV to about 300 companies in biomedicine,” he recalled thirty years later, “and ended up working for three years for Milwaukee-based General Electric Medical Systems.”

Milwaukee, now enjoying revitalization, was “a horrible place then,” but Wozney spent little time there. His GE work took him to major radiology research centers throughout North America, Europe, and Japan. “Because of that experience, to which having an engineering background I believe was critical, I subsequently did a four-year radiology residency, went on to specialize in magnetic resonance imaging, and then joined the faculty of the University of Pittsburgh.”

Since 1990, Paul Wozney, M.D., has been a radiologist in Florida, hunkering down for some hurricanes, dodging others, and moving to presumably safer towns (Spring Hill, Florida, most recently) when the calls get too close (a hurricane killed one person in the building next to his Punta Gorda house), but generally feeling pretty lucky in life.

“I’ve only kept a few things as I’ve wandered around the country,” Wozney said, “but I have the ‘New Breed’ issue of the Engineering Quarterly. I located it in less than five minutes in the attic in Punta Gorda to show my wife. Funny what someone will hold onto. My Cornell engineering experience unquestionably has significantly influenced my life, in unanticipated ways.”
Select Bibliography

In addition to the books and other publications listed in this select bibliography, a variety of archived materials provided historical details for this project: wherever possible, these are credited in the text. Much of this material has been—or is in the process of being—digitized, and is publicly accessible at the Cornell University Library’s online repository, “eCommons@Cornell” (ecommons.library.cornell.edu). Materials not available on eCommons include:

- The *Register*, published yearly by Cornell University from 1869 to 1910, was a combination annual report and prospectus, student and faculty directory, and the list of classes now called *Courses of Study*. The *Register* volumes, in print and microform, are available upon request from the Cornell University Library’s Rare and Manuscript Collections.

- Also in the Rare and Manuscript Collections are papers of eminent Cornell engineers, such as Robert Henry Thurston, as well as annual reports from engineering deans to the university president and, in later years, to the university provost.

- Theses and dissertations by Cornell graduates are not publicly accessible at eCommons@Cornell. Cornell Library privileges are required for online access to publications like *An Experimental Study of the Flow of Sand and Water in Pipes Under Pressure*, the 1905 senior thesis by Nora Stanton Blatch, although the hard copy is in Olin Library and is available to the public.

- The American Society of Civil Engineers (www.asce.org) is one of several engineering organizations with historical archives that informed this book. Among others are the Institute of Electrical and Electronics Engineers (www.ieee.org) and the American Society of Mechanical Engineers (www.asme.org).
• The *Cornell Daily Sun*, source of the blow-by-blow account of the 1971 Carpenter Hall takeover and other details in this book, was digitized by Cornell University Library and is available (cdsun.library.cornell.edu/).

However, almost every other Cornell-published source for this book is migrating to eCommons@Cornell.

The College of Engineering’s journal, which began publication in 1966 as *Engineering: Cornell Quarterly*, is now called *Cornell Engineering Magazine*. The Quarterly published historical reviews of Cornell Engineering, news of the college, and faculty essays on engineering education, research, and technology. Both the quarterly and the magazine are at eCommons@Cornell.

There, too, are the digitized issues of the weekly *Cornell Alumni News*, now called *Cornell Alumni Magazine* and published bimonthly.

When Cornell faculty members pass away, faculty colleagues reminisce in *Memorial Statements*, which from 1938 to 1971 was called *Necrology of the Faculty*.

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**Chapter 13. The Art and Science of Mechanical and Aerospace Engineering**


Chapter 14. ORIE: Scientific Management for the Information Age


Chapter 15. Theoretical and Applied Mechanics (and Math and Engineering Science)


Epilogue: Getting Back to the “New Breed”

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