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Caltech

VOLUME LXXVIII, NUMBER 4, WINTER 2016

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To represent the graduate student experience, we decided to photograph not just a diverse group of these students, but to show the depth and breadth of their lives at and involvement with Caltech. On the cover, from top, are Dorothy Pan, who plays flute and piccolo in the Caltech-Occidental Symphony Orchestra and creates nanoparticles for drug delivery; Siddharth Jain, who plays cricket with Caltech's Cricket Club and studies the evolution of DNA; and Alicia Lanz, who mentors other students and is developing a rocket-borne instrument called CIBER-2. On this page, from left, are: Heather Curtis, Ramya Korlakai Vinayak, Peter Hung, Zachary Erickson, and Sarah Gossan. Learn more about these students in "Seeking a Balanced Equation" on page 10.

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 Instragram posts.

@LowkeyEsteban Only at Caltech do more people show up for the 9pm Chem review session than for the home basketball games

@dakuder Alma mater @Caltech has been busy changing physics and astronomy

@shaunmmaguire The sense of pride you feel when you overhear #Caltech professors talking about one of your smartest friend's work @johnhering #teslaHack

@jodiiegreen I have the sudden urge to move to California and go to Caltech when I finish school

@AstroKatie I have spent the whole day talking and learning and thinking about science and let me tell you it has been fantastic.

@slowe1441 The number of portraits of Albert Einstein in this Caltech bookstore is astonishing and yet not entirely unexpected

@miquai

2015–2016. Let's do this. #caltech

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

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EDITOR IN CHIEF
Lori Oliwenstein

MANAGING EDITOR
Doreese Norman

SENIOR EDITOR
Katie Neith

CONTRIBUTING WRITERS
Andrew Allan, James Astorga, Lori Dajose, Kimm Fesenmaier, Katharine Gammon, Jon Nalick, Katie Neith, Lori Oliwenstein, Rod Pyle, Jessica Stoller-Conrad

COPY EDITORS
Michael Farquhar, Sharon Kaplan

ART DIRECTOR
Keith Knueven

DESIGN AND LAYOUT
Keith & Co.

THE CALIFORNIA INSTITUTE OF TECHNOLOGY
Diana Jergovic, *Vice President for Strategy Implementation*

THE CALTECH ALUMNI ASSOCIATION
Lee Fisher, *President*

Read *E&S* on the go at EandS.caltech.edu

Contact *E&S* at lorio@caltech.edu

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A Grad Experience

Caltech's graduate students are the backbone of its research program; they are key members of any lab and their names sit atop many if not most of the journal papers, poster presentations, and other reports that come out of those research spaces.

And these students are not in the minority on campus, either. Graduate students outnumber undergrads by a not inconsiderable amount. As of October 1 of this year, there were 1,272 students pursuing a master's degree or (more likely) a PhD; undergraduate students numbered 1,005.

So when we decided to do an issue of *E&S* that looked at the many facets of student life at Caltech, we decided to focus first on these hard-working graduate students. And, in order to really get a feel for all they do and contribute, we knew immediately where to turn: the Graduate Student Council, or GSC.

Led this academic year by Jason Pollack (chair) and Natalie Higgins (vice-chair), the GSC comprises all of the graduate students at Caltech. "Our mission is to improve the quality of graduate student life on campus," says Pollack.

Representing—or even just trying to sum up—Caltech's grad student population is no easy task; unlike the undergraduate students, who tend to affiliate with a House or a class year, "the basic unit of grad student life," says Higgins, "is an option or a lab." That's why the GSC is led by a board of directors whose representatives are elected from each of the Institute's options.

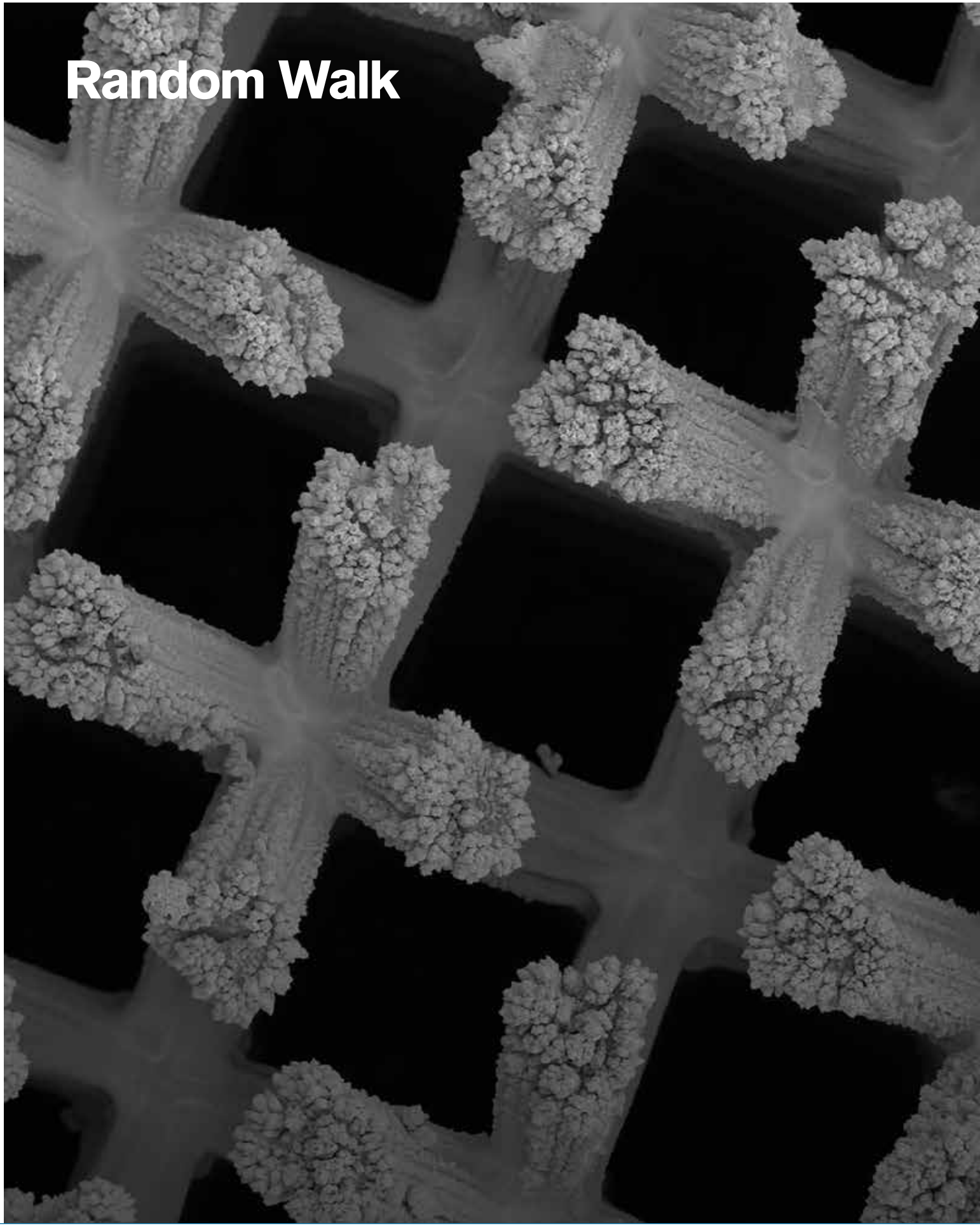
But that doesn't mean that the Institute's graduate students aren't looking for ways to become more involved with and at Caltech beyond the lab. (See "Seeking a Balanced Equation," page 10.) And it's the GSC's job to find or create those opportunities for themselves and their peers. "One of the ways we do that is by funding clubs and events, as well as by organizing events ourselves," says Pollack.

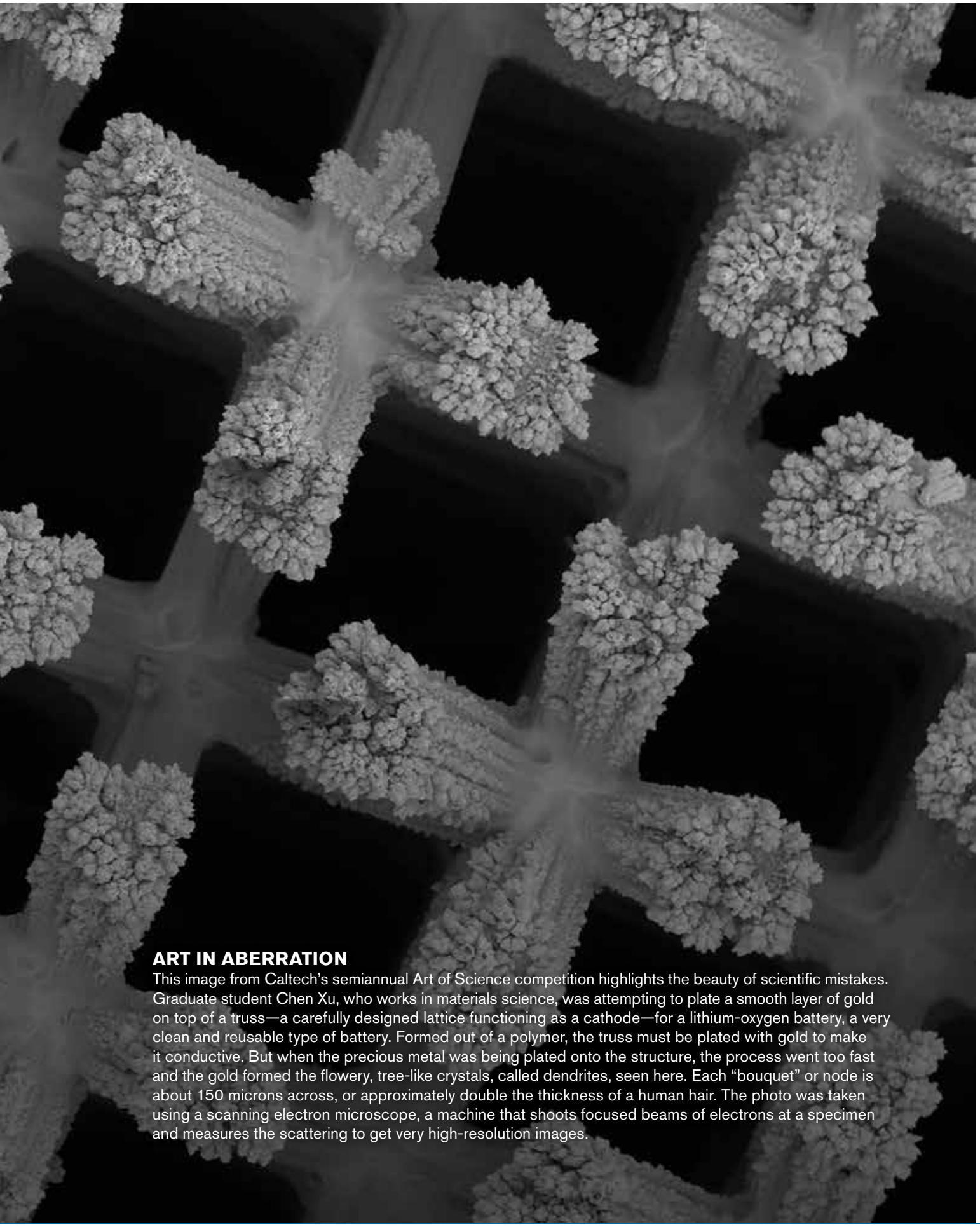
In addition to bringing students together through events, says Higgins, "we also do a fair amount of advocacy for graduate students." For instance, she says, "recently, we've been trying to improve the benefits for people who are married and have children. We've been talking about improving diversity and representation of women and underrepresented minorities on campus. [See "Vive la Difference," page 28.] Basically, we're a liaison between the graduate students and the administration."

None of this is to say—or even imply—that research and teaching, exploring and learning aren't at the heart of the graduate student experience—as you'll find in the various profiles in this issue. Our hope, however, is that you'll walk away from these stories seeing Caltech's grad students through a slightly different, and much wider, lens.

—Lori Oliwenstein, Editor in Chief

Random Walk





ART IN ABERRATION

This image from Caltech's semiannual Art of Science competition highlights the beauty of scientific mistakes. Graduate student Chen Xu, who works in materials science, was attempting to plate a smooth layer of gold on top of a truss—a carefully designed lattice functioning as a cathode—for a lithium-oxygen battery, a very clean and reusable type of battery. Formed out of a polymer, the truss must be plated with gold to make it conductive. But when the precious metal was being plated onto the structure, the process went too fast and the gold formed the flowery, tree-like crystals, called dendrites, seen here. Each "bouquet" or node is about 150 microns across, or approximately double the thickness of a human hair. The photo was taken using a scanning electron microscope, a machine that shoots focused beams of electrons at a specimen and measures the scattering to get very high-resolution images.

