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125

Caltech

VOLUME LXXIX, NUMBER 3 , FALL 2016

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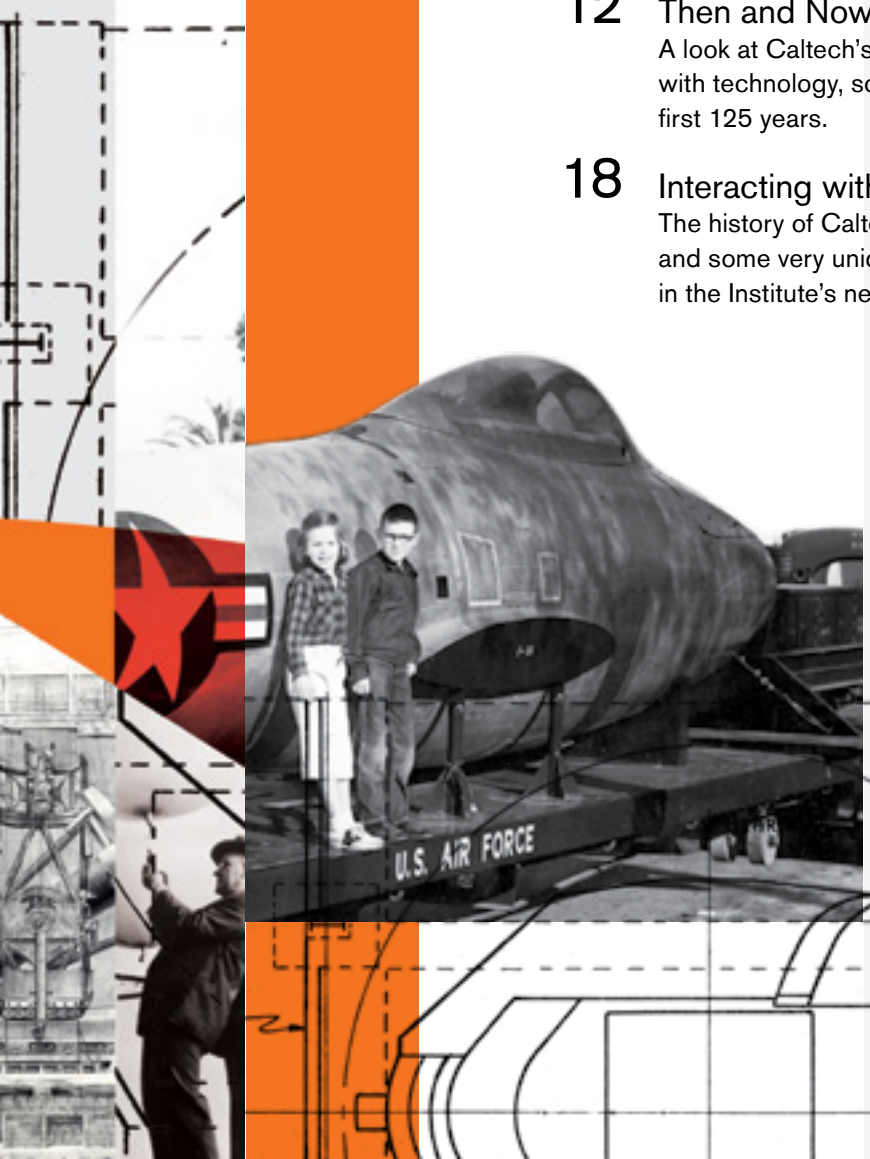
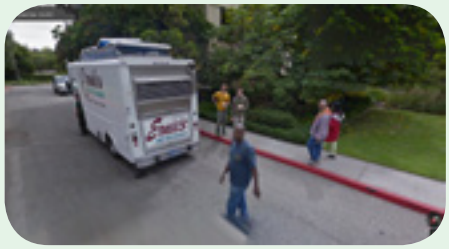


Caltech on Social Media

Follow us, retweet us, regram us, and let us know you're talking about us by including @Caltech in your tweets and @caltechedu in your Instagram posts.

@ianatonks Since I ate at Ernie's for lunch virtually every day at @Caltech, it's pretty fitting this showed up on street view:



@C_Alvarez1711 @Caltech is thankfully abundant in pokéstops

@AstroKatie Was chatting with a cosmic inflation theorist at lunch and may have accidentally destroyed the Universe. Will keep you posted. #GRCaltech

caltechedu Authentic #caltechexperience @alliestifel

…

spent a few hours in a bunny suit today #Caltech #nanoscience #intelisef #NOFILTER #breakingbad

Tweets and Instagram comments may have been edited for spelling and grammar.

Caltech
Engineering & Science

VOLUME LXXIX, NUMBER 3, FALL 2016

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"Knowledge, the wing wherewith we fly to heaven." (Shakespeare, *Henry VI*)

Celebrating 125 YEARS

The founders of modern day Caltech conceived of a new type of academic institution, one devoted to pure science, animated by connections to technology, and informed by lessons from history and literature. Anniversaries, including this quasquicentennial, provide the opportunity to reflect on whether we remain true to the original vision for the Institute. They also raise the question of how do we, as a community, assimilate change?

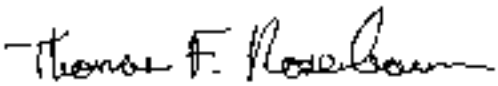
George Ellery Hale, Robert Millikan, and Arthur Noyes have attained iconic status, not because of their particular passions for the challenges of the time, although they certainly had them, but because of their vision for the future. They created enduring intellectual values: attract the most original thinkers to Pasadena and provide the resources for them to succeed; strive to tackle big, impactful problems, with the attendant research focus and administrative discipline; fashion a close community where people interact and disciplinary boundaries dissolve. Taken together, these precepts produce a culture of fearlessness and reinvention.

To me, this culture of fearlessness and reinvention is the most impressive part of Caltech. Physicists and economists become biologists because they want to understand the fundamental mechanisms by which the brain computes; biologists and chemists become geologists because they want to understand how life changed the earth in its earliest days; engineers become medical researchers because they want to alleviate human suffering. There is a rare plasticity of thought and career path at Caltech, where conventional approaches succumb to daring departures in the search for understanding.

Yet pressures to conform, to resist change, are becoming more pronounced in the world around us. Constrained funding emphasizes the incremental advance at the cost of the riskier breakthrough. The restriction of open debate and informed argument—the fundamental educational tools at our disposal—leaves new ideas stillborn. We, as the Caltech community, must consistently reaffirm our commitment to the enduring intellectual values of the Institute's founders by pushing ourselves to ask questions, to seek diverse perspectives, to confront our colleagues' arguments with our own, to engage with the past to reveal the future.

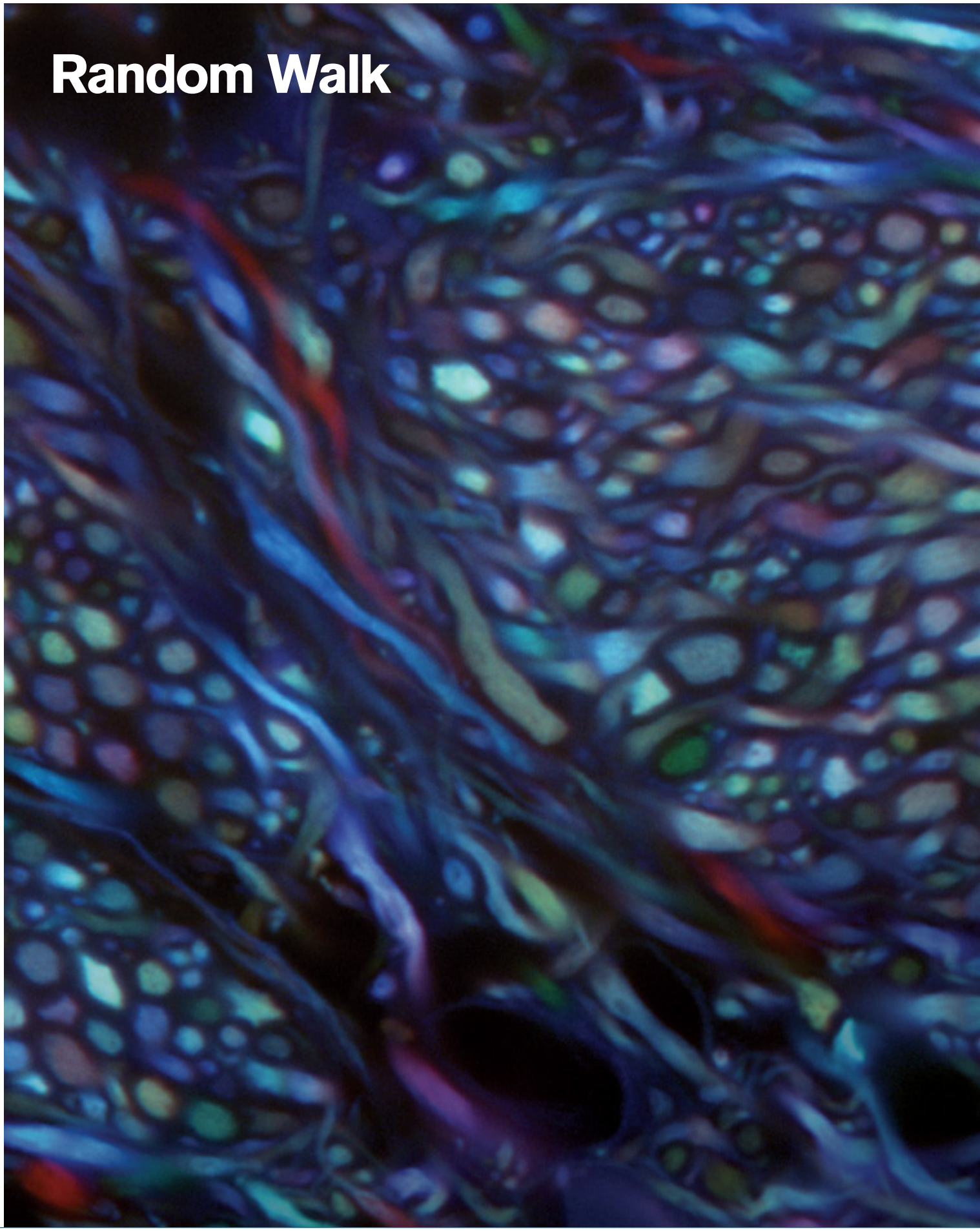
The tension between guiding precepts and change is one that will continue. We are a different community than 125 years ago—45% of our undergraduates are female, 40% of our faculty were born outside the United States—but very much the same in that our fundamental commitment is to make Caltech the destination of choice for those who have the desire and capacity to transform the world. It is an all-consuming passion, original to our founding as an Institute and simultaneously reinvented for the present day.

Caltech faculty, students, staff, and alumni have changed our fundamental understanding of nature and designed unexpected solutions to societal challenges. With attention to our culture and intellectual heritage, embracing reinvention, the Institute is sure to soar to new heights.



