Passing the Torch

By Jessica Stoller-Conrad

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

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

IN THE BEGINNING

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

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

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

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

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

NEW NETWORKS

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

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

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

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

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

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

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

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

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

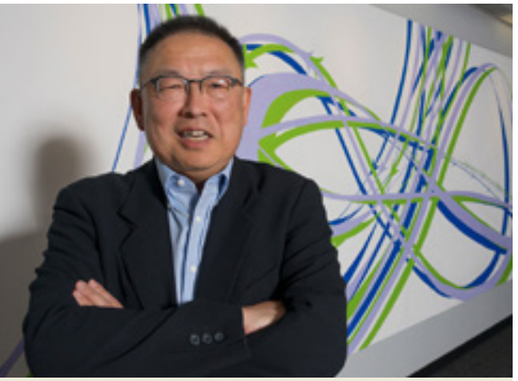
review of the safety and effectiveness of medical devices. I love what I do, and if I hadn't done a SURF project—and through SURF met a mentor who encouraged me to go to graduate school—my career might well have gone in a very different direction," she says, "so I'm extremely grateful for the opportunities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

AN INTERPLANETARY IMPACT

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

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

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



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

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

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

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

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

THE NEXT GENERATION

By spending a summer in the laboratory, students like Gorordo pick up many valuable technical skills. However, they also find the uninterrupted summer research time can be an opportunity to explore difficult questions and contribute to something much larger than a 10-week project.

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

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

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

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

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

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

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

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

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