The Power of Gunpowder

Although Europe represents only about 8 percent of the planet's landmass, from 1492 to 1914, Europeans conquered or colonized more than 80 percent of the entire world. Being dominated for centuries has led to lingering inequality and long-lasting effects, including poverty and slow economic growth, in many formerly colonized countries. There are many possible explanations for why history played out this way, but few can explain why the West was so powerful for so long.

Caltech's Philip Hoffman, the Rea A. and Lela G. Axline Professor of Business Economics and professor of history, has a new explanation: the advancement of gunpowder technology.

"In 1914, really only China, Japan, and the Ottoman Empire had escaped becoming European colonies," says Hoffman. "A thousand years ago, no one would have ever expected that result, for at that point Western Europe was hopelessly backward. It was politically weak, it was poor, and the major long-distance commerce was a slave trade led by Vikings. The political dominance of Western Europe was an unexpected outcome and had really big consequences, so I thought: Let's explain it."

Hoffman's work is published in a new book titled *Why Did Europe Conquer the World?*

"Gunpowder was really important for conquering territory; it allows a small number of people to exercise a lot of influence," he says.

Hoffman put together an economic model of how gunpowder technology has advanced to come up with what he thinks is the real reason why the West conquered almost everyone else. His idea incorporates the model of a contest or a tournament in which your odds of winning are higher if you spend more resources on fighting.

"If you think about it, you realize that advancements in gunpowder technology—which are important for conquest—arise where political leaders fight using that technology, where they spend huge sums on it, and where they're able to share the resulting advances in that technology," he says. "For example, if I am fighting you and you figure out a better way to build an armed ship, I can imitate you. For that to happen, the countries have to be small and close to one another. And all of this describes Europe." —*JSC*

"The STEM fields are part of our everyday experience, which we normally take for granted: without the STEM fields we wouldn't have cell phones, laptops, TVs, cars, airplanes. The list goes on and on! It's important to feed curiosity and teach critical thinking, a skill which is often undervalued. We should not shy away from some of the more difficult questions in science, but instead be driven to understand nature and the world around us."

—Chiara Mingarelli, Marie Curie Postdoctoral Scholar in Astrophysics at Caltech, talking about why STEM is important, on Amy Poehler's Smart Girls website (amysmartgirls.com).

On the Grounds

This photo of a vintage-looking doorknob comes courtesy of Karl Klein, a control specialist in facilities who enjoys photographing details on campus. According to Klein, "Albert Einstein probably used this knob to get to his office barely 10 years after the building was built. Forty years later, students crossed the threshold of this doorway to listen to the Feynman lectures." Where can you touch a piece of history just by opening a door?

Answer: This well-worn knob can be found on the east door of the East Bridge building.

DIRTY WORK

On the grounds of San Marino's Huntington Library, Art Collections, and Botanical Gardens—in the private, half-acre Huntington Ranch area—nearly two dozen middle and high school students spent this past summer measuring the levels of nitrogen in the soils around them to help the ranch determine whether its dirt is up to the challenge of growing an urban garden. This hands-on research experience was part of the Community Science Academy @ Caltech, which is affiliated with Caltech's Center for Teaching, Learning, and Outreach. At left, James Maloney (MS '06), one of the two codirectors of the CSA@Caltech program, helps high school student Kate Samaniego gather soil samples for testing. Other projects involved conducting experiments on ant behavior, and designing and building sensor-carrying remote-controlled powered kites, which the students flew over the library grounds. —*JA*

FACULTY FOOTNOTES

There are approximately 100 billion neurons in the human brain—and the growth, development, and death of these neurons are controlled by thousands of genes. Sorting out how changes in these genes and neurons can lead to changes in behavior seems like a tall order, but that's exactly the problem that biology research professor Carlos Lois is interested in.

- **His work uses songbirds as a model organism for the study of schizophrenia and autism:** "The advantage of working with birds is that they have this very natural behavior—singing—that in many ways is very similar to speech learning in humans. First, they have to listen to an adult tutor—the father bird—and after they listen, they practice until they can make a copy of the song that is very similar to what the father makes. There are not that many other animals that have this vocal learning. In humans there are a few communication-related genes that, when mutated, are associated with schizophrenia and autism. By studying mutations in those same genes in songbirds like zebra finches, we can learn how those mutations affect the bird's ability to communicate with others—one characteristic used to diagnose these disorders."

- **When he first came to Caltech to do a postdoctoral fellowship in David Baltimore's lab, he didn't have a driver's license:** "When I was growing up in Spain, I lived in a big city and I didn't need a car. Then I lived in New York and Boston. I came to Pasadena to do my postdoc and I was 28 years old and I didn't know how to drive. I thought, 'I'm sure I could do fine with a bicycle.' I even went to Manhattan Beach, Santa Monica, and Zuma Beach on my bicycle, but then I decided that was enough, and I got my driver's license."

- **He loves the movies:** "I really like any sort of fiction—like novels, short stories, and especially movies. From 1986 to 2007 I'd say I watched an average of four movies every week. But when my son was born in 2007, it went from four movies per week to four movies per year. So now I mostly read fiction in novels and short stories."

Insider Info

Our graduate students smiled through two days of **97°** heat while we shot the photographs featured on the cover and throughout the magazine. Read their stories on page 10.

Southern India receives, on average, more than **2,000** hours of sunshine a year, making it an ideal test location for Caltech-built solar toilets. Go to page 22 for more info.

16 graduate students are currently working toward dual MD/PhD degrees through joint programs with the medical schools at UCLA and the University of Southern California. Learn more on page 9.

RESEARCH UPDATE:

Solving the Nuclear Pore Complex

In the spring 2015 issue of this magazine, we wrote about André Hoelz, who is using X-ray crystallography to solve the architecture of one of the most elaborate structures in biology, the nuclear pore complex ("X-ray Vision," *E&S,* Vol. 78, No. 1). Recently, a team led by Hoelz, assistant professor of biochemistry at Caltech, reported solving another crucial piece of that puzzle.

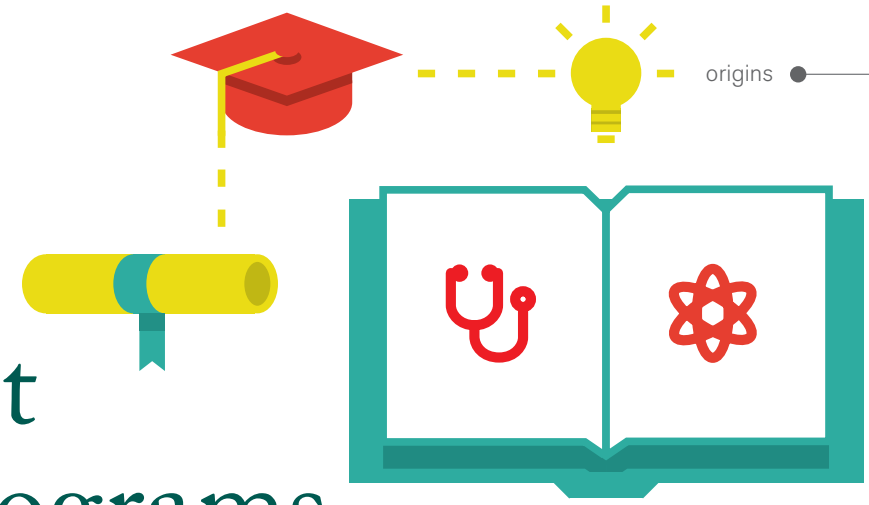
The nuclear pore complex (NPC) acts as a cellular gatekeeper that controls molecules trying to enter or exit the nucleus, the heart of eukaryotic cells where, among other things, genetic information is stored.

For decades, scientists have been trying to figure out how the NPC can be such an effective gatekeeper—keeping out the cellular riffraff while helping to shuttle certain molecules across the nuclear envelope. This is important at least in part because the NPC is targeted by a number of diseases, including some aggressive forms of leukemia and nervous system disorders.

In a paper published in *Science Express* on August 27, the team reported that they have solved the architecture of the pore's inner ring, a subcomplex central to the NPC's ability to serve as a barrier and transport facilitator. Hoelz and colleagues had previously described the atomic structure of the outer rings; now that the architectures of the inner and outer rings of the NPC are known, getting an atomic structure of those combined is "a sprint to the summit," says Hoelz.

"When I started at Caltech, I thought it might take another 10, 20 years to do this," he continues. "In the end, we have really only been working on this for four and a half years, and the thing is basically tackled. I want to emphasize that this kind of work is not doable everywhere. The people who worked on this are truly special, talented, and smart; and they worked day and night on this for years."

Ultimately, Hoelz says he would like to understand how the NPC works in great detail so that he might be able to generate therapies for diseases associated with the dysfunction of the complex. *—KF*



A HEALTHY START:

Building Joint MD/PhD Programs

Science and medicine, it would seem, have always gone hand in hand. But for centuries, they were actually two very disparate fields. Identifying a need for "investigators who are well trained in both basic science and clinical research," the National Institutes of Health (NIH) created the Medical Scientist Training Program (MSTP) in 1964 to help streamline completion of dual medical and doctoral degrees. The purpose of developing this highly competitive MD/PhD program was to support "the training of students with outstanding credentials and potential who are motivated to undertake careers in biomedical research and academic medicine."

Recognizing Caltech's strength in the biological and chemical sciences, UCLA—which first established an MSTP in 1983—formed an affiliation with the institute in 1997 to offer an average of two students the opportunity to perform graduate research at the partner school through the MSTP; PhD thesis work is done at Caltech for UCLA medical students, and when completed they return to UCLA to finish their MD studies.

The vast majority of alumni who have completed their postgraduate training are actively involved in biomedical research as physician-scientists at outstanding research institutions across the country. Although the MSTP represented the first formal affiliation between UCLA and Caltech, the success of the combined UCLA-Caltech MSTP spearheaded and served as a model for several other joint efforts that benefit from the complementary strengths of the two institutions, including the Specialized Training and Advanced Research (STAR) fellowship program for physician-scientists, and the Institute for Molecular Medicine.

A joint program with the University of Southern California soon followed. In 1998, the Kenneth T. and Eileen L. Norris Foundation awarded Caltech funding to support a joint MD/PhD program with the Keck School of Medicine of USC.

The grant established the Norris Foundation MD/PhD Scholars Fund, which supports Caltech PhD candidates from Keck. Administered by Caltech in cooperation with USC, the program accepts two students each year. As with the UCLA program, students spend their first two years in medical school, taking preclinical science courses, with summers spent at Caltech gaining exposure to the academic research environment. They then come to Caltech, spending three to five years on their PhDs before returning to their medical school for the final two clinical years.

The late Caltech biologist Paul Patterson, who passed away in 2014, was instrumental in developing the joint degree program. He believed that Caltech graduate students should also have an opportunity to explore their work in a clinical setting.

"Paul showed creativity both in curriculum development, in student mentoring, and in bringing the Caltech faculty together to support a program that was in collaboration with another major institution," says Richard Bergman, director of the Cedars-Sinai Diabetes and Obesity Research Institute, who helped Patterson form the initial collaboration with USC. "His contributions in this regard educated several generations of students who, today, continue to make important contributions to medical science. This was a great legacy of Professor Patterson."

Additional funding for students in the MD/PhD programs has come from a provost-directed endowed fund called the W. R. Hearst Endowed Scholarship for MD/PhD Students; from the Lee-Ramo Life Sciences Fund; and through lab support for medical research from the W. M. Keck Foundation Fund for Discovery in Basic Medical Research. The Division of Biology and Biological Engineering also provides support to students and scholars who are headed for careers in medicine through an endowed fund from the Walter and Sylvia Treadway Foundation.

Since the start of the two MD/PhD programs, 64 students have been accepted to work toward dual degrees, and 40 have received PhDs from Caltech.