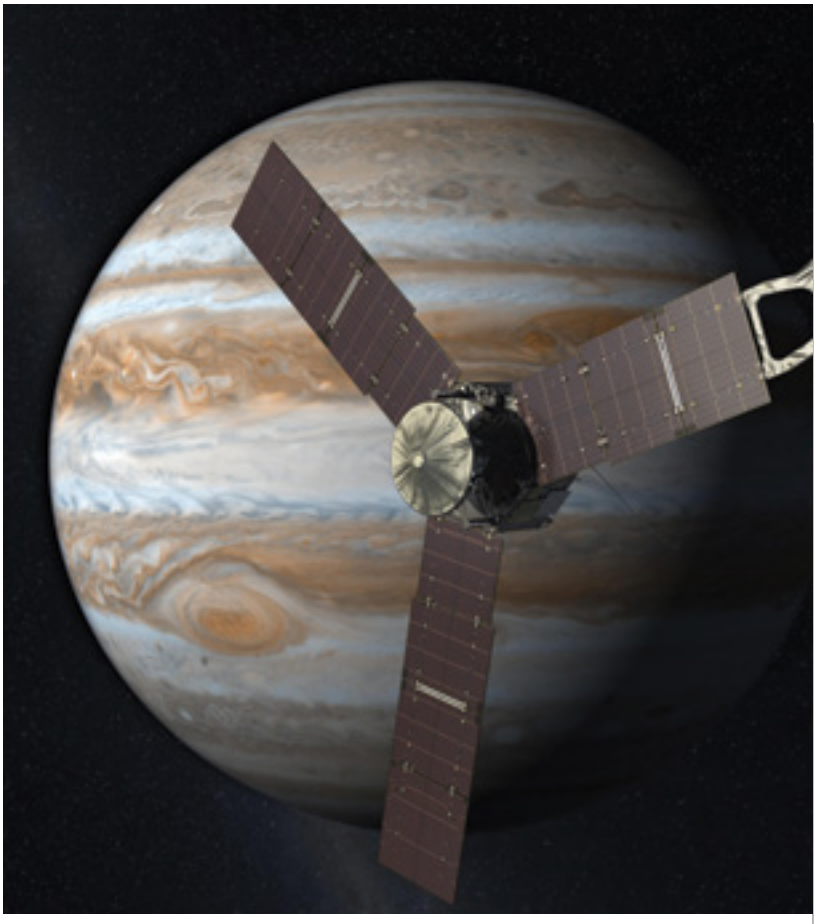
Thomas F. Rosenbaum
President, Caltech
Sonja and William Davidow Presidential Chair and Professor of Physics

Random Walk



A TANGLED WEB

Because billions of neurons are packed into our brain, the neuronal circuits that are responsible for controlling our behaviors are by necessity highly intermingled. This tangled web makes it complicated for scientists to determine exactly which circuits do what. Now, using two laboratory techniques pioneered in part at Caltech, Caltech researchers have mapped out the pathways of a set of neurons responsible for the kinds of motor impairments—such as difficulty walking—found in patients with Parkinson's disease. The different colors in this image represent pathways involving different cells that instruct diverse behaviors. Using optogenetics—which allows researchers to manipulate neural activities using different colors of light—and tissue clearing via the Passive CLARITY Technique developed in the lab of Viviana Gradinaru (BS '05), assistant professor of biology and biological engineering, Gradinaru and other scientists could extract specific pathways for locomotion and reward.



A HOLIDAY HOMECOMING

The Juno spacecraft, which launched on August 5, 2011, finally arrived at Jupiter on July 4. The JPL-managed mission will, for the first time, peer below Jupiter's dense cover of clouds to answer questions about the gas giant and the origins of our solar system. Juno's primary goal is to reveal the story of Jupiter's formation and evolution by observing Jupiter's gravity and magnetic fields, and atmospheric dynamics and composition. To learn more about the mission, go to jpl.nasa.gov/missions/juno.

"Today, you become part of the scientific community, arguably the most powerful collective enterprise in human history. In doing so, you also inherit a role in explaining it and helping it reclaim territory of trust at a time when that territory has been shrinking."

—Surgeon, writer, and public health researcher Atul Gawande, MD, MPH, speaking at Caltech's 122nd annual commencement ceremony on June 10, 2016

On the Grounds

According to *Caltech's Architectural Heritage* by Romy Wyllie, this marble bird bath was purchased in London and given to the geology division in 1939 by Harvey S. Mudd, who later served as a vice president of the Board of Trustees at Caltech. He was the son of mining engineer and philanthropist Seeley W. Mudd, for whom the Seeley W. Mudd Laboratory of the Geological Sciences (North Mudd) is named, and brother to Seeley G. Mudd—a onetime cancer researcher at Caltech—for whom the Seeley G. Mudd Building of Geophysics and Planetary Science (South Mudd) is named. So it's only fitting that this sculpture sits in the small courtyard on the eastern side of the building named for Harvey Mudd's father.

IT'S TODAY, *FROSH!*

On May 27, 2016, Caltech undergrads celebrated Ditch Day, one of the Institute's oldest traditions (see page 14). At right, a team assembles a string of connected cardboard boxes into a 3x3 cube with a single completed face displaying a QR code. The code led to a website where the team found their next clue.

Frances Arnold Wins 2016 Millennium Technology Prize

Frances Arnold, the Dick and Barbara Dickinson Professor of Chemical Engineering, Bioengineering and Biochemistry, has been awarded the Millennium Technology Prize for her "directed evolution" method, which creates new and better proteins in the laboratory using principles of evolution. The Millennium Technology Prize, worth one million euros, is the world's most prominent award for technological innovations that enhance the quality of people's lives.

Directed evolution, first pioneered in the early 1990s, is a key factor in green technologies for a wide range of products, from biofuels to pharmaceuticals, agricultural chemicals, paper products, and more.

The technique enlists the help of nature's design process—evolution—to come up with better enzymes, which are molecules that catalyze, or facilitate, chemical reactions. In the same way that breeders mate cats or dogs to bring out desired traits, scientists use directed evolution to create desired enzymes.

When Science Mentors Art, and Art Plays with Science

When Tira Palmquist wrote her play *Two Degrees*, focusing on a female climatologist dealing with personal grief and professional strain, she knew she had to get the science—and the scientist protagonist—just right.

Fortunately, the Orange County playwright discovered a ready resource in a four-year-old theater festival called MACH 33: The Festival of New Science-Driven Plays at Caltech, presented by Theater Arts at Caltech. MACH 33 pairs playwrights with science advisers from Caltech and JPL who can inform the plays' fictional worlds with scientific authenticity and insight to produce richer dramatic works.

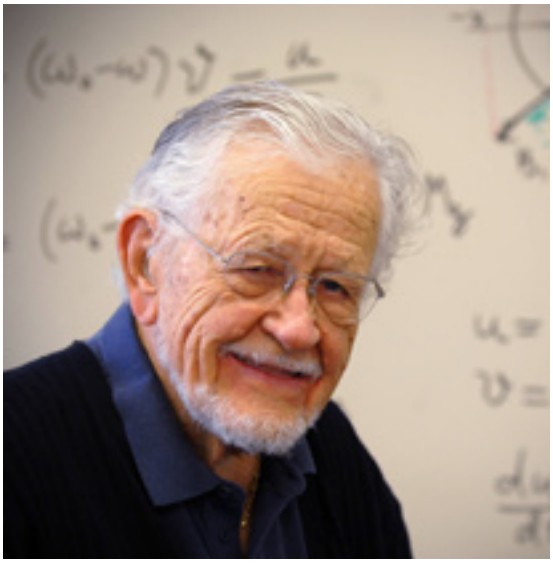
Mach 33 linked Palmquist with Jennifer Walker, a Caltech environmental science doctoral student in Simona Bordoni's research group, who helped shape Palmquist's understanding of her protagonist's work. For example, Walker suggested specifying that the character, originally conceived as a "climate scientist," be recast as a specialist in paleoclimatology—someone whose job is literally to drill deep into the past. The change presented the author with an unexpectedly rich metaphor for the protagonist's desire to understand her own personal history.

Walker says her six-week stint as a science adviser "was interesting and exciting. I had never been involved in theater before and to see this story—especially about a person in a related field—come to life on stage was really fun. There aren't a lot of plays about scientists, so it's nice to have that kind of representation."

In 2013, Caltech formalized the festival, to allow for development of new plays at the nexus of science and art. Since then, MACH 33 has featured plays dealing with such scientific subjects as climate change, quantum information theory, the discovery of Pluto, space flight, cold fusion, and ecology. This year, the Caltech student-driven theater group EXPLiCIT has joined the team to help produce and develop the festival.

After workshopping the plays throughout the academic year, MACH 33 stages readings of the plays during a festival in the spring. In May, MACH 33 presented four such productions, including a comedy about selling your soul for science, a historical fantasy about the discovery of Pluto, a play about the Los Angeles aqueduct and the drought set in the Owens Valley, and a screenplay about Subrahmanyan Chandrasekhar, winner of the 1983 Nobel Prize in Physics.—*JN*

Jack Roberts's *ONLINE SUCCESS*



On June 8, John D. "Jack" Roberts, Caltech Institute professor of chemistry, emeritus, turned 98. A few days later, he became a best-selling online author when his textbook, *Basic Principles of Organic Chemistry,* surpassed 500,000 file downloads. He wrote the first edition with his protégé Marjorie C. Caserio in 1964. The second edition, created in 1977, is available online for free at the Caltech Library, where it has been doing brisk business: between December 2012, when accurate records of the book's popularity began being maintained, and early August of this year, more than 522,000 copies have been downloaded.

Roberts, a proponent of open access to scholarly material, has worked with the Caltech Library for the last decade to make five of his previously published textbooks freely available.

"Since being included in CaltechAUTHORS in September 2011, *Basic Principles of Organic Chemistry* has accounted for more than 10 percent of all file downloads," says George Porter, Caltech's engineering librarian. "This is more than twice the download activity of CaltechAUTHORS' second most highly used resource." —*JN*

LIGO'S SECOND DETECTION: BY THE NUMBERS

On December 26, 2015, scientists observed gravitational waves—ripples in the fabric of spacetime—for the second time.

The gravitational waves were detected by both of the twin Laser Interferometer Gravitational-wave Observatory (LIGO) detectors, located in Livingston, Louisiana, and Hanford, Washington. The LIGO observatories are funded by the National Science Foundation and were conceived, built, and are operated by Caltech and MIT.

The discovery, accepted for publication in the journal *Physical Review Letters* in June, was made by the LIGO Scientific Collaboration (which includes the GEO Collaboration and the Australian Consortium for Interferometric Gravitational Astronomy) and the Virgo Collaboration using data from the two LIGO detectors.

The second discovery "has truly put the 'O' for Observatory in LIGO," says Caltech's Albert Lazzarini, deputy director of the LIGO Laboratory. "With detections of two strong events in the four months of our first observing run, we can begin to make predictions about how often we might be hearing gravitational waves in the future. LIGO is bringing us a new way to observe some of the darkest yet most energetic events in our universe."

Physicists have concluded that these gravitational waves were produced during the final moments of the merger of two black holes—14 and 8 times the mass of the sun—to produce a single, more massive spinning black hole that is

21 times

the mass of the sun.

The merger occurred approximately

1.4 billion

years ago.

The detected signal comes from the last

27 orbits

of the black holes before their merger.

The Livingston detector measured the waves

1.1 milliseconds

before the Hanford detector.

LIGO research is carried out a group of more than

1,000 scientists

from universities around the United States and in 14 other countries.

FACULTY FOOTNOTES

Omer Tamuz, a newly arrived assistant professor of economics and mathematics, studies how people exchange information and learn from each other, in a theoretical sense.

