ENGenious

ISSUE 15, 2018–19

A PUBLICATION FOR ALUMNI AND FRIENDS OF THE DIVISION OF ENGINEERING AND APPLIED SCIENCE

of the California Institute of Technology

Caltech

DIVISION OF ENGINEERING & APPLIED SCIENCE

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We invite you to learn more about the Division through our website, eas.caltech.edu.

ENGenious

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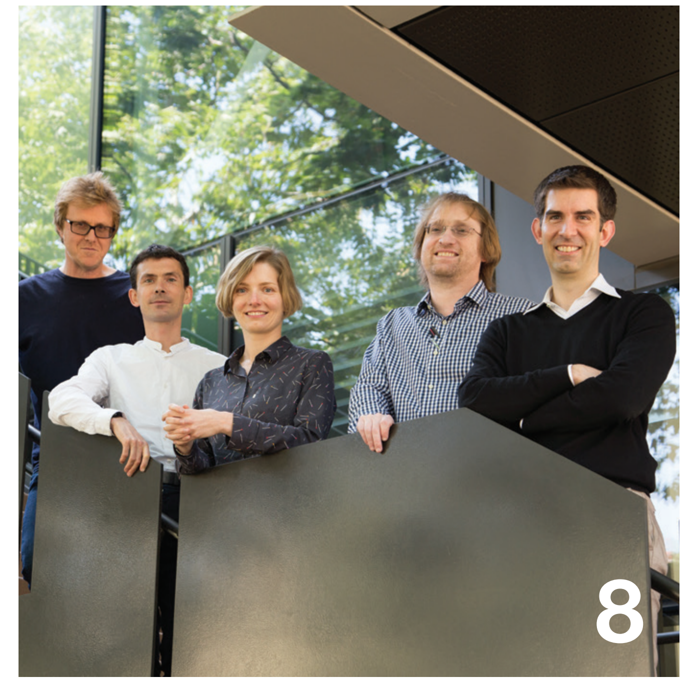
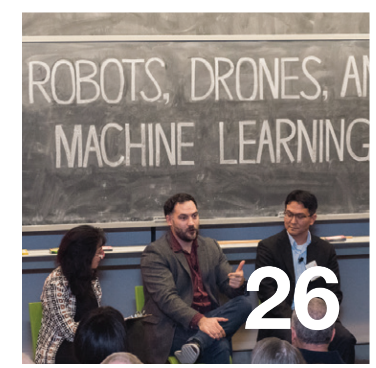
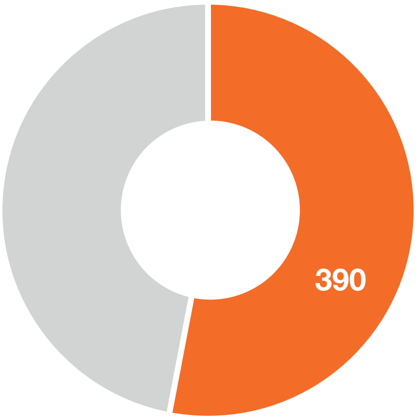
The Caltech Division of Engineering and Applied Science consists of seven departments and supports close to 90 faculty who are working at the leading edges of fundamental science to invent the technologies of the future.





The cover illustration is inspired by the work of engineers and applied scientists at Caltech who explore the potential of autonomous technologies. Autonomous systems such as the unmanned flying ambulance would safely transport a patient in emergencies and negotiate different weather conditions.

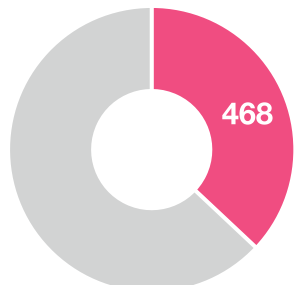


53%

Declared EAS Undergraduates

Total 730 Caltech Undergraduates (Declared Majors)

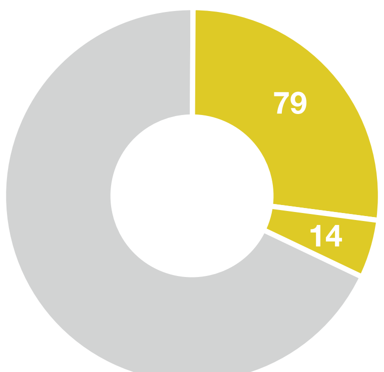
Undergraduate and graduate student data from 2017-18 census statistics. Postdoctoral and faculty data from September 2018.