SEEKING A BALANCED EQUATION

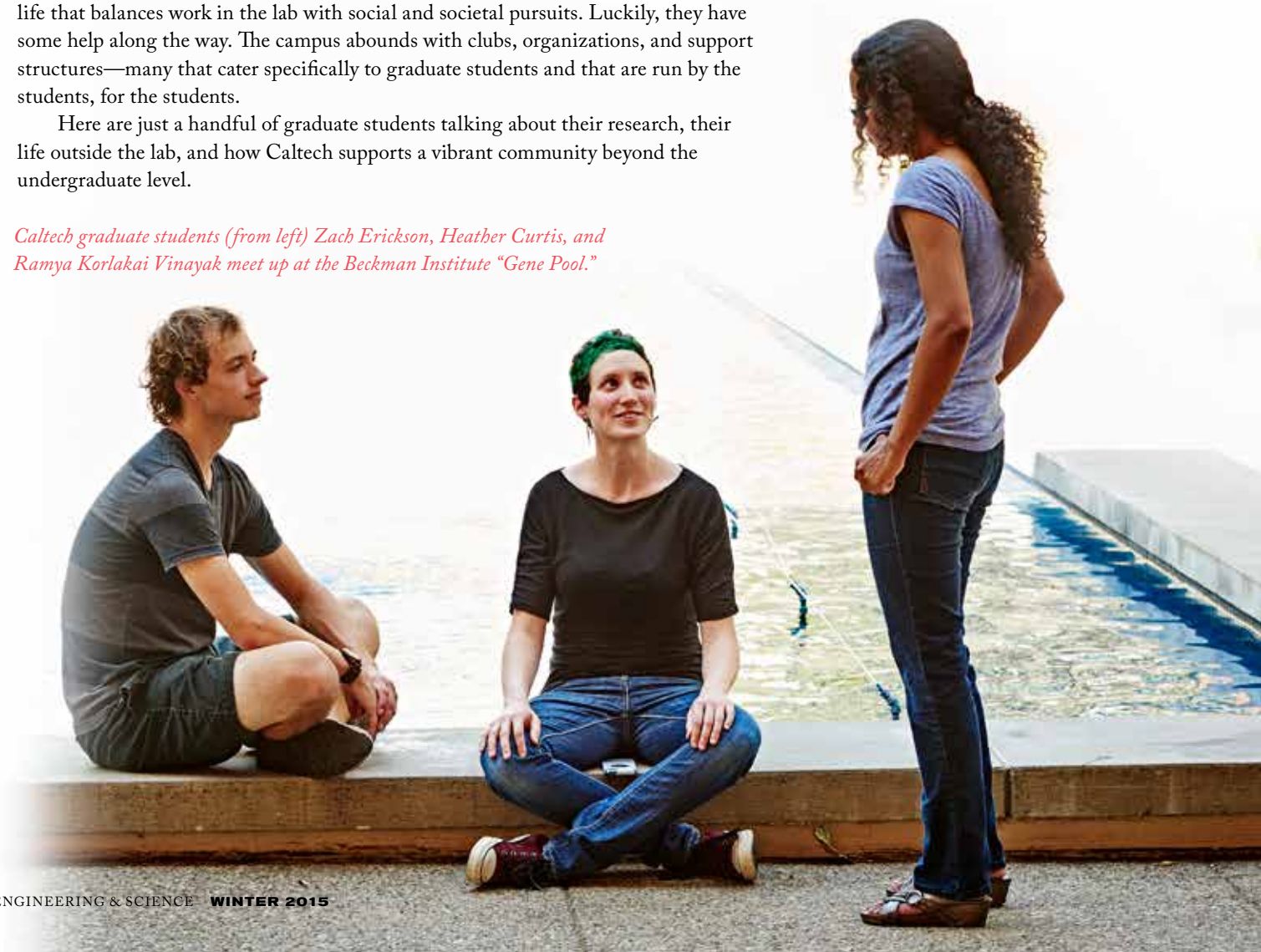
By Katie Neith

Graduate students are tasked with a nearly impossible feat: spend seemingly endless hours doing research in the lab, complete at least a few years of coursework, study for and pass the dreaded qualifying exam, assume teaching assistant responsibilities, and of course—the be-all, end-all source of grad student grief—write and successfully defend a thesis. On top of all that, many PhD students at Caltech are in their 20s and 30s, formative years in which they are working to create a path toward careers they love, developing long-term relationships, building a community of friends, and filling nonwork hours with activities they enjoy. In other words, they are also working to build a fulfilling life while reaching their academic goals.

At Caltech, more than 1,200 students—most working toward their PhDs, as only a handful of master's programs are offered—are pursuing not only academic excellence in six different divisions, but hoping to reach beyond their research to create a multifaceted life that balances work in the lab with social and societal pursuits. Luckily, they have some help along the way. The campus abounds with clubs, organizations, and support structures—many that cater specifically to graduate students and that are run by the students, for the students.

Here are just a handful of graduate students talking about their research, their life outside the lab, and how Caltech supports a vibrant community beyond the undergraduate level.

Caltech graduate students (from left) Zach Erickson, Heather Curtis, and Ramya Korlakai Vinayak meet up at the Beckman Institute "Gene Pool."



HEATHER CURTIS, second-year graduate student in developmental biology
Hometown: Grapevine, Texas
Research: Curtis is studying the directional cues that guide migrating cells during fly development.

Theater Arts at Caltech, or TACIT, typically produces and performs **2 OR 3 PLAYS** each academic year. A musical parody based on *Star Trek* and called **BOLDLY GO!**—written by a grad student in theoretical physics, Grant Remmen, and his brother, Cole—is expected to debut in early 2016.

My work involves live imaging in Drosophila *embryos, and I am learning some pretty neat tricks to visualize transient phenomena. Currently I am working on two methods of visualizing polarized receptor-mediated endocytosis within a group of migrating cells because I suspect that it contributes toward directional migration.*

I lived in Dallas, Texas, and New York City before coming to Caltech. Both cities were great, but it was time for something totally different. That is why when I saw parrots and mountains from the Caltech campus I knew that I could not resist coming here. Apparently the parrots spend their summer days happily munching on tree fruits right outside my lab making the most amusing noises. This place is a paradise!

My first year here I was involved in two Caltech theater performances, Alice Through the Wormhole *and* Two Degrees. *The first was a super funny, original musical spoof on academia, and the second was a serious play-reading meant to educate the audience about global warming and science advocacy. Before Caltech I didn't know plays about science existed! I have made many friends from Theater Arts Caltech, or TACIT, and look forward to the many plays to come.*

What I look forward to most each week is a club that my friends and I hold called The Bioengineering Boba-Talks. It's a combination of all the best things! We come together and take turns informally presenting our current or past research for an hour, and then go out for boba tea or ice cream!

DOROTHY PAN, fourth-year graduate student in chemistry, sixth-year MD/PhD student
Hometown: Saratoga, California
Research: Pan makes nanoparticles for the targeted delivery of therapeutics to tumors. In particular, the therapeutic she is trying to deliver is small interfering RNA (siRNA), molecules that researchers believe have the potential to knock down genes associated with diseases like cancer and macular degeneration.

The Catalina apartments, or the Cats, are basically graduate student dorms but in the form of **199** fully furnished apartments. Approximately **450** students call the Cats home, and there is always a waiting list to get in. The popularity is likely due to the packed social calendar organized by the residential life coordinator, **3** Resident Associates, and **6** Catalina Community Associates.

Nanoparticle drug delivery is exciting because the principal investigator I'm working with, Caltech chemical engineer Mark Davis, has already translated two therapies from the lab to the clinic, and has shown that they are incredibly effective yet have few adverse effects. This makes a huge difference to the quality of life for patients by allowing them to continue their normal activities while being treated for their disease.

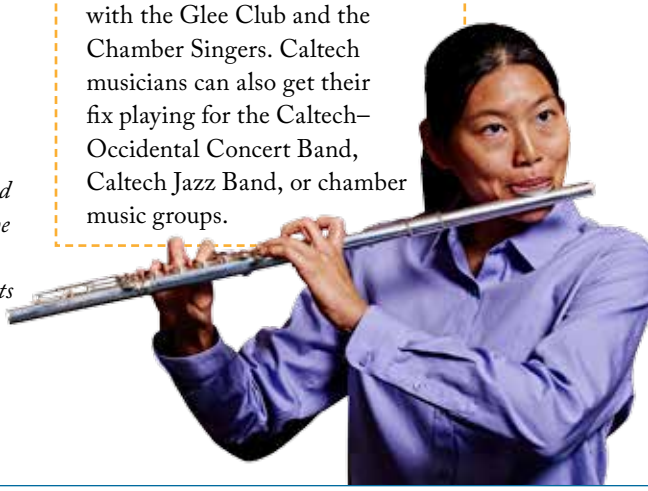
I am an MD/PhD student, so where I would be doing my medical training was as important to me as where I would be doing my graduate work. As a medical student at the University of Southern California (USC) training mainly at the Los Angeles County + USC Medical Center, I am exposed to patients from many different backgrounds with interesting illnesses and am also able to contribute a lot to their care directly.

The first time I met people at Caltech who weren't in my lab was at a Catalina community associate (CCA) dessert night when I started working the summer before first year. I have been a CCA since then, and am currently a resident associate (RA) in the Catalina apartments. We plan a variety of academic, athletic, cultural, and social events for the community that allow the students to meet each other, especially fellow students outside their department or lab, over food or a shared interest.

LEARN MORE about MD/PhD programs on page 9.

I've played the flute and piccolo in the Caltech-Occidental Symphony Orchestra ever since my first year here, and occasionally also play in chamber ensembles or at other events around campus. I have also volunteered to play music in nursing homes, homeless shelters, and hospitals. Music is an artistic, creative, and emotional outlet, and also often touches the lives of those for whom I perform.

The Caltech-Occidental Symphony Orchestra rehearses once a week and performs **3-4 MAJOR CONCERTS** a year, including one combined with the Glee Club and the Chamber Singers. Caltech musicians can also get their fix playing for the Caltech–Occidental Concert Band, Caltech Jazz Band, or chamber music groups.



ZACH ERICKSON, third-year graduate student in geological and planetary sciences
Hometown: Anoka, Minnesota
Research: Erickson uses measurements from autonomous underwater vehicles (AUVs) called Seagliders, which his group deploys into the Southern Ocean for months at a time to characterize phytoplankton blooms and estimate the amount of carbon dioxide these microorganisms export as biomass into the ocean interior.

In April 2015 I went on a research cruise to Antarctica to pick up our Seaglider, which we had deployed the previous December. We saw numerous penguins and whales, but my favorite was the icebergs—towering chunks of ice, often many times larger than our ship, surrounded by the clearest blue water you've ever seen.

In choosing Caltech, I wanted a place with scientific rigor but also a strong graduate student community, where I could engage in extracurricular activities and develop myself in ways beyond simply doing good research.

This year I was elected president of the student club SEPAC (Science & Engineering Policy at Caltech), which educates the student body on how to become engaged and involved in policy decisions that impact their research. We hold monthly discussion groups, bring in faculty and guest speakers, and host workshops.

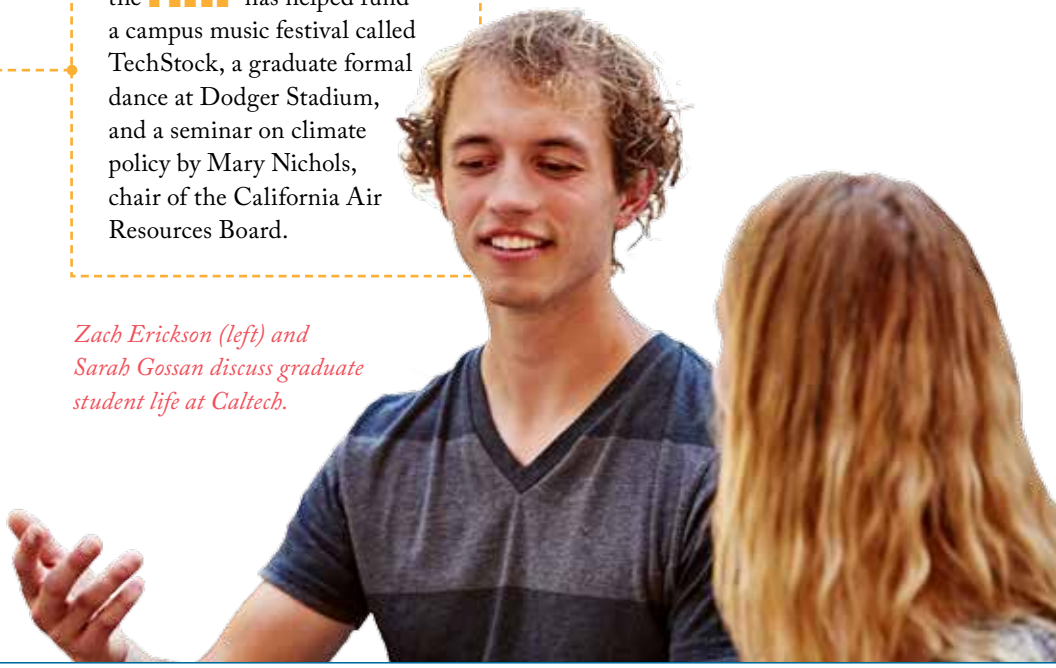
I cofounded the Caltech bikeshare program through funding provided by the Moore-Hufstedler Fund because I wanted to encourage people to bike places instead of driving. Now, anyone with a Caltech library card can check out a bike at the Sherman Fairchild Library just as they can check out a book. We are excited to bring convenient bicycle access to the whole Caltech community and hope to see many more people using bicycles to get around Pasadena!