"We make assumptions about how people behave and we try to model this behavior with math," he says. "For example, we generally assume that people will behave rationally—which means they will always make the optimal choice given the information they have. While this assumption is not always true in reality, it is the framework I work in. There is this huge, rich theory you can build, with unending depth and interesting turns and twists and beautiful math, and very nontrivial things going on that you can learn . . . and maybe sometimes this assumption is not so outrageous and can give us insights about the real world."

Here's a little more about Tamuz in his own words:

- **He has a joint appointment in mathematics.** "My math research is pretty unrelated to my economics work. I study groups—which are the set of symmetries of a certain object. So if I have a cube, I can rotate it many different ways and still get an object that looks exactly the same. All of these rotations that I can do to the cube, together they form a group. It turns out that there are interesting connections between groups and dynamical systems. Dynamical systems are things that evolve and change over time—a machine and its moving gears, or an ecological system with a changing number of animals. You can ask a lot of abstract questions about how dynamical systems behave, and there are many connections to groups."

- **He didn't always study economics.** "As an undergrad, my research was in astronomy, looking for exoplanets—planets outside of our solar system. My work in astronomy involved a lot of analyzing data, trying to find very faint signals in a lot of background noise. We were trying to come up with new statistical methods to get rid of that noise. I found that I really liked to do that, but I didn't care so much about studying the stars themselves. Later, as I was studying probability in graduate school, the things I was looking at overlapped a lot with economics. In mathematical terms, many economics problems are really questions in probability."

- **Originally from Israel, he hasn't quite adjusted to living in Southern California yet.** "What I like about Caltech is that it has such a great spirit and culture. It's exactly the kind of place you want to be in. But I'm still getting used to saying I live in L.A. . . . I'm still trying to develop the L.A. accent."

Learning the Language of the Lab

Through her course, French Conversation (L 175), lecturer Christiane Orcel tries to break down language barrier for students and postdocs who work and study abroad in French-speaking countries.

Orcel, who also teaches several other traditional French classes, came up with the idea for the course after hearing about Caltech students who were interested in studying abroad through the Institute's exchange program with École Polytechnique—one of France's elite schools near Paris—but were nervous about having to take courses exclusively in French.

Although Orcel is not a scientist herself, each meeting of L 175 has a topical theme loosely based on the major study area of one of her students. For example, if a biology student is enrolled, she might focus one class session on genetics; if a physics major is in the class, the focus could be particle physics. For each subject area, she finds a speaker—a French-speaking scientist, usually from Caltech or JPL—to give a 30-minute presentation about his or her research in French, followed by questions from the students, also in French.

Senior mechanical engineering major Edward Fouad is now taking the course for the third time. "It's enjoyable to repeat the class because the speakers are always different and there is always more to learn," he says.

Although the course targets undergraduates who are planning to enroll in the École Polytechnique Scholars

Program in the fall term of their senior year at Caltech, it is also open to graduate students enrolled in the Caltech dual master's degree program with École Polytechnique, SURF students who will be spending their summer doing research at CERN, as well as postdocs and other scientists who are simply wanting to prepare for research experiences abroad. —*JSC*

DEFENDING *the* COURT

When Will Peterson (BS '02) heard that a Supreme Court Justice was on the phone for him, he instinctively stood up and straightened his tie. The 35-year-old attorney held the phone quietly for a few moments before Justice Antonin Scalia came on the line: A case was coming up, and the government had opted not to defend its position. Would he be interested in arguing the case in their stead?

One week later, it was formally announced that Peterson would be presenting oral arguments before the nation's highest court—with less than 120 days to prepare.

The law might seem an unexpected career path for a Techer, but Peterson attributes part of his interest to J. Morgan Kousser, the William R. Kenan, Jr., Professor of History and Social Science at Caltech—specifically his class on the Supreme Court. "He made the justices approachable," Peterson said. "We understood the personalities, gained a sense of constitutional issues, and learned how to read the Court's opinions."

When Peterson went on to become a software developer for Microsoft, he continued to read court opinions out of interest, and soon decided to return to his home state and enter law school at the University of Texas at Austin. After graduating in 2008, he received coveted posts as a law clerk and then joined the Houston-based law firm Beck Redden LLP. The case Peterson was drafted on to, *Reyes Mata v. Lynch*, was a technical one revolving around immigration and jurisdiction.

When Noel Reyes Mata, an undocumented immigrant, was ordered deported, he appealed, first to the Board of Immigration, and when that failed, to the Fifth Circuit—but that court held that it lacked jurisdiction on the issue.

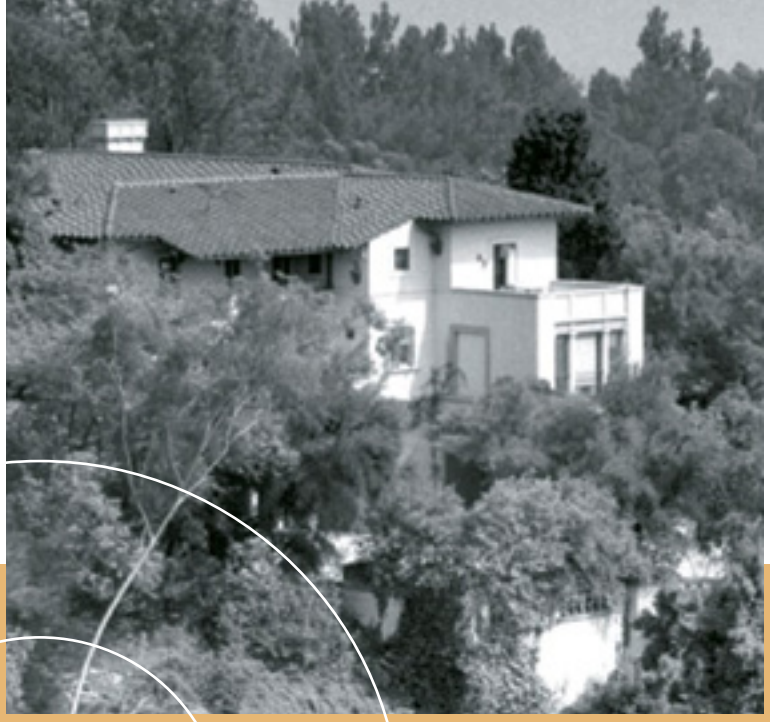
Reyes then appealed to the Supreme Court last fall. Enter Peterson: "My responsibility was to provide the justices with the strongest arguments for affirming the Fifth Circuit's judgment."

Defending a judgment that the government has abandoned is usually a losing battle, and indeed, the Supreme Court held 8-1 that the Fifth Circuit was in error and did in fact have jurisdiction.

For Peterson, though, the experience was the opportunity of a lifetime. In a footnote to her opinion, Justice Kagan expressed the Court's gratitude that Peterson "ably discharged his responsibilities." Peterson believes that his Caltech education has in many ways contributed to his success.

"The law requires a very structured way of thinking, not unlike programming," he said, before pausing a beat. "Reconnecting with Caltech always reminds me that I'm not actually a successful lawyer, but instead just a failed engineer."

We'd object. —*BT*



A SEISMO LAB COMES HOME

The Seismology Laboratory has been hard at work tracking the earth's movements for decades, but it wasn't always in the location now seen on news broadcasts anytime there is a significant earthquake. In order to place its seismometers on bedrock, its first home was located high above Pasadena on North San Rafael Avenue.

A story in the November 8, 1974, issue of *The California Tech* tells the tale of old and new as the Seismo Lab moved from a mansion in the hills to its current location on campus.

The end of an era came when the California Institute of Technology's renowned Seismological Laboratory moved this summer from its old-fashioned home in the San Rafael Hills into the new Seeley G. Mudd Building of Geophysics and Planetary Science on the campus.

Some 65 Seismo Lab people, including faculty, graduate students, and staff, and much scientific equipment made the three-mile move to the new building, which, in addition to housing seismology, provides teaching and research facilities for solid-state geophysics and planetary science.

"Our operation has grown so much after 17 years in the 40-room residence that we were terribly overcrowded," commented Dr. Don L. Anderson, director of the Seismological Laboratory and professor of geophysics. "There was no question that moving was a necessity. It has always been a part of the Institute's overall plan for us to be located on the campus, and it's most helpful to be near the rest of the Division of Geological and Planetary Sciences.

"Still," he acknowledged, "leaving the old building evokes feelings of regret. There are many fond memories of the old hilltop home with its solitude, its muraled ceilings, its landscaped grounds and tennis court and its residential atmosphere."

The facility originally belonged to A. C. Thorsen, a founder of a drug store chain, and was purchased and remodeled for Caltech to supplement the nearby Kresge Seismological Laboratory. The residence was named the Reuben H. Donnelley Seismological Laboratory in honor of the father of one of the donors.

Both laboratories were located in the San Rafael Hills so that certain seismological instruments could be anchored in solid granite in order to record earthquakes accurately. The instruments at Kresge are still operating.

In the 17 years during which Donnelley housed seismologists, it has seen many great men and major advances in seismology. Among the distinguished scientists who have worked at Donnelley are Charles F. Richter, now professor emeritus and originator of the earthquake magnitude scale that bears his name; Beno Gutenberg, director of the lab from 1947 through 1956 and who discovered that the earth's outer core was molten; Frank Press, also a director of the lab, a pioneer in earthquake prediction and now head of geology and planetary sciences at MIT; and Hugo Benioff, inventor of seismological instruments used throughout the world.

Facilities in the new building are named after two of these men who are no longer living—the Hugo Benioff Conference Room and the Beno Gutenberg Reading Room.

THEN AND NOW

by Katie Neith

On November 2, 1891, Throop University, named for its founder, Amos Throop, was born. According to the book *Millikan's School: A History of the California Institute of Technology* by former Caltech archivist Judith Goodstein, the school was a "thoroughly undistinguished little college" that barely survived its first year in Pasadena. Two years later, it expanded its course offerings, becoming "all things to all people, teaching a great variety of subjects, with considerable stress on manual training," for men, women, boys, and girls, grammar school age and up.

It would take 27 more years and two additional name changes before the founders of the California Institute of Technology—astronomer George Ellery Hale, chemist Arthur Amos Noyes, and physicist Robert A. Millikan—established Caltech as the science and engineering stronghold it is today. To honor both the school's humble beginnings and the leaps and bounds it—along with technology, society, and science—has made over these first 125 years, we decided to compare facets of the school, past and present.