37%

EAS Graduate Students

Total 1,277 Caltech Graduate Students



93 EAS Faculty

(79 Primary EAS Faculty; 14 Affiliated EAS Faculty)

Total 311 Caltech Faculty

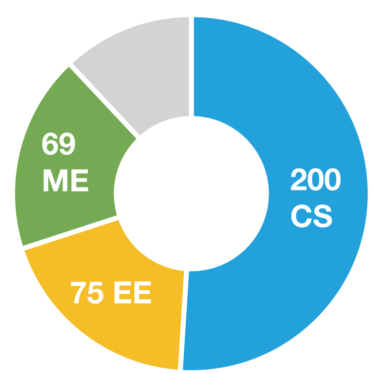
Most Popular EAS Undergraduate Options

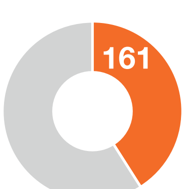
51% Computer Science

19% Electrical Engineering

18% Mechanical Engineering

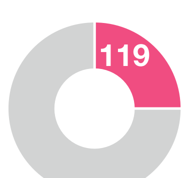
Total 390 Declared EAS Undergraduates





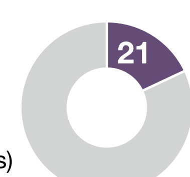
41% Women Undergraduates in EAS (All Options)

Total 390 Declared EAS Undergraduates



25% Women Graduate Students in EAS (All Options)

Total 468 EAS Graduate Students



18% Women Postdocs in EAS (All Options)

Total 117 EAS Postdocs

Dear alumni and friends of the Division,

With visionary faculty and generous donors, we are fortunate in the Division of Engineering and Applied Science to be able to quickly adapt our educational programs to the evolving directions of our research programs. This year, two exciting undergraduate initiatives are underway: the new undergraduate option in Information and Data Sciences (IDS) and Robotrack, a constellation of new and existing courses that brings CS, EE, and ME faculty together to train students in the combined areas of mechanical systems, electrical and electronic components, and software and control. IDS and Robotrack together cover the field of autonomous systems very broadly, are reflective of our research thrusts in autonomous systems and computational thinking, and give our students the opportunity to learn from the uniquely interdisciplinary teams of faculty pushing multiple boundaries in these fields.

IDS draws upon traditional areas that span computer science, applied mathematics, and electrical engineering, including a range of contemporary topics, such as machine learning, network science, distributed systems, and neuroscience—all areas in which Caltech is growing, with our recent faculty hires. The centerpiece of the Robotrack program will be cross-curricular challenges through new project-based courses. These challenges will allow students to gain knowledge and skills by working together for an extended period of time to investigate and respond to authentic, engaging, and complex real-world problems in robotics and autonomy.

Our new state-of-the-art laboratories and facilities, such as the Center for Autonomous Systems and Technologies (CAST) and the EE undergraduate labs, as well as Caltech's new high-performance computing cluster, bring necessary additional infrastructure. As my colleague Joel Burdick (Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Bioengineering and Jet Propulsion Laboratory Research Scientist) explains in "Smart from the Start: Studying and Building Autonomous Systems" in this issue of *ENGenious*, "It's not like we can open up an engineering textbook and say to our students, 'Go build an autonomous system.' We have to build that together, from scratch." Bren Professor Anima Anandkumar from the Department of Computing and Mathematical Sciences challenges us with her observation, "I see right here, right now, the opportunity to shape the fundamental framework of this field—one that will come to define the theory of autonomy." Our faculty are joined by Caltech trustees Lynn Booth and Kent Kresa, who have supported this vision by endowing the Booth-Kresa Leadership Chair for CAST. In addition, the gift of a leadership chair for Mechanical and Civil Engineering from alumnus Cecil Drinkward (BS '50) and his wife, Sally, has further strengthened our ability to soar in several areas including autonomous and robotic systems. Leadership chairs provide discretionary funds for center and department leaders to bring resources to exciting new ideas very quickly—and they are transforming the reach and pace of what Caltech educators and researchers can achieve.