I started playing piano when I was 4 and horn at 14, and have been involved as a musician all my life—even double majoring in music as an undergraduate. I can't imagine a life without making music and am thankful for all the new friends I meet through the Caltech band, orchestra, and chamber music programs.

The small size of Caltech makes it unusual among graduate schools. There is little hierarchy here, so if I need to talk with the director of security operations about bike security, or the director of sustainability programs about a question I have about water usage, or the alternative transportation coordinator to ask about improving bike-commuting incentives, I can often literally walk into their respective offices without an appointment and ask my question or make my suggestions.

Caltech has graduate students working all over the world. In addition to research cruises to places like Antarctica and Tasmania, there are graduate researchers at **CERN**, the South Pole, and ETH Zurich, to name a few.

THE MOORE-HUFSTEDLER FUND is an endowment established to increase the quality of undergraduate and graduate student life at Caltech. In the past year, the **MHF** has helped fund a campus music festival called TechStock, a graduate formal dance at Dodger Stadium, and a seminar on climate policy by Mary Nichols, chair of the California Air Resources Board.



Zach Erickson (left) and Sarah Gossan discuss graduate student life at Caltech.

RAMYA KORLAKAI VINAYAK
(MS '13), PhD candidate in electrical engineering
Hometown: Sagar, India
Research: Ramya works on building optimization algorithms for learning useful information from big data with the aim of making reliable and efficient predictions in various fields—from astronomy to bioinformatics.

As an undergrad I found using mathematical models to understand the laws of nature and using these fundamental ideas to build engineering systems very exciting. A lot of interesting signal processing, information, and communication theory that I learned as an undergrad are behind the algorithms that make the mobile phones actually work. Now I use the ideas from these fields to work on machine learning algorithms to make them reliable and efficient in processing data.

One of the nice things about campus is that the Graduate Student Council, International Student Programs, Caltech Center for Diversity, and Caltech Y, by organizing various events ranging from parties to camping trips throughout the year, help foster a sense of community. Also, I live in the Catalina graduate apartments where we also have a lot of events. As grad students we all tend to get busy with our research and get confined to our labs. I find these events really help me to relax and meet a diverse set of graduate students who work on different areas of research.

I think what is unique about Caltech is its size. It is very easy to interact with grad students from various departments. I am in electrical engineering, and at any event I attend on campus I meet students and professors in biology, physics, mathematics, chemistry, geology, etc. Knowing about the exciting cutting-edge research in the other fields of science and engineering is intriguing and enriching.

The **CALTECH Y** is an independent organization formally affiliated with Caltech that offers hundreds of opportunities to get involved within

5 DIFFERENT

types of programs: educational, outdoor adventures, community service, social activities, and cultural events.

ALICIA LANZ, sixth-year graduate student in physics
Hometown: Tustin, California
Research: Lanz is part of a team developing the Cosmic Infrared Background Experiment 2 (CIBER-2), a rocket-borne instrument specifically designed to study the extragalactic background light, which contains light from the earliest stars and galaxies in the universe.

LEARN MORE about the Caltech Center for Diversity on page 28.

I love the idea of space. I grew up reading science fiction, which left me with a sense of space imbued with wonder and potential. Learning the formal science and math of physics and cosmology has only heightened my appreciation and fascination. I love that we mere humans can use our senses and our minds to study everything from the world around us to the history of the universe long before our existence.

A practical factor that influenced my decision to attend Caltech was the proximity to my family, specifically for the child-care help they generously provide for my two young daughters. It would be much harder to balance parenting with research and student involvement without them.

I really appreciate that many organizations on campus offer wonderful programming that helps build community. It can be lonely in the lab, and many majors do not organize much in the way of social activities. I'm involved in the Women Mentoring Women program at the Caltech Center for Diversity, which provides opportunities for personal and professional development. The Graduate Student Council (GSC) does a great job of hosting both academic and social events throughout the year, and it's really fun to meet brilliant people in other areas of science who value service and work to create community.

This year I'm the secretary of the GSC. I'm organizing a yearlong series of events around the theme "Exploring Nonacademic Careers" for graduate students and postdocs, in conjunction with many other groups and organizations on campus. Through workshops and industry panels, participants will be able to identify at least one industry with a good fit and know the procedure for being a competitive applicant.

One really unique aspect about studying at Caltech is that graduate students here are often given a lot of autonomy. We are given access to many tools, many ideas, and many potential collaborators with few limits on what we should do or how we should go about doing it. This allows for much more impactful research than is achievable through other models, and such minimal direction is great for creativity and new ideas. Sometimes I can hardly believe I get to launch a rocket to try to understand a bit more about the history of the universe!

38 STUDENTS are elected each year to uphold the GSC's mission to "work to maximize the quality of life for the graduate student community at Caltech." One of the GCS's biggest social events is on Thanksgiving, when more than **500 PEOPLE** traditionally gather together for a celebratory meal.

SARAH GOSSAN, PhD candidate in physics
Hometown: Bristol, England
Research: Gossan's research aims to use gravitational wave observations to infer the physical processes occurring inside core-collapse supernovae.

Core-collapse supernovae are giant explosions in space that happen when massive stars die—pretty much the coolest thing ever! Our simulations, however, sometimes have trouble exploding. It's a field of research where there are a lot of unanswered questions, and with Advanced LIGO having come online in September 2015, we now have a chance to observe core-collapse supernovae in a way that's never been done before. This is groundbreaking research that is so phenomenally exciting.

I remember one of my first days at Caltech, I walked past three Nobel Prize winners having lunch at the Athenaeum—it totally blew my mind, and to be a part of the history of this institution? I feel incredibly privileged and honored to be able to do cool science here.

I think my favorite moment so far would have to be the LIGO panel that I was on with Rana Adhikari and Kip Thorne. We answered questions on the science behind Advanced LIGO and the astrophysical sources that we might expect to see. Kip has been an idol of mine for as long as I've wanted to be involved in physics, and to sit on a panel of experts alongside him? I was so humbled by the experience, and it has been the highlight of my career so far!

SIDDHARTH JAIN, third-year graduate student in electrical engineering
Hometown: Chandausi, India
Research: Jain is working to understand the role of duplications in the evolution of DNA.

OASIS is just one of more than 10 international student organizations. In 2014–2015, 60 percent of applicants and **42 PERCENT** of the graduate population were non-U.S. students. For more than 10 years, the top **5 COUNTRIES** that grad students hail from are China, Canada, South Korea, India, and Taiwan.

There are several interesting information-theoretic and combinatorial problems that arise in my research area. I have always been excited about these theories, and my research gives me an opportunity to use them to understand something about DNA evolution or, in other words, life.

Besides research, I am involved with OASIS, which is an Indian subcontinent organization that organizes several programs representing various aspects of the subcontinent culture. We celebrate several subcontinental festivals, organize potluck dinners, and do movie screenings. We have a Diwali show and annual show where we have dance, music, skits, poetry, and a subcontinental dinner. It gives us an opportunity to showcase our culture to the whole Caltech community. It is always a nice feeling when you showcase your culture to others, as it gives them a chance to learn about it and also to appreciate it.

From childhood, I have been passionate about cricket. I am involved with the Cricket Club at Caltech, which officially started in 2014. Before that, we just brought our own stuff and practiced. Now, we have matches or practices every week during the fall, winter, and summer terms. I play the role of medium-paced bowler for my team. It was very exciting to win a university tournament that we played in the spring 2015 term against UC San Diego and UC Irvine.

Both of these activities have made my experience at Caltech very enriching. By being involved with OASIS, I learned about organizing shows and about logistics, since I had never done this at such a level in the past. By playing with and against several experienced players both inside and outside Caltech my cricketing skills have improved. More importantly, I have made many great friends and got experience working with a team due to these activities.

There are more than **100 STUDENT CLUBS** and sports organizations on campus, with interests ranging from juggling and alpine climbing to entrepreneurship and robotics.

PETER HUNG (BS '08), eight-year graduate student in applied physics, who at press time was set to defend his thesis in January 2016
Hometown: Hong Kong and Arcadia, California
Research: Hung does mass spectrometry and inertial imaging.

In our lab, we shoot molecules of different sizes and shapes at really small mechanical resonators—tiny bridges almost 1,000 times smaller than the width of your hair—and use the change in the resonant frequency (how fast these bridges are vibrating) to reconstruct the shape and mass of the molecules that we're shooting.

To me, it is absolutely amazing how changes in the vibration speed of these tiny bridges can allow us to determine the shape and size of some unknown molecule, which may one day help us to detect cancer and other harmful cells.

I've also been involved with the Graduate Student Council, serving as the treasurer for two years, and the Graduate Honor Council, which helps uphold the Honor Code. I am currently student president of the Caltech Y, and I chaired the Graduate Orientation Planning Committee, serve on the Caltech Project for Effective Teaching planning committee, and was the volunteer and student coordinator for the first TEDxCaltech in 2011. I also founded the Caltech Science Olympiad Club.

I'm extremely honored to be the inaugural recipient of the R. Bruce Stewart Prize for Excellence in Teaching Physics. It has been an absolute delight to work with so many spectacular students, both in classes and in research. I have personally had a number of role-model TAs and professors at Caltech who will do literally everything to help students learn, like coming in at 7 a.m. or staying until past midnight to answer questions or designing experiments to demonstrate strange theories and foreign ideas so that we can see them with our own eyes. The most rewarding part of teaching has been using different methods to explain a new concept to the students and then seeing the sparkle in their eyes when all of a sudden everything just clicks. E&S

The Caltech Project for Effective Teaching helps members of the Caltech community, including graduate teaching assistants, become

EFFECTIVE EDUCATORS

through seminars on best practices, practical training, an improved understanding of pedagogy, and teaching resources on campus.

The Graduate Honor Council (GHC) is the official student group that reviews cases of alleged coursework Honor Code violations, and is led by two chairs. When considering Honor Code violations, the chairs will select

7 MEMBERS

of the GHC to hear the case.

Graduate student Peter Hung (center) relaxes on campus with some of his peers.

INVENTING ROMANCE

By Katharine Gammon

Two Caltech grad students, Alex Pai and Betty Wong, found inspiration in a dating spat to spin off a new product—and they're taking their love for innovation to new heights.

Love can strike at the most unusual times—just like the inspiration to invent something new. Last year, electrical engineer Alex Pai (PhD '15), then a graduate student, was pining for fellow graduate student Betty Wong. Although the two had both grown up in Northern California and attended UC Berkeley, they had met for the first time at Caltech. Pai spent months trying to woo the biochemist, even employing his engineering skills to handcraft a tech-savvy necklace for Wong. In the end, however, it was a simple home-cooked Valentine's Day steak dinner that won her over.

But early in the relationship, Wong started to notice a persistent problem when she spent time with her boyfriend. If she got up to use the bathroom in the middle of the night, she'd inevitably run the risk of falling into the toilet because the seat was up.

Then one night she got up and noticed a glow coming from the commode. Pai had painted the inside of the toilet lid with glow-in-the-dark paint so she'd know it was safe to go.

"It was such a simple thing," says Wong. "I don't have to change my habits and he doesn't have to change his habits." On that night, Wong said her admiration for Pai's creativity grew, and an idea took hold: they should share this product with the wider world.

From that toilet seat, the duo created Potty Glo, photoluminescent adhesives that give off light and let people know when the toilet seat is down. The stickers, made with strontium aluminate, glow for up to 12 hours after receiving 30 minutes of artificial or natural light. After doing some research, Wong and Pai say they chose strontium aluminate because it's a newer photoluminescent chemical that can give off light 10 times longer than the traditional zinc sulfide used for glow-in-the-dark stickers.