THEN

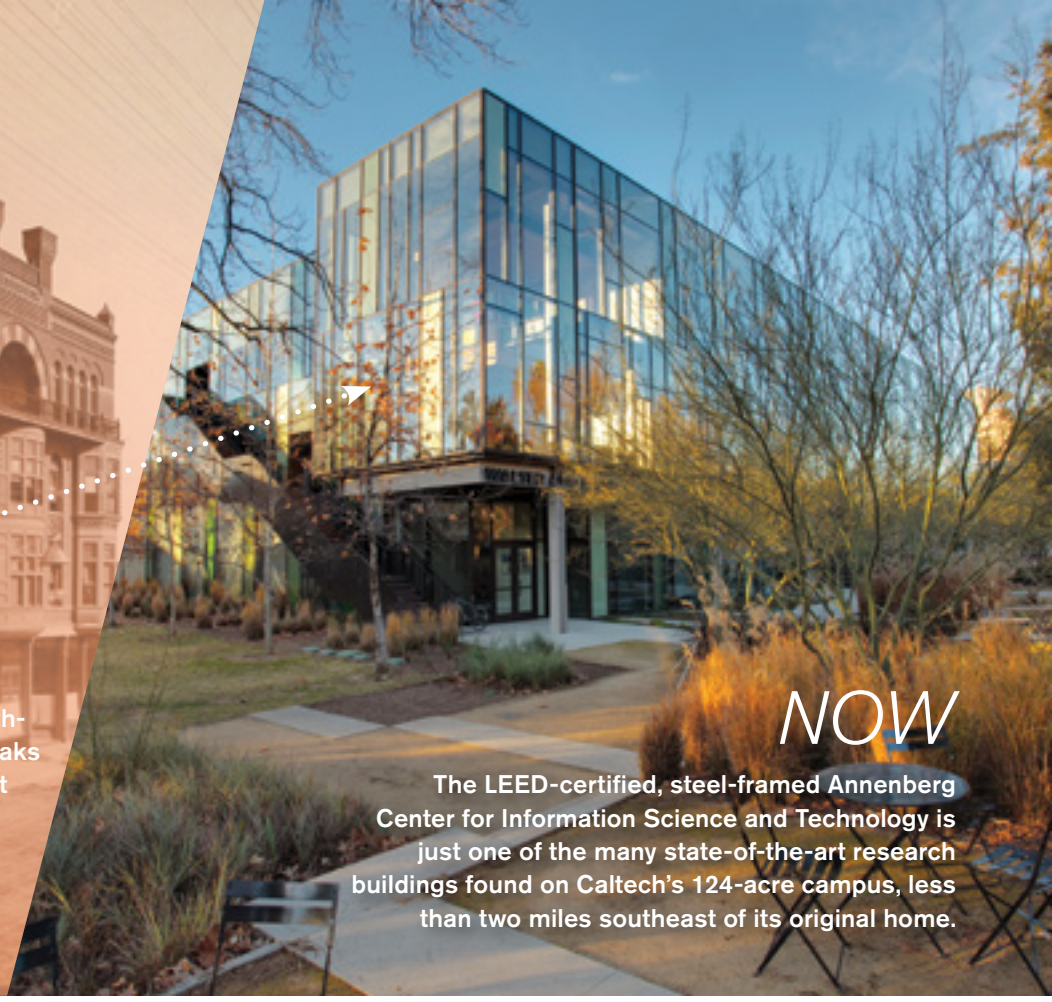
A Caltech Archives photo shows a typical representation of students in the mid-1930s, perhaps gathered for a game of hoops. At the time, the all-male undergraduates had their choice of two degree tracks: science or engineering.

NOW

From left: Mojo Sonola, president of Fleming House, is a senior working toward a degree in chemical engineering with a minor in computer science. Michael Abrams is a graduate student working to learn more about tissue regeneration in jellyfish. Stephanie Huard, a junior, is a double major in biology and philosophy, and does research in neuroscience. Monica Li (BS '16) recently graduated with a mechanical engineering degree and was one of only three female members of the men's soccer team. Partly due to her efforts, a women's soccer team is launching at Caltech this fall.

THEN

Caltech got its start in 1891 on the southeast corner of the intersection of Fair Oaks and Green Street in rented quarters that served as a vocational school. Throop University was founded by Pasadena businessman and politician Amos G. Throop (pronounced "troop").

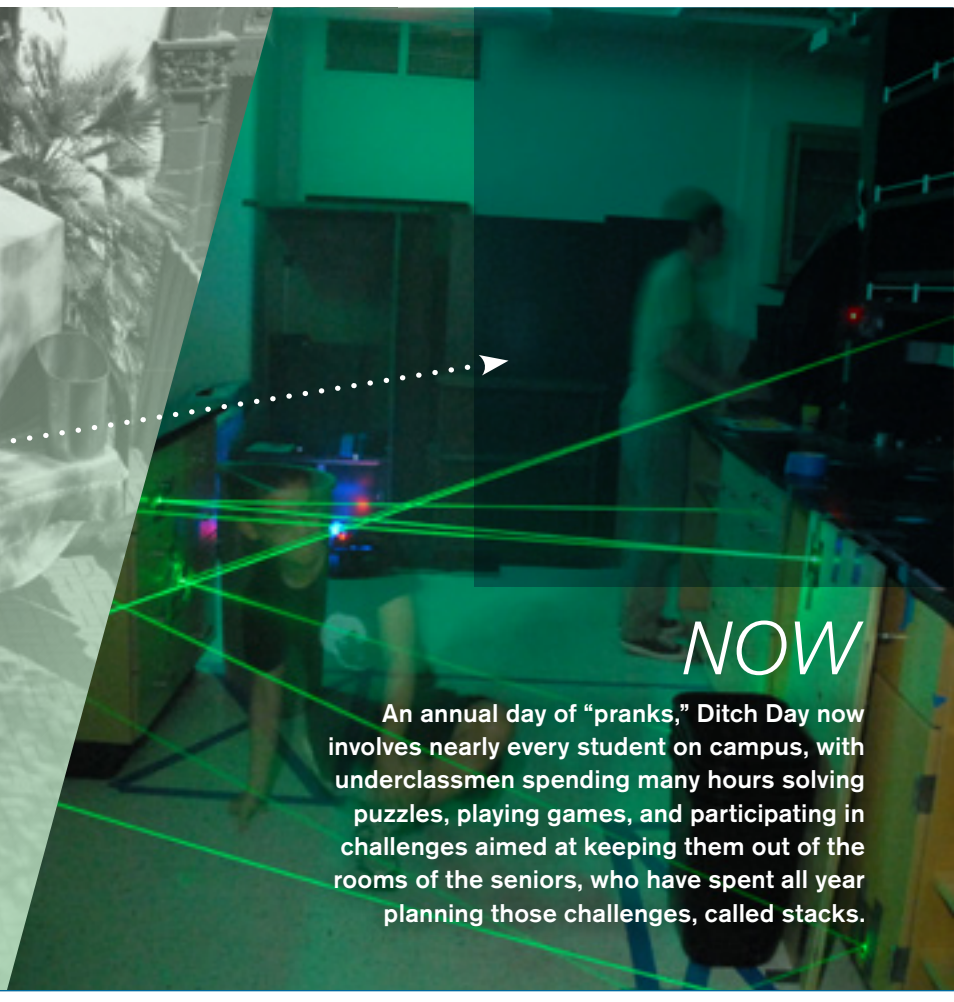


NOW

The LEED-certified, steel-framed Annenberg Center for Information Science and Technology is just one of the many state-of-the-art research buildings found on Caltech's 124-acre campus, less than two miles southeast of its original home.

THEN

Pranks often used to involve moving items—planes, flip-cards, furniture—as this 1957 Ricketts student discovered when he found the contents of his dorm room hanging from a tree in the house's courtyard.



NOW

An annual day of "pranks," Ditch Day now involves nearly every student on campus, with underclassmen spending many hours solving puzzles, playing games, and participating in challenges aimed at keeping them out of the rooms of the seniors, who have spent all year planning those challenges, called stacks.

THEN

Explorer 1 became the first satellite launched by the United States when it was sent into space on January 31, 1958. The Jet Propulsion Laboratory received the assignment to design, build, and operate the artificial satellite that would serve as the rocket's payload, a job it completed in less than three months. The primary science instrument on Explorer 1 was a cosmic-ray detector designed to measure the radiation environment in Earth's orbit.

NOW

JPL's NuSTAR (Nuclear Spectroscopic Telescope Array) mission was launched in 2012 and is the most powerful high-energy X-ray telescope ever developed. By focusing high-energy X-rays, NuSTAR is able to study some of the hottest, densest, and most energetic phenomena in the universe, including black holes, collapsed stars, and supernovae remnants.

THEN

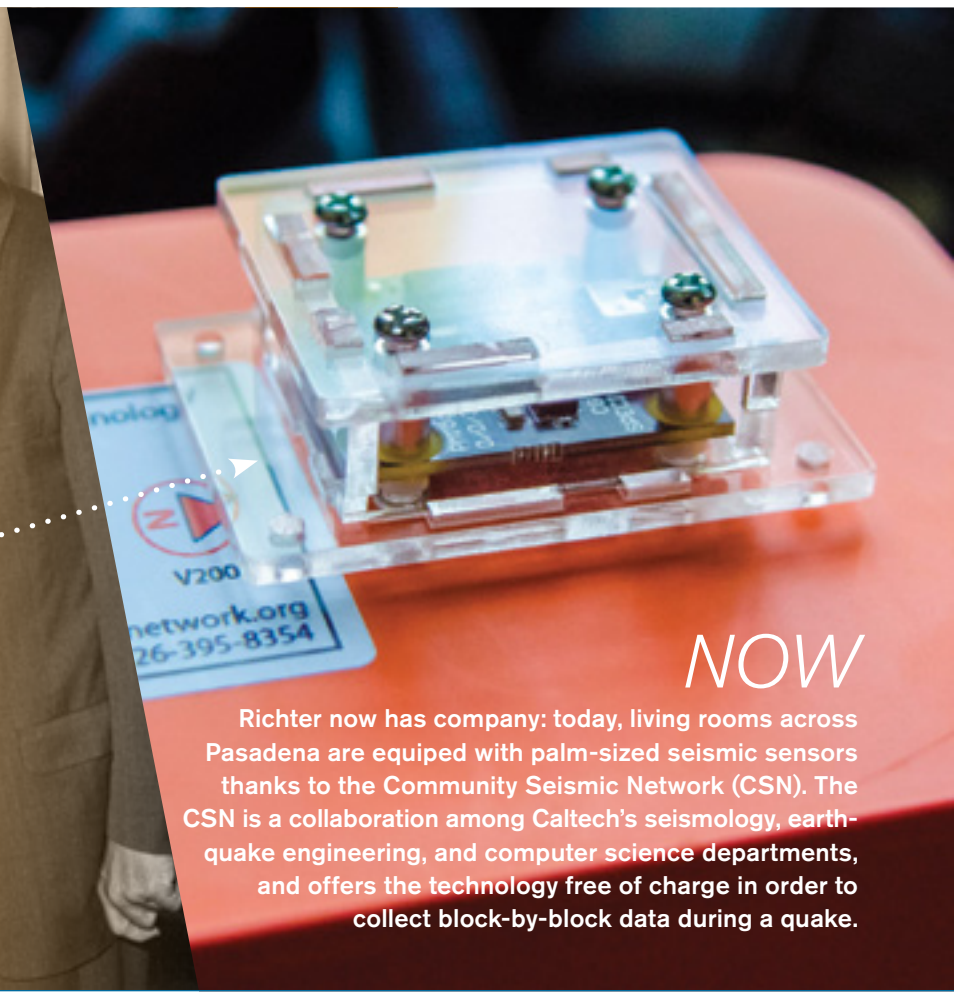
A Throop Polytechnic chemical laboratory, from sometime in the mid-1890s, doubles as a classroom.

NOW

While students do much of their learning in classrooms, they also get to spend time in state-of-the-art labs like this one belonging to Professor of Chemistry Sarah Reisman (left).

THEN

Charles Richter, creator of the Richter magnitude scale for measuring earthquakes, was likely the only person in the 1960s to keep a seismometer in his living room; most were much larger and housed in basement laboratories.