Through the profiles in this issue, I invite you to meet two of our alumni, Jennifer Dionne (PhD '09), who is a professor at Stanford University, and Julie Eng (BS '89), who is the executive vice president and general manager of 3D Sensing at Finisar in Silicon Valley. Both offer inspiration and insight into the transformative power of a Caltech education—and each has developed a career rich in interdisciplinary challenges, with opportunities to change people's lives for the better.

Deep curiosity, together with the desire to invent and to make the world a better place, continue to guide our efforts in EAS, as they have for decades. Please visit campus when you can—and stay in touch. As always, I look forward to receiving your thoughts and comments.

Guruswami Ravichandran
Otis Booth Leadership Chair, Division of Engineering and Applied Science

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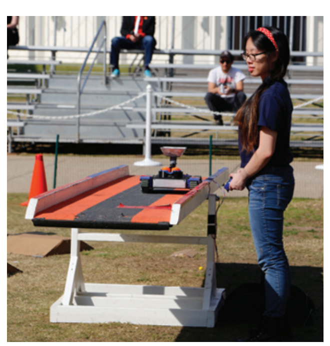
Left to right: Diandra Almasco, Caroline Paules, Hannah Chen, and Mohar Chatterjee

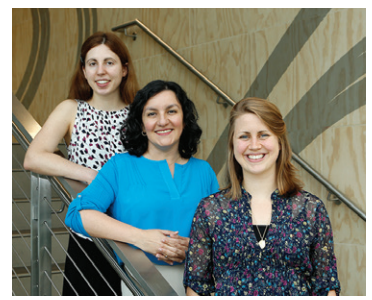
All-Female Team Wins Robotics Competition

After 20 battle rounds at this year's mechanical engineering and design competition (ME 72), the Riveters—Mohar Chatterjee, Caroline Paules, Diandra Almasco, and Hannah Chen, who named their team after Rosie the Riveter—emerged victorious, having never lost a single match. They used a track-wheeled tank design topped by flywheel-based cannons and relied on a consistent and effective strategy of capturing two key bases quickly and holding onto them for the remainder of the match. Even at the end of the competition, after having fought through seven grueling rounds, the Riveters' designs held up so well that they never had a tank fail during battle. Though the Riveters were the only all-female team, women outnumbered men in this year's ME 72 course for the first time in its 33-year history.

Learn more at www.mce.caltech.edu/events/me72.