There are potential health benefits from using Potty Glo rather than, say, a nightlight, the pair says. The stickers shine a pale green light, which is not as disruptive to sleep cycles as blue light—the kind that comes from smartphones, television screens, and most nightlights. Sleep disruption can throw off the body's circadian rhythm, an effect that has been linked to diabetes, obesity, and depression, among other health problems.

The couple went through five iterations of the product, tweaking and perfecting the design before putting it out on Kickstarter. The campaign raised more than $3,000—enough to turn their little idea into a real product. Wong drew the designs for 10 different types of stickers, from a chubby penguin to the anglerfish pictured above, after getting requests from parents to make kid-friendly designs.

One might think that two graduate students, already swamped with research work, would struggle to find time to be entrepreneurs. But Wong and Pai jumped into the work of business with both feet. They feel the experience has brought them closer together than most couples in the first year of dating—and probably closer than most business partners.

"You can't always get the emotional support from a business partner," says Wong. "When I would feel down about the challenges, he would be there to pick me back up."

Between Potty Glo and their graduate studies, they have little time for doing anything else, so the business became a way of spending quality time together.

"This is our Netflix," says Pai. "This is what we do for fun, at midnight, when the research is done for the day."

Inspired by their first successful collaboration, the duo was up for more inventing when they found out about NASA's International Space Apps Challenge. The two-day hackathon in April 2015 involved nearly 1,000 teams of technologists, scientists, entrepreneurs, developers, and students collaborating to design innovative solutions for global needs, from mapping clean water on Earth to aggregating data about asteroids. Wong and Pai assembled a team of engineers and designers from Caltech and other institutions to tackle the issue of growing food in space during a two-week project period that culminated in the hackathon.

The team came up with the concept of AstroGro, a 3D-printed pod integrated with artificial intelligence to grow a renewable plant food supply for a future mission

The couple recruited a team to produce AstroGro, an open-source project for self-sustained plant growth. The AstroGro pod (below) has many high-tech features such as environmentally adaptive lighting, hydration sensing, light spectrum control, and wireless connectivity.

to Mars or beyond. They developed smartphone software and an interface to simplify growth conditions by determining the hydration and lighting requirements of a specific plant and then adjusting accordingly, using LED lights to provide energy for the plants to grow. The lighting system detects ambient lighting and supplements the light as necessary, and light cycles are optimized depending on the plant variety and age.

Though the two admit that they are just starting to scratch the surface of plant biology in space, the project was a regional first place and international finalist for the Galactic Impact award at the end of the competition, and, as an added bonus, Ultimaker, a 3D-printing company, and Advanced Circuits, a manufacturer of printed circuit boards, decided to sponsor Wong and Pai.

"We are now working with Ultimaker on an education initiative to use AstroGro as a learning tool in schools—a high-tech portable garden to promote STEM education and enhance children's food literacy," Wong says.

Still, their days revolve around the lab. When they aren't putting their minds together for innovative product development, they are both involved in different areas of interdisciplinary brain research. Pai graduated with his doctorate in June 2015, but is sticking around as a postdoctoral fellow in the Caltech High-speed Integrated Circuits (CHIC) lab of Ali Hajimiri, the Thomas G. Myers Professor of Electrical Engineering. There Pai is working on therapeutic applications for treating gliomas—fast-moving brain cancers—using a person's own immune system.

In order to guide immune cells capable of destroying tumors to their intended target, Pai and his colleagues have devised a system in which different types of immune cells are loaded with iron oxide nanoparticles, and then magnets are used to direct them within the brain. As the tumor changes or proliferates, the application can retain immune cells at specific sites and stimulate their activation.

While gliomas make up 80 percent of malignant brain tumors, traditional ways of fighting this type of cancer—surgery, radiation therapy, and chemotherapy—don't always work well and come with their own set of complications, says Pai. "By utilizing the patient's own immune cells, we hope to minimize the harmful side effects of treatment," he explains.

In a recent animal study, the process eradicated tumor cells in 60 percent of mice, and the researchers were able to show that the immune system retained a memory of the cancer cells, so it could attack them again if the cancer came back. Pai says that the eventual goal is to develop a helmet with a dynamically programmable magnetic field to guide immune cells tailored to an individual's cancer-killing needs.

Wong, who has two more years to go in her biochemistry and molecular biophysics doctoral program, is examining the brain at a molecular level in the lab of Dennis Dougherty, the George Grant Hoag Professor of Chemistry. She is studying a type of neuroproteins called nicotinic acetylcholine receptors that are believed to play a role in neurodegenerative diseases like Alzheimer's and Parkinson's as well as in addiction.

Her research uses fluorescent microscopy—which involves a special microscope that illuminates fluorescent tags on the neuroproteins to image and detail how the structures of the

molecules relate to their functions. Nicotinic acetylcholine receptors are key proteins that signal for muscular contractions upon a chemical stimulus.

That same pathway is involved in memory and learning in addition to control of movement—so when the pathway is compromised, i.e., neurons expressing these proteins become degraded, someone may have impairment of cognitive and motor functions, as in Alzheimer's and Parkinson's disease. The same protein binds the drug nicotine to mediate nicotine reward, dependence, and addiction—making it a useful target for treating both illnesses and drug addiction.

The idea is that understanding the structure better will lead to improved drug treatments for neurodegenerative diseases and addiction. "If we can better understand the molecular structure of these proteins, we can develop better candidate drugs to target them and treat related neurodegenerative diseases," says Wong.

Wong and Pai say their experiences in research have helped them think on their toes in innovation. "Research is a series of debuggings on a daily basis," says Pai. "The faster you get over those bugs, the faster you'll make progress, and being a good researcher requires mastering new skills all the time."

For example, Wong had to learn fluorescent microscopy on the fly at Caltech. At the same time, she also picked up skills in design and illustration for Potty Glo, which the couple continues to push forward. The product now has a full-fledged online store, with orders coming in from around the globe, and Wong and Pai have some ideas for new markets. For example, they have received inquiries about Potty Glo in nursing homes, where residents need a safe way to find the toilet in the dark. And this summer, they partnered with the outdoor music and arts festival Burning Man and a contractor to conduct a trial run of Potty Glo for portable toilets at the event. Lighting fixtures can't be added because portable toilets are cleaned with a high-powered hose, so Potty Glo could be a cheap and easy solution for adding a warm glow, while potentially improving people's aim and therefore the cleanliness of the outdoor facilities as well.

For now, the pair enjoy completing whatever side projects they can, including developing their STEM initiative with AstroGlo, while maintaining research as their first priority. In the future, they hope to use their experiences as a springboard for whatever venture they pursue, be it brain-related research or more.

"We hope to save more than just butts by doing work that could saves lives and projects that improve education and health," Wong says. E&S

In the future, [Pai and Wong] hope to use their experiences as a springboard for whatever venture they pursue, be it brain-related research or more.

Betty Wong and Alex Pai are pictured here with "like button" bling, 3D-printed electronic necklaces handmade by Pai at the beginning of their courtship. From Pai's perspective, the gift "was a perfect example of coming on too strong." From Wong's perspective, "it was a sweet example of coming on too strong."

Science with a Smile

By Rod Pyle

The choice of career path—from teacher to musician to engineer—often results from experiences during one's formative years. For children born after 1985, it's likely a certain bow-tied, rumple-haired figure wearing a blue lab coat figured prominently in the lives of those who went on to pursue science and technology.

"I really admire Bill Nye due to his ability to inject a lot of entertainment and fun into teaching," says Caltech graduate student Sho Takatori. He was one of those kids who grew up watching *Bill Nye the Science Guy*, the long-running and award-winning science education series that originally aired on PBS Kids. "His wacky blend of engaging science concepts, wild experimentation, and humor was very compelling. His enthusiasm really got me fired up about science."

Growing up in Sacramento, California, in the 1990s, Takatori was a loyal fan of the show's fast-paced blend of science and amusement. This appreciation would later inspire him in ways he could have never guessed. After realizing the depth of his zeal for science in high school, Takatori moved on to UC Berkeley to earn a bachelor's degree in chemical engineering. While there, he worked with the California Environmental Protection Agency to help draft regulatory policies for the California Green Chemistry Initiative, a regulatory effort to develop safer chemicals and consumer products through the principles of green chemistry.

Takatori now works in the lab of John F. Brady, Chevron Professor of Chemical Engineering and Mechanical Engineering, where his work focuses on the fluid mechanics of particles suspended in liquids. "I'm looking at self-propelled microscopic particles suspended in a solution, in an area referred to as active soft matter," he says. "I'm interested in how these tiny bodies move, and in analyzing their mechanics and dynamics."

Microorganisms often move collectively, much like swarming bees, schools of fish, or flocks of birds. Takatori is studying what he and Brady call "swim pressure," a unique pressure (or stress) required to confine or contain active bodies inside a region. This kind of research may help explain the pattern formation in all active matter, which can include both living and nonliving entities, including bacteria, certain polymers, and potentially even nanorobots. The primary requirement to be classified as active matter is simply that the particles or organisms be capable of independent motion.

In some cases constituents of active matter, such as bacteria, are propelled by their own bodies. "A perfect example is *E. coli* bacteria," Takatori says. "They are only a few microns in size, yet are still able to move using a whiplike appendage, or flagellum." But in other instances, such as inanimate particles that can be used for focused drug delivery in the body, there are effects that randomize motion and are independent of larger external forces such as gravity, magnetism, and thermal gradients.

While nonliving particles have different mechanisms behind their movement than living ones, the outcomes are not necessarily that different. "Movement can be biological in nature or due to inanimate interactions, but in both cases the actions can be collective. A passive inanimate object placed into a swarm will move with that swarm," he says.

Although Takatori is involved in fundamental research, there are a lot of practical applications for this kind of work, he says. By studying how active bodies such as bacteria and molecular proteins move in fluid environments, researchers can better understand how to control the motion of active systems.

"This type of information could lead to the development of new delivery systems for pharmaceuticals and to novel materials," he says.

For example, Takatori is currently working in the laboratory to fabricate soft, compressible materials that can have their size, shape, and motion manipulated by loading the material with active matter. He hopes to create materials that can compress or expand, elongate, and move on command, and that could one day be used to create micro- or nanomechanical devices and motors that could have multiple applications in medicine and other fields.

If watching Bill Nye as a kid sparked Takatori's interest in science, his enthusiasm for *teaching* was positively ignited by the performer and engineer. "To keep people engaged, especially students, you need to make science fun, and I really admire Bill Nye's ability to do that," he says.

It appears that students admire Takatori's ability to do it as well. In spring 2015, his own teaching style in a fluid dynamics class resulted in the Excellence in Teaching as a Teaching Assistant award from Caltech's Graduate Student Council.

Reactions from his students range from enthusiastic to downright effusive. "Sho is perhaps the best TA I've ever had. He explained everything with crystalline clarity and was always available and happy to help," said one. And Takatori's personal favorite? "You may have to fire Sho because he makes every other instructor look bad. I do not think it would be possible for him to improve his performance without coming to our rooms at night and whispering course material in our ears as we fell asleep."

"When I read that one, I thought it was hilarious," Takatori says. "When you get a comment like that, from even one student, it makes it all worthwhile."

Making science fun may look easy to his students, but it takes a lot of preparation, Takatori says. "A few hours before a class, I will copy all of my lecture notes by hand. Since the equations are fresh in my head, I can write them on the chalkboard without referring to notes. This way, I think I appear more confident and seem like I know what's going on from the students' perspective."

Like any grad student, Takatori has faced challenges. But one goes well beyond the norm and continues to apply pressure to his performance as a student, teacher, and researcher.

"In my sophomore year of high school, I was diagnosed with ulcerative colitis, a chronic autoimmune disease," he remembers. "I continue to have flare-ups every year or two, and they might last a couple of months. When it gets bad, I can't even leave home, and I might lose 10 or 12 pounds."

Takatori's medical condition has resulted in a lot of time spent in clinics and hospital rooms, experiences he says have contributed to his desire to help others through teaching and mentoring. But this drive also extends to the lab, where he hopes his work might enable better delivery of medicines. "I've always enjoyed teaching and public speaking, but there's something about the act of doing, of creating something that will help people, that's just incredibly rewarding," he says. E&S

SUN-POWERED SANITATION FOR A CLEANER WORLD

By Kimm Fesenmaier

In October 2012, graduate student Clément Cid attended a meeting in Durban, South Africa, with the glamorous title of Second International Faecal Sludge Management Conference. Convened by the Sustainable Sanitation Alliance, the gathering brought together delegates from around the world to discuss the challenges associated with installing and maintaining sanitation systems in locations that lack the infrastructure to provide water and electricity.