NOW

Richter now has company: today, living rooms across Pasadena are equiped with palm-sized seismic sensors thanks to the Community Seismic Network (CSN). The CSN is a collaboration among Caltech's seismology, earthquake engineering, and computer science departments, and offers the technology free of charge in order to collect block-by-block data during a quake.

THEN

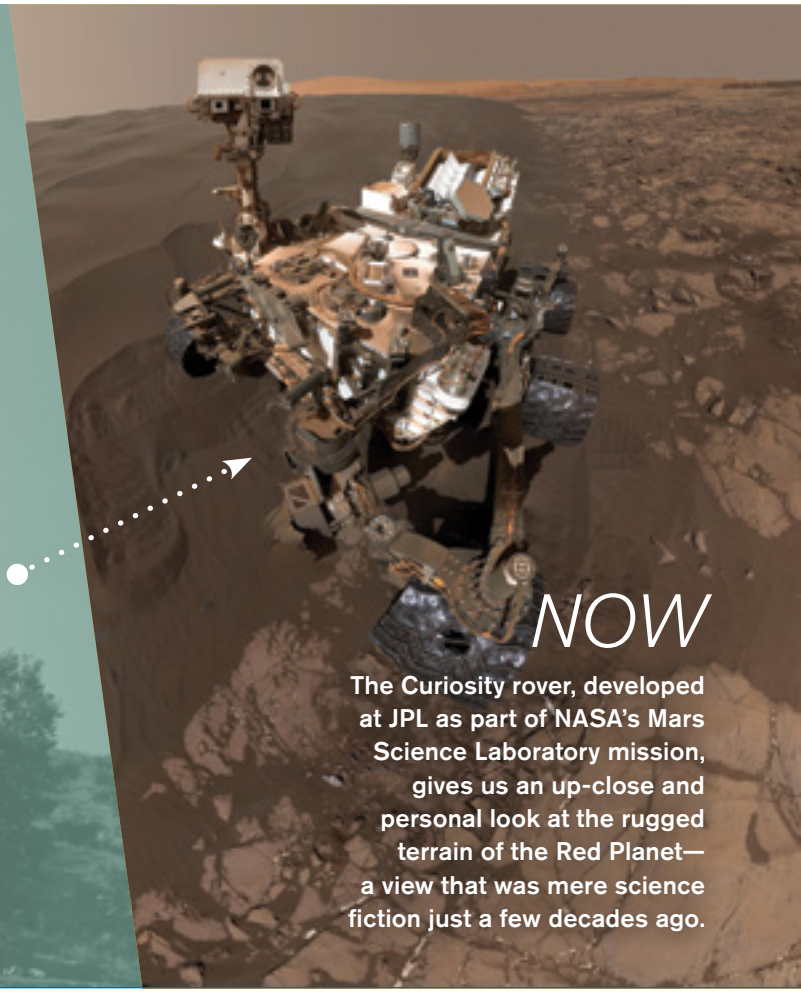
Caltech founding father Robert A. Millikan sends cosmic-ray measuring instruments to high altitude by balloon in Bismarck, North Dakota, in 1938. Millikan had previously coined the term "cosmic ray" after he proved that the high-energy radiation first detected by others in the early 1900s was indeed coming from outer space.

NOW

Particle physics has moved beyond balloons to giant experiments like the particle detectors at CERN's Large Hadron Collider, where Caltech researchers work with scientists from around the world to hunt for and learn about new particles like the Higgs boson.

THEN

In 1937, pastoral mountaintops—seen here at the Palomar Observatory site, with the 18-inch Schmidt and 200-inch Hale telescope domes in the background and workers' cottages in the foreground—were some of the best places from which to get a look at outer space.



NOW

The Curiosity rover, developed at JPL as part of NASA's Mars Science Laboratory mission, gives us an up-close and personal look at the rugged terrain of the Red Planet—a view that was mere science fiction just a few decades ago.

INTERACTING *with* HISTORY

The history of Caltech is one of intriguing people, significant places, and some very unique things … all of which can be explored in the Institute's new interactive history map, created to celebrate its 125th year. The map—which can be found at caltech.edu/historymap—is a bit of a self-guided tour, meant to give visitors to campus the ability to learn about this exceptional place as well as give those who call it home a closer look at what has come before. Here is just a taste of what Caltech's Interactive History Map has to offer.

Chester Stock, who joined Caltech in 1926, dedicated his paleontology research to the fossil mammals of western North America and the deposits in which they occur. His early career in particular focused on the Pleistocene mammalian fauna of Rancho La Brea, or the La Brea Tar Pits. As a result of Stock's work, a skeleton of *Smilodon fatalis*, the saber-toothed cat, is on display in the **Arms Laboratory of the Geological Sciences**.

The Graduate Aerospace Laboratories of the California Institute of Technology (GALCIT)—housed here in the **Guggenheim Aeronautical Laboratory**—got their start in 1926, when Daniel Guggenheim provided $300,000 to both construct a new laboratory building and establish a graduate school in aeronautics. By 1929, Theodore von Kármán—an aeronautics expert known as the father of supersonic flight—was persuaded to emigrate to the U.S. and join Caltech. In 1930, von Kármán became the first director of what was then called the Guggenheim Aeronautical Laboratory at Caltech. The laboratory was built around a 10-foot wind tunnel that was the biggest and fastest on the West Coast for many years. It was used to perform more than 1,100 tests on all sorts of models and aircraft, including most of the Allied aircraft used in World War II as well as commercial planes from Northrop, Douglas, Boeing, Lockheed, and Hughes. The wind tunnel remained in use until its decommission and dismantling in 1997. Today, aerodynamics research and testing continues in Guggenheim's John W. Lucas Wind Tunnel.

On the fourth floor of the **Downs-Lauritsen Laboratory** is a mural of diagrams depicting discoveries made over the years by Caltech's high-energy physicists. Richard Feynman introduced these diagrams to represent his formulation of quantum electrodynamics (QED); the mural includes his illustration describing how two electrons approach one another, exchange a photon, and then scatter. Another diagram shows a high-energy electron scattering off a proton, having changed the proton itself; this scattering yields evidence of quarks, the fundamental building blocks of matter, which were independently proposed by Nobel Prize winner Murray Gell-Mann and grad student George Zweig (PhD '64). John Schwarz's discovery of the mechanism depicted in a hexagonal diagram revitalized the field of string theory.

GUGGENHEIM AERONAUTICAL LABORATORY

DOWNS-LAURITSEN LABORATORY

THE ATHENAEUM

The Athenaeum was part of George Ellery Hale's vision to provide a social gathering place for the great thinkers of Caltech and its associated institutions. It was built thanks to a gift of stocks and bonds given to Caltech by Allan and Janet Balch in 1929. Fortunately, the securities were liquidated prior to the stock market crash in the same year, generating nearly $500,000 in cash for the building's completion. The Athenaeum held its first formal dinner in 1931 with three Nobel laureates (and two Alberts) in attendance: Robert Millikan, Albert Einstein, and the University of Chicago's Albert Michelson, who in 1907 had become the first American to receive a Nobel Prize in the sciences.

Passing the Torch

By Jessica Stoller-Conrad

This past summer, 307 Caltech students—and 97 students from colleges and universities around the world—decided to spend their time SURFing in laboratories or in the field, instead of surfing a wave or the internet. As part of SURF, the Summer Undergraduate Research Fellowships program, they're studying atmospheric chemistry, investigating human olfactory receptors, and exploring vernacular musical composition in Middle English manuscripts, among many other projects, while having an impact on society and its knowledge base that few of their peers will have the opportunity to match.

Since 1979, this 10-week intensive has allowed undergraduate students to apply the theories they've learned in the classroom to address real-world research problems at Caltech, JPL, and a variety of other institutions. It is, says Candace Rypisi, director of the Student-Faculty Programs Office, a true career-shifting opportunity for students as well as a chance for today's scientists, engineers, and graduate students to pass the proverbial torch to the next generation of researchers.

IN THE BEGINNING

Since the early days of the Institute—long before the first SURFer hit the nonexistent shores of Pasadena—undergraduate research has been a part of the Caltech student experience. In the early 1920s, Arthur Amos Noyes, one of the three founders of the Institute and its first chemistry chair, made independent research a requirement for all chemistry majors. Although undergraduates generally had to compete with graduate students for coveted summer research spots, each spring Ernest Swift, professor of analytical chemistry, emeritus, encouraged his top freshman chemistry students to spend the summer helping him with his research at Caltech's marine biology station in Corona del Mar.

In addition to Swift, several other faculty members started recognizing that undergraduate students could be valuable contributors in the laboratory. Although there wasn't a formal arrangement, even at that time Caltech undergraduates showed up as coauthors in research publications. In 1928, for example, Linus Pauling, then an assistant professor at Caltech, coauthored a paper in the *Journal of the American Chemical Society* with undergrad Edwin McMillan; eventually, both Pauling and McMillan went on to win Nobel Prizes.

However, in 1929, when the stock market crashed, the various programs like Swift's—which offered students free room and board and a $50 stipend each—were no longer financially feasible. In fact, it wasn't until after World War II, when federal research contracts began providing additional funding to universities, that summer laboratory jobs for undergraduates became more plentiful at Caltech . . . although those jobs generally involved washing glassware rather than performing actual experiments.

Then, in 1968, Caltech received a gift from the Paul K. and Evalyn E. Cook Richter Memorial Funds—a gift donated specifically for the support of projects that would enable "opportunities for students to work closely with faculty to promote individual achievement." These funds, followed by a donation from Caltech Trustee Lew Wasserman in 1978, provided sufficient financial support for a small group of students to receive a modest summer stipend and the opportunity to work with a Caltech faculty mentor on an independent research problem.

What started in 1979 as an experimental program to provide support for 18 student researchers on campus has now blossomed to more than 300 Caltech students each summer in laboratories and field stations.

NEW NETWORKS

When Heather Dean (BS/MS '00) began her freshman year at Caltech, she felt fairly settled in her career path: she would follow in her father's footsteps to become an electrical engineer and go directly into industry after graduation. As an engineer, she was interested in artificial neural networks—algorithms, inspired by the brain, that allow computers to "learn" in much the same way that humans do. However, soon after starting her undergraduate career, chats with Blacker House resident advisers—graduate students in computation and neural systems—inspired her to start studying the biological side of neural networks and the brain circuitry that spawns them.

To further explore her new interest, Dean decided to take a neurobiology course with Gilles Laurent, the former Lawrence A. Hanson Jr. Professor of Biology and Computation and Neural Systems at Caltech. The course so inspired her that she decided to do a neurobiology SURF project in Laurent's lab.

"A graduate student in the lab had been working on finding a behavioral assay for testing locust olfactory preferences"—i.e., figuring out which smells they are most drawn to—"and had so far not come up with a good solution," Dean recalls. "He had built boxes for the locusts to move horizontally toward an odor, but that hadn't worked well. I noticed that much of the movement in the locust colony was vertical, so I built a device that allowed a locust to move up into one of two chambers into which we could pump odors. We could then look at which chamber the locust preferred."

Although her SURF experience was less about neural networks and more about techniques that allowed them to better study the locusts' behavior, Dean also had the opportunity that summer to observe graduate students and postdocs as they recorded neural activity in the locusts. "I was fascinated," she says, "and I became interested in the links between the neural activity revealed through electrophysiology and the animal's behavior."