He was there to present Caltech's solar toilet, which earlier that year had won the Bill and Melinda Gates Foundation's first Reinvent the Toilet Challenge in Seattle. But Cid didn't really come to Caltech with a sanitation job in mind.

"I mean, who wants to start working with shit? You kind of have to fall into it," he points out.

In fact, when Cid began working with Michael Hoffmann, Caltech's James Irvine Professor of Environmental Science, in 2011, his research focused on the use of lithium batteries to drive water splitting for hydrogen fuel production. But when Hoffmann heard about the Toilet Challenge, he recruited Cid and others to put together a proposal for a self-contained toilet and wastewater treatment system that could safely dispose of human waste for less than five cents per user per day. In the end, his team created a system that uses a solar-powered electrochemical reactor to break down water and human waste, producing fertilizer and hydrogen gas that can be stored and used in fuel cells as backup electricity, as needed. The solar toilet's treated water can also be reused for flushing.

Through that work, Cid began to see how big a problem the lack of proper sanitation is throughout much of the developing world. According to the Gates Foundation, about 2.5 billion people across the globe practice open defecation or lack adequate sanitation facilities while another 2.1 billion use facilities that do not safely dispose of waste. This is a source of environmental pollution and contributes to the spread of diarrheal diseases such as cholera and dysentery, which kill about 700,000 children every year.

"It's one thing to read all of the numbers, but it's another to actually meet a person who lives in these places," says Cid. That's what happened at the faecal sludge conference. There, he spoke with a pit emptier, who digs up human waste in the Durban area and dumps it in a nearby treatment facility. He met with a local politician who told him that most everyone in his village defecates in a field—a practice that is not only unsanitary but also makes people, especially women and girls, feel unsafe at night.

"Hearing those kinds of stories was a real switch point for me," says Cid. "I decided there that I wanted to focus on this problem, to make it my principal project—to really try to make a change."

Since then, Cid and the rest of Hoffmann's team have built working prototypes of their solar toilet, which are housed in shipping containers and include safety features such as doors that lock and minimal lighting. The Caltech group worked with two universities and a local municipality to install three toilet systems in India and China, where people now use them regularly. There are also plans to set up several larger units with multiple stalls in South Africa.

In 2013, Cid traveled to India for the first time, spending several nights in a remote village that has only one toilet. Deepen Sinha, father of Caltech undergraduate Anusha Sinha, grew up there, heard about Hoffmann's solar toilet, and got in touch with the team to see if the system could be installed in his home town. Although the technology was not yet ready to be used in such a remote location, Cid wanted to visit the site to experience how people were living and to see how they might react to the solar toilet.

"Contrary to the popular belief that people often resist changes involving behavior, I found that the villagers were really willing to try the technology and to volunteer to take care of whatever maintenance would be needed," says Cid.

Since that first trip, Cid has returned to India three more times to install and service the sanitation systems as well as to train local people to analyze the performance of the toilets. "Because these are first-generation prototypes, they do tend to break down. And we need to keep up with their maintenance so that people know that they can rely on them," says Cid. "So even a relatively minor problem, like a broken pipe, can require that one of us flies over and fixes it." In part that's because there aren't enough trained sanitation engineers around locally to evaluate the problems and fix them. But also the first solar toilets were built with American components that use the imperial system of measurements while most of the parts available in India use metric measurements. "Sometimes I have to bring a second suitcase full of Home Depot connectors and pipes," says Cid.

Graduate student Cody Finke helped Cid install two of the toilets and did one of the servicing trips to India last year. He was struck by how unsustainable the process was in terms of maintenance.

"The technology is awesome, but there's no way it's going to work if you

The Caltech solar toilet unit on display at the 2014 Reinvent the Toilet Fair in New Delhi, India. Finke and Cid are pictured (from left) with Yan Qu, a former postdoc from Hoffmann's group who was very involved in developing the treatment system, and George Friedman (far right) of Kohler Co. The unit shown is now being used at Mahatma Ghandi University in Kottayam, Kerala, India.

don't have a plan for maintenance," Finke says. And, he points out, in the ideal situation where the team's solar toilet really takes off and is adopted on a large scale across India—a country with a population of 1.2 billion—there could eventually be as many as three-quarters of a billion units up and running. "You can't send Clement to repair 750 million toilets," he says with a chuckle.

That problem got Finke thinking, and, in talking with other members of the group, he realized that the solution could be right in their pockets. They could create a mobile-based program that would empower anyone with a cell phone—more than three-quarters of the planet's population, according to the World Bank—to serve as a maintenance engineer for one of their toilets.

Since the solar toilet unit is relatively simple, running on one reactor unit with well-understood parameters, Finke determined that he could use inexpensive sensors to monitor the status of its parts and have the system send alerts of any malfunction via cell phone text or audio message to a local operator. That operator would then go check on the toilet unit and follow step-by-step pictorial instructions on a video display that shows how to replace the malfunctioning part.

And now that the units are being built with metric parts in the country where they will be used, replacement parts can be easily accessed at local markets, eliminating the need for suitcases filled with spares.

"The cool thing about our technology is we've designed it so everything can be repaired with just a single screwdriver," says Finke. "The parts can simply be replaced."

In June 2015, Finke, Cid, and their colleagues won first place in Vodafone's Wireless Innovation Project for their maintenance solution, a

project that they have dubbed Seva, meaning "service" in Hindi. The Vodafone prize came with $300,000 in funding that will be awarded over three years. Thus far, the team has solved the self-diagnosis problem, and Finke is writing the algorithms to automate the system and interface the sensors with a mobile phone. He says they hope to begin field-testing by early 2016.

For Finke, the solar toilet and maintenance project is just the sort of thing he hoped to get involved with when he came to Caltech. Although he started out in the MD/PhD joint program that Caltech offers with USC, he decided in his first year of medical school that it wasn't for him.

"I came in wanting to make a difference in the environmental and social problems around the world—health, pollution, these sorts of things," Finke says. "But I quickly realized that, in my opinion, what was needed was better technology. For sanitation, you don't solve the problem by treating dysentery and other diseases; you need technology that will prevent people from getting those diseases in the first place."

So he dropped the medical portion and met with Hoffmann, whose website described projects aimed at developing light-harvesting materials for solar panels and determining the source of aerosol pollution. "I was interested in those projects because they both dealt with aspects of environment and health," he remembers. "But then Mike said, 'Right now we're actually working with poop,' and I said, 'That's great! It's an even more critical problem that's both environmental and social.'"

Organizations across the globe agree with Finke. In 2014, Indian prime minister Narendra Modi launched a campaign known as the Swachh Bharat Abhiyan to clean up the country, pledging that the sanitation problem in India will be fixed by 2019. One of the United Nation's Millennium Development Goals for global action, approved in 2000, has been to halve, by 2015, the proportion of the population without sustainable access to basic sanitation. While progress has been made in that direction, the UN has recommended ongoing work in this area. Similarly, the Gates Foundation says the need for better waste management in the developing world is clear. They put on the Reinvent the Toilet Challenge in part to get people talking about sanitation, a topic that can be quite taboo in many cultures.

With the Gates Foundation's support, the Caltech solar toilet team has teamed up with companies like Kohler and Eram Scientific in India, helping those companies to adopt some of the solar toilet's technology for use in other systems, including one for recycling treated wastewater at apartment buildings in India. The Techers have also formed a joint venture with a government-run environmental group in China called GIEI and an environmental engineering firm called CIES with the goal of manufacturing self-contained solar toilet units with multiple stalls for use in schools and other public places. All of the groups share a common goal to make the largest positive impact on the sanitation problem in the shortest amount of time.

As Bill Gates said after the Reinvent the Toilet Challenge, "Imagine what's possible if we continue to collaborate, stimulate new investment in this sector, and apply our ingenuity in the years ahead." E&S

Cid stands in the first-generation prototype of the self-contained toilet system he helped develop. The prototype, located in the parking lot behind Jorgensen Laboratory on the Caltech campus, helps the team test different treatment technologies and improve the solar toilet.

A BRIGHT FUTURE IN PHOTOVOLTAICS

By Jon Nalick

Carissa Eisler's first science experiment could have been her last.

When she was 7, Eisler and a friend decided to "play chemist" by mixing various noxious liquids they found in the garage. They survived without harm, but when Eisler's parents found out, she feared her days as a scientist were over.

Instead, she says, after their initial horror subsided "they had the best reaction possible: they encouraged my curiosity. From that point on, a lot of my birthday presents were science gifts—which were always used in well-ventilated areas."

In the 19 years since then, Eisler has pursued her passion for science, earning a bachelor's degree in chemical engineering from UCLA and working to earn a doctorate in the same subject from Caltech. One reason she chose to come to Caltech was her desire to work with Harry Atwater, the Howard Hughes Professor of Applied Physics and Materials Science.

After meeting him at a visiting weekend for graduate students, Eisler says she was sold on trying to get into his group. "Not only does Harry have a great intuition for picking really interesting and impactful projects, but he also is a really warm person that people love working for," she says.

Entering the Institute as a graduate student with impressive recommendation letters, Eisler quickly earned a spot in Atwater's lab, working on photovoltaics—the conversion of solar energy into electrical energy using semiconducting materials. She is part of a group tasked with developing an ultrahigh-efficiency solar-cell module that involves designing solar collectors, optical components, and electronics.

The current world record for efficiency belongs to a French industrial firm's solar-cell module capable of transforming 38.9 percent the sunlight it receives into useable

electricity; Eisler and her teammates aim to build a module that pushes that number beyond 50 percent. To achieve that ambitious goal, they have chosen to totally rethink how solar cells are designed.

At the heart of all solar cells are semiconductors—materials typically made of silicon, but also arsenic, boron, or other elements that conduct electricity under certain conditions but not others. Crucially, semiconductors are subject to the photoelectric effect, in which photons—particles of light—striking a semiconducting material knock electrons free and generate an electric current, effectively transforming light energy into electrical energy. For technical reasons, panels made of simple solar cells can only efficiently convert light from a narrow range of wavelengths, such as visible light, while failing to capture others such as infrared or ultraviolet. So to collect more energy, the panels must be made bigger.

A better way to harvest solar energy is to make sure to convert the widest possible range of wavelengths, Eisler notes. "The only way you're going to get to a very high efficiency is if you use different materials that are optimally tuned to absorb and convert different portions of the solar spectrum," she says. "You need to have one material that's really good at converting the blue light and another one to convert the red and so forth. That way you can absorb the entire solar spectrum and get the highest voltage possible for every photon you convert."

Current designs based on this approach use stacked layers of materials—each tuned to different frequencies—so that the first layer might absorb ultraviolet and visible light, the second near-infrared light, and the third infrared light, increasing the overall efficiency of the cell. But this approach requires an extraordinary degree of precision in aligning the materials at an atomic level: the layers must stack like Legos atop one another or the gaps between them may propagate as a crack throughout the material and hinder the flow of electrical current. Also, because the materials are wired in a series—like holiday lights in which a single blown bulb will darken all the downstream bulbs—the cell is often limited to the efficiency of its least efficient layer. Fine-tuning the layers to achieve the best solution is additionally complicated by the fact that the solar spectrum changes dramatically throughout the day and throughout the year, which means that what is "most efficient" is constantly changing.

To tackle those problems, Eisler's team is developing a solar cell that spreads out the different materials side by side, like lanes on a freeway. An optical element functioning like a prism splits incoming light spatially so that each color falls only on the lane best suited to absorb it. As a result, the electrical output is always maximized no matter how the solar spectrum changes over time, making the module capable of delivering far more power than other alternatives. Moreover, the design, which also enables each lane to be wired separately, has the added advantage of eliminating the holiday-lights problem.

For her part, Eisler has been working on finding the right combination of materials and design to optimize the optical element to divide light into its component parts. Her work has garnered fellowship awards and recognition as an Everhart Lecturer, an award honoring graduate students with exemplary research and presentation skills. The second prototype she helped develop, pieced together with reflecting filters and silicone concentrators, resembles the end of a fork, but made of glass.

"With each iteration, we get closer and closer to our efficiency goals," which is crucial, she says, because project funding from the Department of Energy is contingent on meeting those short-term goals. "It's stressful, but it's fun."

In the spectrum-splitting optical prototype for high efficiency solar cells pictured above, incident sunlight is divided into different frequency bands by the stack of filters. Each band of light is concentrated by a triangular silicone concentrator before conversion in the solar cell best tuned to that band.

To help balance out the stress of the job, Eisler makes a concerted effort to encourage young scientists to be unafraid in their pursuit of difficult scientific challenges. She has served three times as a mentor in Caltech's Summer Undergraduate Research Fellowships program, and also mentored an undergraduate student from Occidental College and served as a committee member for his senior thesis this May.

"I see of a lot of potential in these undergraduates, and it's important to me to foster that potential," Eisler says. "I want to make them feel that they're supported in such a way that they can learn something entirely new and not be afraid to stumble along the way. I think failure's a big part of the learning process."

At press time, Eisler had successfully defended her thesis and accepted an offer to join Paul Alivisatos's group at UC Berkeley in 2016.

"The most important lesson I've learned from Caltech is that learning itself makes life fulfilling," she says. "Caltech is full of passionate people, and being immersed in that culture makes every new challenge —scientifically related or otherwise— an exciting opportunity to learn something new. I hope that by continuing this enthusiasm, I can pass this joy onto the students I teach and mentor in the future." E&S

Vive la Difference

By Lori Oliwenstein

Once upon a time," starts Caltech vice provost Cindy Weinstein, ever the professor of English, "fifty, sixty years ago, the humanities were taught mostly by white men, as was the literature that students read: Sophocles, Shakespeare, Dickens, Zola, Faulkner. But beginning in the sixties and seventies, women and African Americans entered graduate school in greater numbers, and they were reading different things—for example, Frederick Douglass's *Narrative of the Life of Frederick Douglass* or Harriet Beecher Stowe's *Uncle Tom's Cabin*—or reading the same books but asking different questions. In doing so, diversity has brought new life—what we might think of in the scientific context as 'innovation'—to the study of literature.

"Indeed excellence," Weinstein says, "has been the result of diverse scholars entering the field, reexamining many of its traditional assumptions and developing creative interpretations or making new 'discoveries' possible. Excellence, diversity, creativity. That's what we're about at Caltech."

Jackie Barton, the Arthur and Marian Hanisch Memorial Professor of Chemistry and chair of the Division of Chemistry and Chemical Engineering, agrees. "When you ignore large portions of the population, you're missing out on all that talent. For instance, I always have a lot of women graduate students; I think of them as my secret weapon. They help my lab to do outstanding work—the best work we can do."

But does the fact that they are women actually change the questions that are asked, the research that is done? Barton, ever the scientist herself, pauses. "Well, I can't say," she finally replies. "Because I can't do the control."

What she—and many others—*can* say is that building a diverse community of students, faculty, and staff is critical to fulfilling the Institute's mission, to keeping Caltech at the top of its game.

"Diversity and excellence are symbiotic," says Caltech president Thomas Rosenbaum. "If we're not drawing people from different races and genders, then we're not getting the best and brightest, period."

"Science is based on creativity," notes Emily Blythe, a graduate student in biochemistry and molecular biophysics and the diversity officer for Caltech's Graduate Student Council (GSC). "It's that diversity of ideas and experiences that will enrich our science, that will let us do the best science."

"We need to be a destination for people whose passion is to do great science," agrees Weinstein. "Which means we need to make Caltech a place where everyone feels welcomed. If you're not worrying about or experiencing bias in the lab, you're going to do better science."

Creating Diversity

Important and honorable goals, for sure, but the reality is that they are not always easy ones to reach—especially at a school the size of Caltech, where the student population is small to begin with. Indeed, talking about diversity—in general as well as from a higher-education perspective—is a bit of a chicken-and-egg situation, says Barton. "Students need to feel like they have a community," she notes. "We need to establish critical mass, and to make sure there are enough women on the faculty as well as among the students."

Barton adds that if students don't see themselves—see people with whom they can identify—walking around Caltech when they come to visit, they are much less likely to see themselves attending Caltech. And if those students choose not to attend Caltech, of course, the next class of students—and potential faculty and staff, for that matter—will have just as hard a time envisioning themselves here.

Blythe recalls arriving at Caltech for her graduate student orientation from her small liberal arts—read: majority female—undergraduate school. "It was a bit of a shock," she recalled. "For the first few weeks, I actually felt 'different' because I was a woman."

It was that experience that prompted her involvement in the GSC's diversity programming. "We have such a welcoming community," she says. "It's important that we make sure it's open to everyone, that diversity issues don't hinder anyone's career."

Great sentiments, all, but what do they look like in practice? How do you embrace or even create diversity?

Caltech has done it, in part, by creating the Caltech Center for Diversity (CCD), run by director Eva Graham and assistant directors Taso Dimitriadis and Erin-Kate Escobar. The CCD is devoted to "supporting access, equity, and inclusion," says Escobar, who focuses on women's services and support and on gender equity. Specifically, the center aims to help provide wide-ranging access

to admissions information and other campus resources, and to support those activities that work toward the inclusion of women, as well as the underrepresented, underserved, and minority (URM) and lesbian, gay, bisexual, transgender, and questioning (LGBTQ) faculty, staff, postdocs, and students at the Institute. The CCD also provides confidential consultations, and works with Felicia Hunt, Caltech's Title IX coordinator, to ensure compliance with the 1972 federal law that prohibits discrimination on the basis of sex in federally funded education programs or activities.

At the Grad Level

To signal—and to solidify—the Institute's commitment to increasing diversity at the graduate and postdoctoral levels, in 2013 Caltech joined with UC Berkeley, Stanford, and UCLA to create the California Alliance for Graduate Education and the Professoriate (AGEP) to support the professional development of underrepresented minority students in the fields of mathematics, the physical sciences, computer science, and engineering. The four institutions have committed to increase diversity by creating programs specifically to recruit, retain, and advance URM students. According to data from the California Alliance, while there's been a gradual increase in the number of URM students over the past several decades, the numbers drop off at each step along the path to a faculty appointment, with underrepresented minorities making up 10 percent of new PhDs, 9 percent of continuing PhDs, 8 percent of conferred PhDs, 6 percent of postdocs, and only 4 percent of faculty.

So the California Alliance was created "to not only diversify our own campuses," Joseph E. Shepherd (PhD '81), Caltech's new vice president for student affairs who was, until recently, dean of graduate studies, said in an interiew about the alliance, "but also to contribute to diversity [at campuses] throughout the nation" by working to increase the number of underrepresented minorities who become faculty—and who then, by being present and visible as well as by taking active mentoring roles, will encourage others to follow in their footsteps. AGEP seeks to accomplish this by creating a community of graduate students, postdocs, and faculty members across the four California institutions, providing faculty training, and conducting research to identify exactly what factors—both positive and negative—impact a student during his or her preparation for a career in research and academia.

In 2015, AGEP—which is funded by a grant from the National Science Foundation—held its second annual mentoring and network-building retreat on the Caltech campus. Rosenbaum welcomed the group by talking about the importance of going beyond the typical image of white-coated scientists alone in subbasement laboratories, and instead recognizing that science can be—is—"this enormously convivial enterprise."

Of course, he noted, those white lab coats do exist, and that "too often and for too long [they] have been filled solely with white males." This, he said, is a problem for the science community as a whole. "We're in the people and talent business. And, a priori, if we are not attractive and we're not attracting people from all backgrounds, from all perspectives, from all experiences, we will not be attracting the best people."

The Best Ideas

Of course, not every possible path to increased diversity has to involve the creation of a center or an alliance or even a large-scale program. Some of the best ideas, in fact, can be the simplest. Take for instance, the program that Blythe is currently spearheading—one that is trying to address the so-called "small numbers problem." Caltech's individual options are small enough that a woman or URM or LGBTQ individual might feel isolated when visiting campus.

And so, Blythe says, "when graduate students are admitted, or even before, we want to bring all of them together—from all of the options—on a given weekend. We want them to see that there may not be a community in their option, but that there is a community on campus. We want them to know that they're welcome here."

But feeling welcome isn't enough; a true community is one that constantly grows and evolves to meet

its members' needs. The CCD's Women Mentoring Women program, for instance, matches postdoctoral scholars with upper-level graduate women and upper-level graduate women with first-year graduate women for a one-to-one mentoring experience.

Similarly, this past summer, the GSC collaborated with the diversity center to kick off what they hope will be a series of "Coffee and Conversation" meetings on diversity, the first of which focused on gender and diversity in science, technology, engineering, and mathematics (STEM). As a result of that conversation, Escobar says, the group came up with "a few strategies to address bias on campus." These included education around implicit bias, or the ways in which attitudes can affect our judgment and behavior at a subconscious level; training offered on bias and empathy; bystander intervention training, or training around the proper actions to be taken by those who witness, though are not involved in, troubling or harmful behavior; community building; and perspective sharing.

"It was one of the first campuswide conversations on gender and diversity in STEM," says Blythe. "We had a lot of staff and faculty come, in addition to grad students. I think people are just excited that the conversation is happening."

And while these types of discussions are happening at all levels, graduate students are coming to Caltech with a unique perspective, says Dimitriadis, whose focus at the CCD is on LGBTQ issues. "They can compare and register differences from what they experienced as undergrads," he points out. "They can help us to better pinpoint the ways we can improve."

From an Early Age

Of course, if you're trying to build diversity in science and engineering, you don't stop (or, for that matter, start) with graduate students. Caltech's administration is convinced that the pipeline to a more diverse professoriate begins not even at the figurative front door to campus, but as early in a science-interested young person's life as possible.

That's why the Institute partners with groups like Project Scientist to provide weeklong day-camp experiences to nurture the innate curiosity of girls ages 4 to 14 who are interested in STEM. It's why we partner with IEG Global Corporation to create a two-week international version of our Community Science Academy, in which young students learn core science and engineering concepts and the research skills to perform experiments and build projects around those areas relevant to their home communities' needs, such as agriculture, urban planning, and the environment.

At least some of those students, if they continue their interest in STEM, will wind up at Caltech. And once these best and brightest of students have chosen Caltech, the Institute wants them to grow, to thrive, to feel at home on campus. That was, in part, the impetus behind the Freshman Summer Research Institute (FSRI), which was created to start engaging students and building a community for them before they even begin their first year of coursework.

Caltech has also been a part of the Mellon Mays Undergraduate Fellowship (MMUF) program. MMUF is a national effort to increase the number of underrepresented students who will pursue PhDs in core fields in the arts and sciences, by working with them at the undergraduate level. MMUF fellows receive up to $10,000 in undergraduate debt forgiveness, stipends with which to pursue summer research, support to attend national and regional conferences where they can network, and mentoring by faculty members.

> "True success has to do with creating a campus environment that practices empathy and allyship."

Diversity isn't just about hitting a particular number or percentage, says Escobar. It's about who we are as a campus. "The numbers are really important and getting critical masses is really important, but true success has to do with creating a campus environment that practices empathy and allyship," she notes. "We have to go beyond just celebrating different cultures to actual empathy and understanding and inclusion."

Of course, once you've created that environment, you have to be sure people are aware—and are able to connect with—what is being offered. "We do our best to create an environment where people have access to resources, to advocacy, to allyship [allying oneself with underrepresented individuals or groups]," says Dimitriadis, "an environment where there is always support." As an example, the CCD has created a Safe Zone program, which identifies and and educates community members supportive of the LGBTQ community at Caltech.

"At such a small institution it can feel isolating for everyone on campus sometimes, no matter who you are," notes Dimitriadis. "So emphasizing those resources and the ways we can provide advocacy and allyship for each other—to enhance that climate and culture—is really important."

Blythe agrees. "That," she says, "sounds awesome." E&S

HAVE COURAGE

by Gregg Wright (BS '69)

As an undergraduate at Caltech in 1968, at the urging of our then student body president, Joe Rhodes, I became involved in a project bringing Caltech students and faculty to underprivileged Pasadena schools as science consultants. For me, and for most of the other Caltech students and faculty who participated, this was the first step into an elementary school since we were sixth-graders. I was struck by the eager enthusiasm of the third-graders I taught, and by the absolute importance of public schools, especially in contrast to the importance given them by society.

I found working with the elementary school students to be eye-opening and wrote about my experience in an *E&S* article ("OK, Teacher, What Does Living Mean?" October 1969). "To let the students lead, and switch from facts to creative thinking and learning to learn," I wrote, "a teacher must be confident enough to follow and experienced in both creative thinking and self-education. He, then, can set up the conditions for the students to experience problem solving, experiment with new approaches, and learn to learn."