After her SURF project and an additional nine-month research stint in Laurent's lab, Dean began reconsidering her once-certain career path. "He was a great mentor; we discussed my future plans in depth, and he suggested that I stay in neuroscience," she says.

Following his recommendation, Dean went on to pursue graduate studies in neurobiology at Duke, where she received her doctorate in 2006. But her career shifts weren't over quite yet.

"After graduate school, I went on to a postdoc at NYU with a fellow Caltech alumnus, Bijan Pesaran (PhD '02)," Dean says. "It was an amazing experience, but I realized I was more interested in big-picture questions about science and policy," she says. Dean applied to and received a AAAS Science and Technology Policy Fellowship at the National Science Foundation, where she worked on projects related to the BRAIN Initiative and improving reproducibility in science.

Now, as a pre-market reviewer in the Office of Device Evaluation at the Food and Drug Administration, Dean has an opportunity to combine all of her experiences and interests. "I'm now bringing my background in both engineering and neuroscience to the

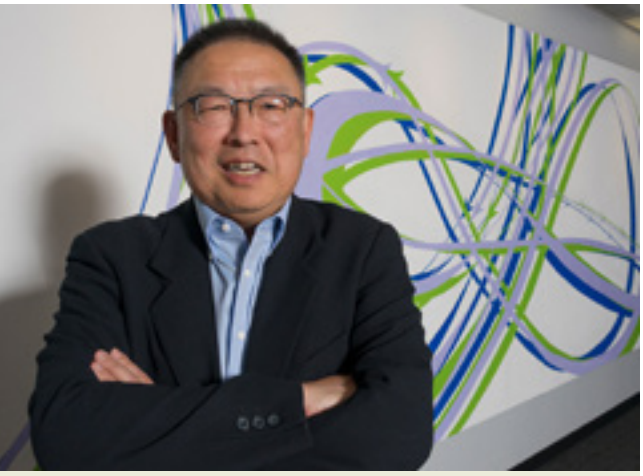
Heather Dean (BS/MS '00) credits SURF projects in neurobiology for setting her on a career path that now has her working as a pre-market reviewer for the FDA.

review of the safety and effectiveness of medical devices. I love what I do, and if I hadn't done a SURF project—and through SURF met a mentor who encouraged me to go to graduate school—my career might well have gone in a very different direction," she says, "so I'm extremely grateful for the opportunities I was given."

AN INTERPLANETARY IMPACT

Although the SURF program had yet to announce its first class of fellows when Martin Lo graduated from Caltech in 1975, he says the program had a profound impact on the direction of his research—because of the experience and insights that SURFers have brought to his work.

In 1996, Lo, a member of the technical staff at JPL, was working on a proposal to measure the cosmic microwave background (CMB)—a thermal signature in the universe left over from the Big Bang. The plan was to launch an instrument that could detect the CMB; the problem was that Lo, who studies a branch of mathematics called dynamical systems theory, would have to figure out how to get the instrument to take on a particular orbital pattern to get the reading.



Martin Lo (BS '75), a member of the technical staff at JPL, says that the work of SURF students in his lab has contributed to breakthroughs in his research.

Between any pair of massive bodies—such as between a planet and the sun—there are five sets of balance points, called Lagrange points. At these points, the combined gravitational pull of the planet and the sun and their rotational forces are exactly enough to pull an object into orbit around the Lagrange point. Lo realized that he could use the chaotic dynamics of orbits around these balance points to his advantage, exploiting the nonlinear effects of the gravitational pull to move the instrument into a distant orbit with very little fuel. Furthermore, he posited, if all of the objects in the solar system are connected gravitationally in this way, the network of orbit patterns could create a system of "ultra low energy" paths throughout the solar system as well as in other planetary systems, with important implications for the future of space travel and exploration.

To determine if such paths truly exist, Lo needed help calculating the orbits—help he got from a work-study undergraduate student named Shane Ross (BS '98, PhD '04). "Shane started working for me during the second quarter of his frosh year, and that summer, we applied for and won a SURF for him to continue his work," Lo says. As a result of Ross's calculations, Lo discovered that it would indeed be possible to transport spacecraft using the chaotic dynamics of gravity, if you connected the dots of the Lagrange points; they called their discovery the Interplanetary Superhighway.

"After the initial discovery, I worked with two more SURF students on the project, and Shane and I continued working together for 10 years as he went through Caltech for his BS and his PhD," Lo says. "Along the way, we developed the concepts that helped the space exploration program of 2004 to get its initial congressional approval, created a new concept to serially orbit the moons of Jupiter, and discovered how comets and asteroids can approach a planet through the superhighways."

Because the superhighways can move objects using very little fuel, several space missions have since taken advantage of them, with spacecraft traveling to their destinations using much less fuel than was needed before. "Because of this experience, I have a special fondness for and gratitude to the SURF program," Lo says. "You can say that is has changed my life and enabled some important programs in our space program. How cool is that for work done in collaboration with a freshman?"

This past summer, Caltech undergraduate Tom Gorordo carried on Ross's legacy, using computer models to analyze the low-energy orbits that run the Interplanetary Superhighway. "I'm really excited by the work and can't wait to get started," Gorordo, a sophomore, said of his SURF project before it began. "The potential applications of this work have broad implications for the future of space travel and mission planning, so I think it will be incredibly rewarding work in the long run. My project is a useful addendum to work that has already been done, and I'm glad to be able to help and to get exposure to the field."

THE NEXT GENERATION

By spending a summer in the laboratory, students like Gorordo pick up many valuable technical skills. However, they also find the uninterrupted summer research time can be an opportunity to explore difficult questions and contribute to something

> It's really quite exciting to have been encouraged to start research early on, when many scientists don't have the opportunity to get a real taste until graduate school."

Sophomores Clare Hao (right) and Cherie Jia (left) work with professor of political science Michael Alvarez on a SURF project to analyze social media mentions in a study of voting trends during an election year.

much larger than a 10-week project.

For example, under the mentorship of professor of political science Michael Alvarez, sophomore and first-time SURF student Clare Hao used her computer coding skills to analyze social media mentions in a study of voting trends during an election year. Hao, along with fellow sophomore Cherie Jia, developed a set of code to analyze data from a database that monitors Twitter, collecting tweets that include specific keywords related to the upcoming election—specifically, words related to problems people might face when trying to vote.

The database collects information about these tweets, and the two women built programs that can analyze this data and organize the information in order to create graphical representations. The graphics will be uploaded to and regularly updated on the website of the Voting Technology Project (vote.caltech.edu)—a joint venture started by Caltech and MIT and codirected by Alvarez that "seeks to develop better voting technologies, to improve election administration, and to deepen scientific research in these areas," according to the site.

"We have a collection of potential ideas, but the main goals for the project this summer was to at least implement graphics to represent geographical data, sentiment, and communication networks. A side goal was to finish a collaborative report and to improve the efficiency of the database," Hao says, "This whole project has been going on for a few years. I'm picking up where others have left off, so my personal goal is to learn something new and to gain experience."

"It's really quite exciting to have been encouraged to start research early on, when many scientists don't have the opportunity to get a real taste until graduate school," says Michelle Dan, another sophomore first-time SURFer. Dan spent the summer doing research at the Marine Biological Laboratory in Woods Hole, Massachusetts, under the direction of Dianne Newman, professor of biology and geobiology, and Jared Leadbetter, professor of environmental microbiology. She was able to sharpen her technical skills in the unique academic village at Woods Hole while helping to answer questions about interactions between ecosystems and pollution.

Pollution due to synthetic plastics has become a widespread environmental concern, in part because plastic particles collect in oceans and threaten vast ecosystems. However, certain marine microorganisms are capable of synthesizing biodegradable plastic polymers into a compound, called polyhydroxybutyrate (PHB), that is later degraded in sediment. Dan's research investigated bacteria that degrade this plastic in environments lacking oxygen—in her case, saltwater marshes. Dan designed a medium in which to grow the bacterium and determine whether or not the organism could possibly provide a model for the remediation of plastic pollution.

"I'd feel fulfilled to uncover a novel physiology of a bacterial species, but more than that, I'm excited to contribute to research that could potentially relieve monstrosities like landfills and marine-trash vortexes," she says.

Uncovering a potential pathway toward a solution to major ocean cleanup efforts may seem like a substantial goal for a summer research project, but Dan notes that SURF, as a training experience for young scientists, is more about the journey than the destination. "SURF affirmed for me that research can offer a stimulating and adventurous path that I plan to pursue," she says. "I definitely caught a glimpse of the 'Jacques Cousteau' type of marine field-research I've been dreaming about since I was a kid."

Saving the oceans and living out a childhood dream? Not bad for a summer vacation. E&S


Romantic Revolutionary

Between the Archives and the Athenaeum: Caltech as Living History

By Daniel J. Kevles

Daniel J. Kevles is the J.O. and Juliette Koepfli Professor of the Humanities, Emeritus, at Caltech and the Stanley Woodward Professor of History, Emeritus, at Yale University. He was on the faculty of Caltech's Division of the Humanities and Social Sciences (HSS) for more than 35 years (1964–2001), focusing on the history of science. His research and writings encompass the interplay of science, technology, and society past and present with a focus on the United States. He is recognized for historical works that integrate diverse sources into accessible, analytic narratives, and is the author or coauthor of five books.

On January 28, 2016, Kevles was the first speaker in a lecture series celebrating the 50th anniversary of HSS. The text that follows is a revised and expanded version of that talk.

Both the Athenaeum and the germ of what became the core of the Archives—Robert Millikan's correspondence files—figured prominently in my introduction to Caltech, which I first visited while on a doctoral research trip in 1962. I discovered and worked with Millikan's papers, which were stored unattended in six or seven file cabinets in the dimly lit basement of the Arms geology building, and I stayed at the Athenaeum, savoring its understated opulence as I sat in the dining room under the portrait gaze of George Ellery Hale, Millikan, and Arthur A. Noyes.

I found myself at the Athenaeum again during a three-day weekend two years later, in February 1964, when I was under consideration for appointment to an assistant professorship in the humanities division. On Sunday morning, as I was about to leave for the airport, Hallett Smith, the chair of the division, stopped by, offered me a job, and gave me a week to decide. The Millikan papers and the Athenaeum remaining vivid in mind, I said "yes" before the week was out. I arrived in Pasadena at the beginning of September 1964.

The Division

At the time, the division was beginning to rumble with initiatives for change in both scope and character. The ideas concerning scope were, I believe, connected to the issue that the physicist and novelist C. P. Snow had raised in his provocative and influential essay, *The Two Cultures and the Scientific Revolution*, published in 1959. Snow's main point was that science and technology were transforming the world and that citizens in democratic societies knew too little about them to participate knowledgeably and intelligently in a civilization teetering on the edge of nuclear armageddon. Educators and cultural critics responded to Snow's book by calling for better educating nonscientists in the sciences.

At Caltech, various faculty approached Snow's provocation with efforts to bridge the two cultures in the opposite direction—that is, by building bridges from the humanities and social sciences to the natural sciences. In a sense the division had been doing this for a long time, aiming to give students a patina of liberal and practical education by requiring them to take nominally a fifth of their courses in history, literature, econom-

On the back wall, a portrait of George Ellery Hale, Millikan, and Arthur A. Noyes watches over the main dining room of the Athenaeum.

ics, and a smattering of electives in both humanities and social sciences.