Surviving Caltech as an undergraduate gave me the idea that anything is possible with enough gutting it out. After I graduated, I went on to medical school at Case Western Reserve University in Cleveland, Ohio, but I didn't lose the seed of interest in education that had been planted during my work in a Pasadena grade school. With the blessing of the dean at CWRU, I took a year off between my sophomore and junior years in medical school to get a master's in elementary education at the University of Massachusetts. After returning and finishing medical school, completing a pediatric residency and then a fellowship in school health and child development, I began my first career on the school health faculty at the University of Texas Medical Branch at Galveston. There, as part of the pediatric faculty, I taught pediatric

residents to interact with schools, an increasingly important skill for any community pediatrician facing the complexities of special education and school health. I watched many of these residents experience the same eye-opening visit to an elementary school that I had experienced at Caltech.

Later, I had an opportunity to broaden my interest in community health by returning to my home state of Nebraska as the director of the State Department of Health. I was working at the health department when the space shuttle *Challenger* blew up, killing a crew that included Christa McAuliffe, the New Hampshire high school teacher chosen to be the first "teacher in space." Because of my work in public schools, I was particularly touched by the death of that courageous teacher. In what I count as the best impulse of my life, I donated some money to begin a Nebraska Christa McAuliffe Prize for Courage and Excellence in Education—a way to honor the many courageous teachers I had worked with from Pasadena to Galveston.

With the help of many other donors, we have now awarded 29 excellent Nebraska teachers each a $1,000 prize—one each year since the *Challenger* disaster. These teachers have each demonstrated an important form of courage in their professional lives.

For example, some of our winners stood up for what was right even when others refused to do so. This includes a teacher who publicly championed the cause of "dream generation" students when nearby communities were trying to expel them, and another who jumped into a highly controversial, local low-level nuclear waste issue to help his students learn the physics of radiation—despite his principal's urging against engaging the controversy. Other winners did what was right even when it was hard. This group includes an art teacher at the state juvenile detention facility, several junior high reading teachers, and many dedicated special education teachers. Over the past 29 years, in other words, we on the McAuliffe Prize Committee have learned much about what courage looks like in Nebraska schools, and it has been inspiring.

But courage is an elusive concept. Before our experience rewarding excellent teachers for their courage, we did not have a clear idea of what makes a teacher courageous. We knew that Christa McAuliffe was courageous, boarding the *Challenger* in order to take America's students on the ultimate field trip. But we couldn't have known about the many forms of courage our winners have demonstrated.

In honor of what will be the 30th McAuliffe Prize award next spring, I am working to start two new prizes in Nebraska: one for early childhood professionals, and one for higher-education professionals. In addition, I want to organize a symposium to explore courage in many other fields. I believe that we need to honor courageous educators at all levels, because I believe that courage is needed in every corner of society.

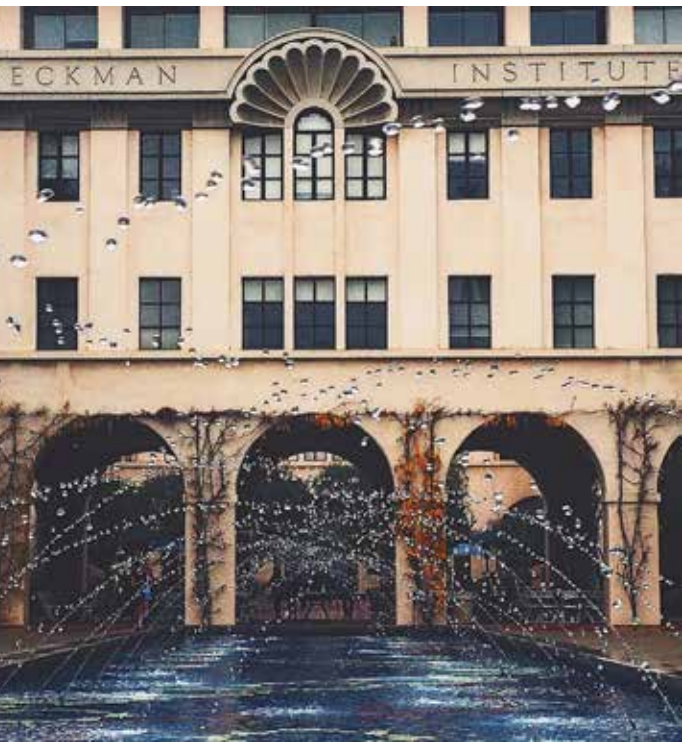
I believe that we need to honor courageous educators at all levels, because I believe that courage is needed in every corner of society.

All of this has left me wondering what courage looks like at Caltech. I think about Max Delbrück, who taught my first biology course at Caltech. Delbrück left Nazi Germany in 1937 as a 31-year-old physicist. He accepted a fellowship in Caltech's biology department that year, but returned to teaching physics at Vanderbilt. Then, in 1947—the year I was born—he came back to Caltech to pursue biology; in 1969—the year I graduated—he won the Nobel Prize in Physiology or Medicine. It must have taken courage to leave physics for biology in 1947. Perhaps it also took courage to keep teaching my class of undergraduates in 1966 when his research career was at its peak.

I think about Richard Feynman holding up the O-ring at the investigation of the *Challenger* explosion after learning that the engineers at Morton Thiokol had realized that the launch was too cold for the solid rocket booster design—even though they hadn't been able to get the attention of NASA officials to postpone the launch. That took courage. I realize that every engineer needs the courage to speak up when financial or political pressures conflict with engineering design.

In a 2006 publication marking the 20th Nebraska McAuliffe Prize, Bob Kerrey, the former U.S. senator from Nebraska, said, "Courage is not taught by a curriculum; it is caught from the example of others." Many students of Nebraska's McAuliffe Prize winners have undoubtedly "caught" their teachers' courage.

Caltech is a leader in producing scientists and engineers for increasingly complex careers all over the world. At Caltech, these future scientists and engineers come into contact with models of courage that shape their later careers. When and where does that happen? Who are the people at Caltech who are standing up for what is right even when others refuse? Who is doing what is right even when it is hard? We need to think about—and talk about—courage more often than we do. And we need to reward it when we see it. Perhaps we need a Caltech McAuliffe Prize for Courage and Excellence in Education. E&S



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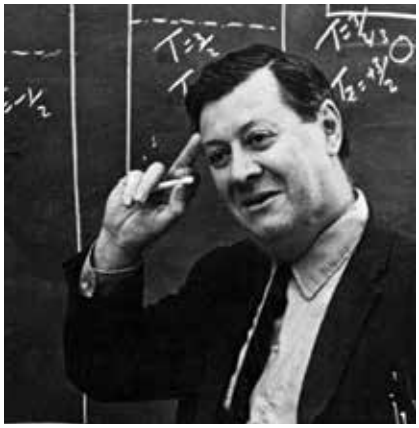
In his spare time, Michael captures the beauty of campus and shares his photography with Caltech's yearbook, the Big T.

Charles A. Barnes 1921 – 2015



Charles A. Barnes, professor of physics, emeritus, at Caltech and an expert in the study of both the weak nuclear force—one of the fundamental forces of nature—and of the nuclear reactions that produce the majority of the elements in our universe, died on August 14, 2015. He was 93.

Barnes received his bachelor's degree in physics and mathematics from McMaster University in 1943 and his master's degree in physics from the University of Toronto in 1944. He earned a doctorate in physics from the University of Cambridge in 1950. He came to Caltech as a research fellow in 1953 and became a senior research fellow in 1954, an associate professor in 1958, and a professor in 1962. Barnes retired in 1992. He was a fellow of the American Physical Society and the American Association for the Advancement of Science.

An experimental physicist who specialized in nuclear physics, Barnes performed pioneering research in two key areas. The first was in the study of the so-called nuclear weak force, which governs the radioactive decay of elements and is responsible for the fusion of protons to form deuterium. This fusion releases the energy that is the source of heat from our sun and other stars. Barnes studied the breakdown of "mirror symmetry" in the weak force, the phenomenon that causes an experiment and its mirror experiment to give different results.

Barnes was also an expert in nucleosynthesis, the formation of new atomic nuclei from simpler ones, a process that occurs on a cosmic scale in the cores of stars. In 1974, Barnes and his student Peggy Dyer (PhD '73) performed the first careful measurement of this reaction. Through his work, Barnes provided critical input in determining the final distribution of the chemical elements produced in stars—and whether the final fate of a star is to become a black hole or some other celestial object, such as a neutron star.

Barnes was predeceased by his wife of six decades, Phyllis, who passed away in 2013. He is survived by his son, Steven Barnes, and his daughter, Nancy Wetherow; four grandchildren; and two great-grandchildren.

To learn more about Barnes's life and work visit caltech.edu/news/physicist-charles-barnes-dies-47561.

James F. Rothenberg 1946 – 2015

James F. Rothenberg, chairman of the Los Angeles–based Capital Group Companies, Inc. and Caltech trustee, died on July 21, 2015. He was 69.

As chairman of the Capital Group, where he held leadership positions since 1970, Rothenberg oversaw the firm's rise to what would become the largest stock mutual fund in the world. He also served on several corporate boards, including those of Capital Research and Management Company and American Funds Distributors, Inc., and he was a portfolio counselor for the Growth Fund of America and vice chairman of the Growth Fund of America and Fundamental Investors.

Rothenberg was elected to the Caltech Board of Trustees in 2006. He chaired the board's Business and Finance Committee, served as vice chair of the Development Committee, and was a member of the Investment Committee. He has played a key role in the life of the Institute as campaign cochair and as a member of the Caltech Associates.

In March, Rothenberg and his wife, Anne, donated $15 million to Caltech to endow graduate student fellowships and support research innovation through the Caltech Innovation Initiative (CI2).

Beyond Caltech, Rothenberg served with a wide variety of nonprofits, including as director of the Huntington Memorial Hospital in Pasadena and on the boards of KCET, the J. Paul Getty Trust, and the RAND Corporation. He was a governor of the National Association of Securities Dealers from 1996 to 2002 and a member of the board of directors of NASDAQ from 1996 to 1999. Rothenberg was elected to the American Academy of Arts and Sciences in 2015.

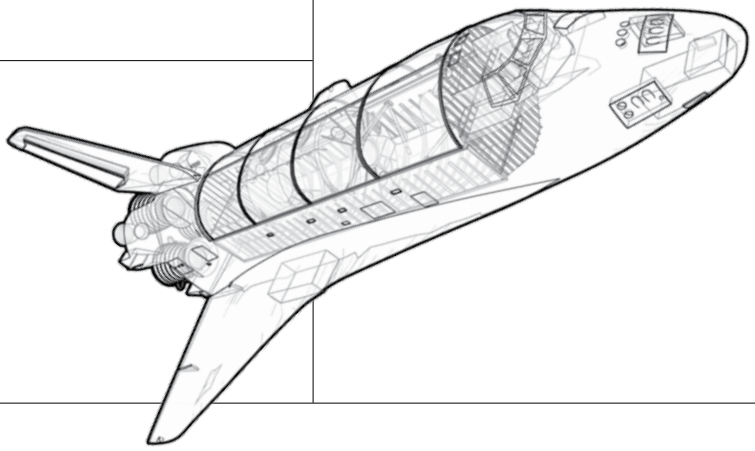
Rothenberg is survived by his wife, Anne F. Rothenberg; their three children, Catherine Rothenberg Wei, Erin Rothenberg Baker, and Daniel H. Rothenberg; and six grandchildren.

To learn more about Rothenberg's life and work visit caltech.edu/news/james-f-rothenberg-caltech-trustee-1946-2015-47401

We asked alumni: Who is the most **COURAGEOUS** teacher, scientist, or engineer you know, and why? Here's what a few of them had to say.

Salman Khan, founder of Khan Academy, has dared to make high-quality education available to the masses for free. And he is an exceptionally excellent teacher.

RICHARD FEYNMAN, who was willing to state his opinion and stand his ground on the *Challenger* disaster. His appendix to the commission report is a must-read on safety analysis.



The most courageous researcher is **SOMEONE WE DON'T YET KNOW...** someone swimming against what the rest of us "know" to be true.

Professor **IRENE PEDEN** (emeritus), University of Washington Electrical Engineering, was the first female professor in my department and remained the only woman for at least 20 years. That must have been lonely and quite frequently infuriating.

Hans Liepmann, professor of aeronautics and applied physics, was the best teacher I had at Caltech—he was unafraid to teach what he thought was important and to apply his knowledge far and wide. Also, he was a leader in bringing women into Caltech.

MY FATHER. A mathematician working tirelessly on his own, outside the academic system without any conventional encouragement or reward, motivated purely by a dream to understand vision.

I'd give the award to **Galileo Galilei.** He championed heliocentrism and scientific method in the face of the Roman Inquisition, and spent his life under house arrest.

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