Now, in the wake of Snow's *Two Cultures*, a number of the Institute's scientists involved in advising the government and of the divisional faculty counted it advantageous to instruct students in public affairs—especially concerning science, technology, and foreign policy—and establish public affairs in general as an intellectual presence on the campus. That purpose generated an effort to bolster the social sciences.

At the beginning of 1964, the social sciences were already represented by eight professors, or about one-third of the professorial faculty. They covered political geography, international economics, macroeconomics, business, industrial relations, and psychology. None used any mathematics to speak of in their work. The drive to bolster the social sciences was spearheaded in the division by a coalition of several of these faculty and a few of the historians. Their idea was to hire social scientists who would deal with issues in science and society such as national security, arms control, and development in the Third World. This effort produced the acquisition of Thayer Scudder, a social anthropologist with extensive postdoctoral experience in the African field, who also joined the faculty in 1964. It was in recognition of the social science faculty already in place—and of the division's ambitions to expand in the field—that 50 years ago, at the beginning of 1966, the Caltech Board of Trustees authorized a change in the division's name to the Division of the Humanities and Social Sciences.

During the next couple of years, several more economists were hired, including Lance Davis, who came to Caltech as a full professor from Purdue in 1968. Lance was 40 and already a highly distinguished economic historian, a pioneer in the application of economic theory and quantitative analysis to the development of financial and business institutions in the United States. His appointment marked a milestone, turning the future of social sciences at the Institute away from a focus on science and society, and toward an innovative program in mathematically grounded micro-politics and microeconomics.

Judy Goodstein, left, with Dan Kevles reviewing materials for the Caltech Archives. Goodstein was the first archivist at Caltech, a position and program created by Kevles. Today the Archives' unique research collections in the history of science and technology range from the time of Copernicus to today. To learn more, visit archives.caltech.edu.

In 1970, Smith's chairmanship ended after more than 20 years, and Robert Huttenback, well known for his scholarship on the history of the British Empire and at the time the popular Master of Student Houses, was named acting chair. He became full chair in 1972.

Huttenback led the way in establishing demonstrated scholarly promise and accomplishment as new criteria for appointment and promotion, along with teaching and service; these standards came to prevail in the division and to be supported by the Institute as a whole. He obtained and made readily available resources for research and brought the faculty procedurally into decisions on curriculum, programs, hiring, and promotion.

The 50th anniversary that we celebrate this year thus marks the inauguration in HSS of a double transformation: the establishment of the social science program and, across the division, of standards of high achievement in scholarship as well as teaching. Both changes quickly returned substantial dividends. Huttenback expanded the social science faculty still more, bringing in several exceptionally promising younger economists and political scientists who practiced or were strongly oriented toward microeconomics and micro-politics. The Institute faculty approved the establishment of a doctoral program in the social sciences that quickly achieved national prominence. Recruitment in the humanities over the years followed a similar course of high aspirations, with the appointment at both the junior and senior professorial levels of distinguished literary scholars and critics; political, cultural, and economic historians (two of whom were jointly appointed in social science); and philosophers. Within a decade or so, the division had substantially increased in size.

The Archives

The inspiration to create the Caltech Archives came not only from my awareness of the Millikan papers sitting in the basement of Arms but also from my becoming acquainted

with the papers of George Ellery Hale. Caltech sprang arguably from Hale's vision and entrepreneurial energies. An accomplished solar physicist, he had persuaded Andrew Carnegie early in the century to establish the Mount Wilson Observatory and had mobilized the National Academy of Sciences for defense in World War I by creating the National Research Council and recruiting Robert Millikan to run it. A few years later he persuaded Millikan to head the new Caltech.

In the fall of 1967 (or thereabouts), Horace Babcock, the director of the Mount Wilson Observatory, asked me to help him decide what to do with Hale's papers, which were taking up a good deal of space in the observatory's offices in Pasadena. A quick look revealed that this collection was bigger even than Millikan's and rich with materials bearing on Hale's life and career, his role at Caltech, and his multiple activities in national and international science. At my suggestion, Horace happily allowed its temporary loan to Caltech. With the help of an undergraduate, I organized the collection, had it microfilmed—using a grant from the National Historical Publications and Records Commission—and wrote a catalogue for the 100 reels it filled.

When I was working on the Hale papers, a letter arrived from a young scholar named Judy Goodstein, who was just finishing her doctorate in the history of science at the University of Washington. Judy said she was coming to Pasadena with her husband, David Goodstein, who was joining the Caltech physics faculty, and wondered if she might find a position in the history of science at the Institute. We had no faculty positions available, but Judy's inquiry prompted me to think: "Here is a possible archivist. All we need is an archive."

I broached the subject with President Lee DuBridge, telling him about the Hale and Millikan collections and saying that Caltech ought to establish an archive where they could be cared for and made available to scholars. I added that the archive could be a repository for the papers of other Caltech scientists and engineers when they retired, thus building a vital ongoing record of the life and work of the Institute. I also told him about Judy. Lee liked the idea and asked me how much it would cost. I said about $6,000 a year would be enough to cover a half-time archivist plus expenses for materials. Adjusted for inflation, $6,000 then is about $41,000 now, not a trivial sum. Without blinking an eye, Lee said, "Fine. Go ahead." So, after about 15 minutes, Caltech had an archive.

Judy accepted the job and swiftly took charge. Today the Caltech Archives houses multiple treasures and is one of the leading repositories of materials for the history of science and engineering since the beginning of the 20th century.

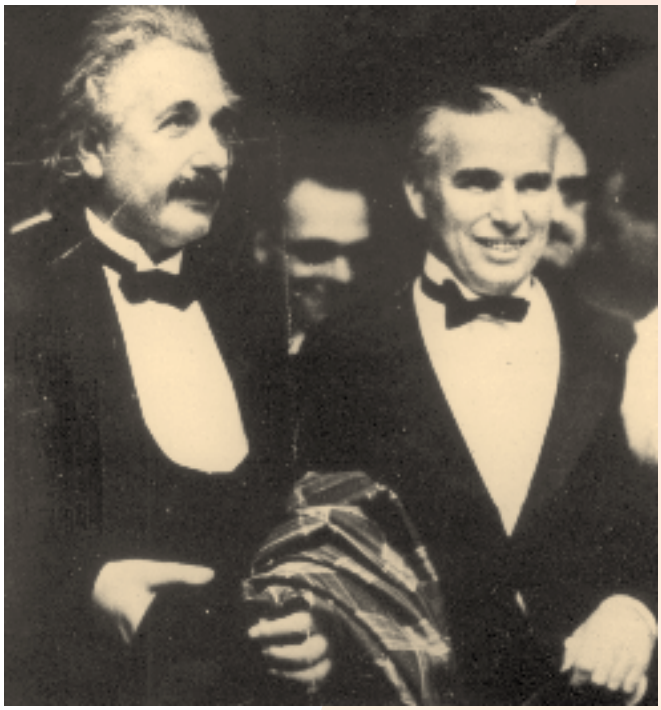
THE 50TH ANNIVERSARY THAT WE CELEBRATE THIS YEAR THUS MARKS THE INAUGURATION IN HSS OF A DOUBLE TRANSFORMATION: THE ESTABLISHMENT OF THE SOCIAL SCIENCE PROGRAM AND, ACROSS THE DIVISION, OF STANDARDS OF HIGH ACHIEVEMENT IN SCHOLARSHIP AS WELL AS TEACHING.

The Institute

The Millikan and Hale papers were essential for my own historical work, and once I expanded my repertoire into the history of genetics, eugenics, and molecular biology, so were other collections that Judy acquired. But no less important was the resource of Caltech's faculty, a number of whom had been students or young faculty at the Institute before World War II and many of whom I got to know.

Caltech was then, as it is now, small, informal, and, for the most part, a welcoming place, a kind of republic of science and scholarship. Like other universities, it was some-

A Round Table gathering of graduate students at the Athenaeum in the mid-1930s.



Albert Einstein joins Charlie Chaplin at the Los Angeles Theater in 1931 for the premiere of Chaplin's movie City Lights.

what tainted by anti-Semitism in faculty appointments, but its ambition for world-class standing trumped its lingering discriminatory leanings.

I came to know the faculty in a variety of ways but in none more rewarding than frequenting the "Round Tables," where notable scholars from various disciplines gathered to dine, debate, and discuss at the Athenaeum. Like so many other features of the Institute, the Athenaeum was intended to foster crosstalk among faculty in different disciplines. From the beginning it was an appealing gathering place for graduate students, postdocs, and professors.

My Round Table luncheon companions were usually eager to chat about the news of the day (political, cultural, scientific, and otherwise), reflect on the state of their fields, or simply reminisce. Faculty who regularly ate at the Round Tables—as well as those who did not—formed for me a vital link between past and present, a corps of living history, not only for the 1930s but for World War II and the Cold War. Most of the physical scientists and engineers I encountered at the Round Tables had been part of the wartime mobilization, developing microwave radar, solid fuel rockets, jet-assisted takeoff, and the atomic bomb. During the postwar years, a number of the same scientists and engineers had become deeply involved in issues of national security and federal science policy. Some were political conservatives, many were liberals, but all struck me as adhering to a code of human decency as each struggled in his way to prevent the world from hurtling to some thermonuclear armageddon.

The Einstein Papers

Perhaps no one better exemplifies the living-historical links between the Archives and the Athenaeum than Albert Einstein. The Hale papers include a striking letter from Einstein in October 1913 outlining for astronomers, with a hand-drawn diagram, a striking consequence of his then-incipient general theory of relativity: that a ray of starlight would be deflected when it passed near the mass of our sun and that the deflection might be observed during a solar eclipse. British scientists announced in November 1919 that they had confirmed the prediction, and Einstein was hailed around the world as the Newton of the 20th century.

Each winter term, from 1931 to 1933, Einstein visited Caltech, living in the Athenaeum in rooms that are now called the "Einstein Suite." Political conservatives in greater Los Angeles did not like Einstein, but Hollywood adored him. When he joined Charlie Chaplin at the premiere of *City Lights*, Chaplin reportedly remarked, "I'm famous because everyone understands me. You're famous because no one understands you."

But physicists have now long understood another profound prediction of Einstein's general theory of relativity: that massive objects violently accelerating in space would generate gravitational waves. The ruminations on the topic of Einstein and his theoretical circle are revealed in his correspondence, the editing and publication of which—both in print and online—are now ongoing at Caltech in the Einstein Papers Project under the exceptionally capable leadership of Diana Buchwald. Physicists at Caltech and elsewhere have been collaborating for some three decades to detect gravitational waves, designing and developing for the purpose the Laser Interferometer Gravitational-wave Observatory (LIGO). In September 2015, LIGO yielded the first direct experimental evidence of gravitational waves: a chirp of a signal, etching another entry in the catalogue of Caltech's living history, its roots discernible in the Archives, in Einstein's papers, and in the ghosts of the Athenaeum. E&S

In Memoriam

Tom M. Apostol 1923–2016

Tom M. Apostol, professor of mathematics, emeritus, passed away on May 8, 2016. He was 92.

Apostol received his bachelor of science in chemical engineering in 1944 and a master's degree in mathematics in 1946, both from the University of Washington, Seattle. In 1948, he received his PhD in mathematics from the University of California, Berkeley. In 1950, he arrived at Caltech as an assistant professor; he was named associate professor in 1956, professor in 1962, and professor emeritus in 1992.

Apostol was the author of several influential textbooks. For more than five decades, undergraduate introductory mathematics courses at Caltech have used Apostol's two-volume text, *Calculus*. He also worked with a Caltech team that produced *The Mechanical Universe . . . and Beyond*, a 52-episode video lecture series based on *The Mechanical Universe: Introduction to Heat and Mechanics* and *Beyond the Mechanical Universe: From Electricity to Modern Physics*, the introductory physics textbooks that Apostol coauthored.

Apostol later was the creator, director, and producer of *Project MATHEMATICS!*, a series of award-winning computer-animated videos that explore basic topics in high school mathematics. The nine videos are estimated to have been viewed by 10 million people worldwide.

To learn more about Apostol's life and work visit caltech.edu/news/tom-m-apostol-1923-2016.

Charles Peck 1934–2016

Charles W. Peck (PhD '64)—an eminent physicist, dedicated educator, and former chair of the Division of Physics, Mathematics and Astronomy—passed away on July 21, 2016. He was 81 years old.

Peck was born in Freer, Texas, and earned his bachelor of science degree from New Mexico College of Agriculture and Mechanical Arts in 1956. He went to Caltech for his graduate studies, receiving a PhD in 1964. Peck spent his entire professional career at Caltech, first as a research fellow (1964–65) and then as assistant professor (1965–69), associate professor (1969–77), and professor of physics. He retired in 2004. From 1983 to 1986, Peck served as executive officer for physics; he was PMA chair from 1993 to 1998.

Peck was a "great scientist, a kind individual, and an amazingly dedicated and successful teacher," says Fiona Harrison, the Benjamin M. Rosen Professor of Physics and the Kent and Joyce Kresa Leadership Chair of PMA.

Peck's research was in the area of experimental particle physics, designing and conducting experiments to study the basic constituents of matter. As a graduate student, he used the electron synchrotron at Caltech to investigate a class of exotic short-lived particles known as "strange." He participated in a wide range of accelerator-based studies aimed at probing the structure and properties of quarks—the fundamental building blocks of matter—and at clarifying the nature of the strong and weak nuclear interactions, two of the four fundamental forces of nature.

To learn more about Peck's life and work visit caltech.edu/news/charles-w-peck-passes-away-51393.

Gerald J. Wasserburg 1927–2016

Gerald J. Wasserburg, the John D. MacArthur Professor of Geology and Geophysics, Emeritus, passed away on June 13, 2016. He was 89 years old.

Wasserburg's research focused on the origins and history of the solar system and its component bodies. His work established a timescale for the development of the early solar system including the end of the process of nucleosynthesis and the formation about 4.5 billion years ago of solid objects such as the earth and the moon, other planets, and certain meteorites. He also is acknowledged widely for his isotope studies of lunar materials collected by the Apollo missions and his involvement in U.S. space research programs. He and his colleagues also did important work on the dating of rocks, on the evolution of the earth through time, and on the modern oceans.

Wasserburg earned his SB, SM, and PhD degrees from the University of Chicago (in 1951, 1952, and 1954), and joined the Caltech faculty in 1955 as an assistant professor of geology. He became an associate professor in 1959, professor of geology and geophysics in 1963, MacArthur Professor in 1982, and he retired in 2001.

He served as chair of the Division of Geological and Planetary Sciences from 1987 to 1989 and as executive officer for geochemistry over the same time period.

To learn more about Wasserburg's life and work visit caltech.edu/news/gerald-wasserburg-1927-2016-51073.

Simon "Si" Ramo 1913–2016

Alumnus and life member of the Board of Trustees Simon "Si" Ramo (PhD '36), a founding giant of the aerospace industry and chief architect of the nation's intercontinental ballistic missile system, passed away on June 27, 2016. He was 103.

First appointed to the Caltech Board of Trustees in 1964, Ramo was elected a Life Member of the board on May 7, 1985, in which capacity he served Caltech until the time of his death.

In this tribute to Ramo, Thomas Everhart, Caltech President Emeritus, shares some thoughts about the ways in which Ramo impacted both the Institute and the world around him.

Dr. Simon Ramo was an eminent scientist-engineer, a visionary businessman, and a leader in almost everything he undertook. While he could have been a concert violinist, he actually did write books on tennis and on serving on committees, as well as on science, engineering, and business. He not only had a profound impact on our nation's defense capabilities—leading the Intercontinental Ballistic Missile program during the Eisenhower administration—but also continued to advise several of the presidents who were elected after Eisenhower. He laid the foundation for the Hughes Aircraft Company to become an aerospace leader and at one time the largest such company in California. With Dean Wooldridge, he founded the Ramo-Wooldridge division of Thompson Products, which evolved into TRW and played a crucial role in aerospace defense.

Si Ramo was not only a great leader, but also an important mentor to many. He had an important influence on my life as well as thousands of others. He was CEO of Hughes Aircraft company when I joined the Hughes Research Laboratories in 1953 after graduating from college. Although he left shortly afterwards to form what became TRW, his impact on Hughes during the two years I worked there was substantial, even to a young employee. The leaders he chose for Hughes were the foundation for its continued success.

My next encounter with Dr. Ramo was when Ruben Mettler, chairman of the Board of Trustees of Caltech, flew me to be interviewed by the Trustee Selection Committee for the presidency of the Institute. Dr. Ramo's questions and statements during that interview provided background and context for my 10 years at Caltech. Although he was already a Senior Trustee at the time, he was active on the board during my first few years, was available for consultation on Institute problems, introduced my wife and me to American leaders at dinner parties that he and his wife, Virginia, hosted at their home, and was supportive in all ways to me—and to the Institute.

After I retired from Caltech, I had the privilege of seeing Dr. Ramo at W. M. Keck Foundation meetings, where he continued to provide insight and leadership in support of research in science, engineering, and medicine.

The nation, Caltech, the Keck Foundation, and the many other organizations to which Dr. Ramo provided insight, leadership, and personal support have lost a great friend. We are all richer for having known him.

Ahmed Zewail 1946–2016

Ahmed Zewail, the Linus Pauling Professor of Chemistry, professor of physics, and director of the Physical Biology Center for Ultrafast Science and Technology at Caltech, passed away on Tuesday, August 2, 2016. He was 70 years old.

Zewail was the sole recipient of the 1999 Nobel Prize in Chemistry for his pioneering developments in femtoscience, making possible observations of atoms in motion on the femtosecond (10^{-15} seconds) timescale. These developments led to the establishment of the discipline of femtochemistry. More recently, he and his group developed "4D" electron microscopy for the direct visualization in the four dimensions of space and time of materials and biological behaviors.

For his contributions to science and for his public service, Zewail received honors from around the globe. Fifty honorary degrees in the sciences, arts, philosophy, law, medicine, and humane letters were conferred on him, including those from Oxford University, Cambridge University, Peking University, École Normale Supérieure, Yale University, University of Pennsylvania, and Alexandria University.

Zewail was decorated with the Order of the Grand Collar of the Nile, Egypt's highest state honor, and was named to the Order of Légion d'Honneur by the President of France, among other state honors. He was an elected member of academies and learned societies including the National Academy of Sciences, the Royal Society of London, the American Philosophical Society, the French Academy, the Russian Academy, the Chinese Academy, and the Swedish Academy. Postage stamps have been issued in commemoration of his contributions to science and humanity.

"Ahmed was the quintessential scholar and global citizen," says Caltech president Thomas F. Rosenbaum, the Sonja and William Davidow Presidential Chair and professor of physics. "He spent a lifetime developing instruments that interrogate nature in fundamentally new ways, and defining new directions that cut across the physical and biological sciences. Ahmed's fervor for discovery never abated and he serves as an inspiration to colleagues and generations of students. The Caltech community deeply mourns his loss."

"Ahmed Zewail was a great man for chemistry, for science, and for society. All of us at Caltech grieve his loss," says Jacqueline K. Barton, Arthur and Marian Hanisch Memorial Professor of Chemistry and Norman Davidson Leadership Chair of the Division of Chemistry and Chemical Engineering.

Among the more than 100 international prizes and awards, he was the recipient of the Albert Einstein World Award, the Benjamin Franklin Medal, the Leonardo da Vinci Award, the Robert A. Welch Award, the Wolf Prize, the King Faisal Prize, the Othmer Gold Medal, and the Priestley Gold Medal. In his name, international prizes have been established in Amsterdam, Cairo, Detroit, Trieste, and Washington, D.C.; in Cairo, the AZ Foundation provides support for the dissemination of knowledge and for merit awards in arts and sciences.

Following the 2011 Egyptian revolution, the government established Zewail City of Science and Technology as the national project for scientific renaissance, and Zewail became its first chair of the Board of Trustees.

In 2009, President Barack Obama appointed Zewail to the Council of Advisors on Science and Technology,

and in the same year he was named the first U.S. Science Envoy to the Middle East. Subsequently, in 2013, Secretary General of the United Nations Ban Ki-moon invited Zewail to join the U.N. Scientific Advisory Board. In Egypt, he served in the Council of Advisors to the President.

Zewail was the author of some 600 articles and 14 books, and was known for his effective public lectures and writings not only on science but also in global affairs. For his leadership role in these world affairs, he received, among others, the "Top American Leaders Award" from *The Washington Post* and Harvard University.

Born in 1946 in Damanhur, Egypt, Zewail received his early education in Egypt and earned his BS and MS degrees from Alexandria University in 1967 and 1969. He received a PhD from the University of Pennsylvania in 1974 and completed an IBM postdoctoral fellowship at UC Berkeley before joining the faculty at Caltech in 1976 as an assistant professor. He became an associate professor in 1978 and a professor in 1982. He was Linus Pauling Professor of Chemical Physics from 1990–97, was named professor of physics in 1995, and was named Linus Pauling Professor of Chemistry in 1997.

Zewail is survived by his wife, Dema Faham, and his four children, Maha, Amani, Nabeel, and Hani.

In honor of Caltech's 125th, we asked alumni: *What's your favorite Caltech story, personal or historical?* Here are just a few of those memories.

It is such an honor to be one of the ***first four woman graduates*** of Caltech and the only one in engineering. I thank the late Professor Pol Dewez for giving me my first taste of research, which has been my excitement for over 40 years.

Late one night in 1954, I joined numerous Ricketts Rowdies to cheer on housemate miscreants as ***THEY MOVED A 3-DIMENSIONAL RECRUITMENT POSTER*** (a wingless F-84 fighter jet) from the Olive Walk to a convenient parking spot in front of Caltech's AFROTC commander's residence on Allen Avenue.

When I helped form Caltech's first gay (LGBTQ) student group in 1971, the flyers I posted around campus for the first meeting all disappeared in one day. So, I replaced them that night and again for several more days **until they eventually stayed up**. Change takes perseverance—even today.

As a math major and senior, I took graduate-level physics courses taught by Richard Feynman, Rudolf Mössbauer, and Kip Thorne. THREE GREAT TEACHERS teaching three great courses, each in a subject for which the teacher is, to put it mildly, well known.

My favorite of all time was the great **ROSE BOWL HOAX OF 1961**. Maybe that dates me, but I was swollen with Caltech pride when I read about it in the national media just after graduation. It was done completely low tech with skills familiar to most of that generation's Techers (lock picking and copy centers!).

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