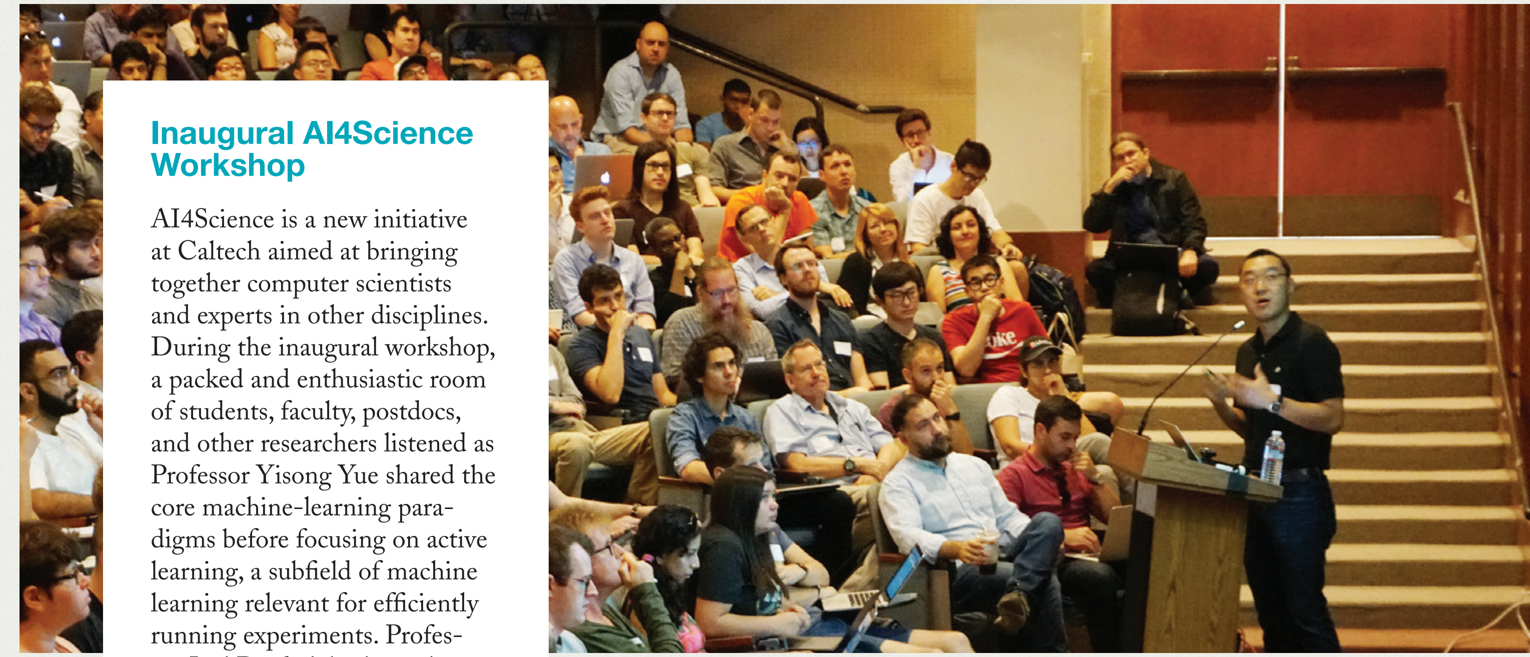
The Riveters deployed what would become their signature strategy: parking one robot at the apex of the seesaw, turning it into an elevated plank that was unassailable by their opponents.



Left to right: Ellen Feldman Novoseller, Trity Pourbahrami, and Rachel Gehlhar

Her Path to Engineering

The EAS Division hosted a salon, in partnership with TEDx-Pasadena, featuring three women and their stories of science and engineering passion. The diverse audience met graduate students Ellen Feldman Novoseller and Rachel Gehlhar, who shared personal and professional challenges and opportunities that guided their path to Caltech engineering. Feldman Novoseller's research involves programming electrode arrays in the backs of paraplegic and quadriplegic patients to assist in standing and walking. Gehlhar's work involves building a robotic prosthetic leg that learns from and adjusts to the human body. The salon also included facilitated small-group discussions led by EAS Director of Communications Trity Pourbahrami on different paths to engineering.



Inaugural AI4Science Workshop

AI4Science is a new initiative at Caltech aimed at bringing together computer scientists and experts in other disciplines. During the inaugural workshop, a packed and enthusiastic room of students, faculty, postdocs, and other researchers listened as Professor Yisong Yue shared the core machine-learning paradigms before focusing on active learning, a subfield of machine learning relevant for efficiently running experiments. Professor Joel Burdick built on this, discussing bandit algorithms and how they have been useful in optimizing input stimuli to help paralyzed spinal-cord-injury patients stand again. Professor Andrew Stuart added that using data to learn about model error is an area in which machine learning can have a tremendous impact. He used the specific example of predicting the weather, which involves hundreds of years of knowledge about physics but also vast amounts of data from satellites, aircraft, weather balloons, and numerous other instruments. Professor Anima Anandkumar elaborated on deep neural networks as particular models that can be used in supervised learning. She then pointed out that humans are theorized to do a lot of unsupervised learning, so a deeper understanding of that process would help to push the field forward. Plans are already underway to organize the next workshop, and one area that is of great interest is machine-learning applications in astrophysics.

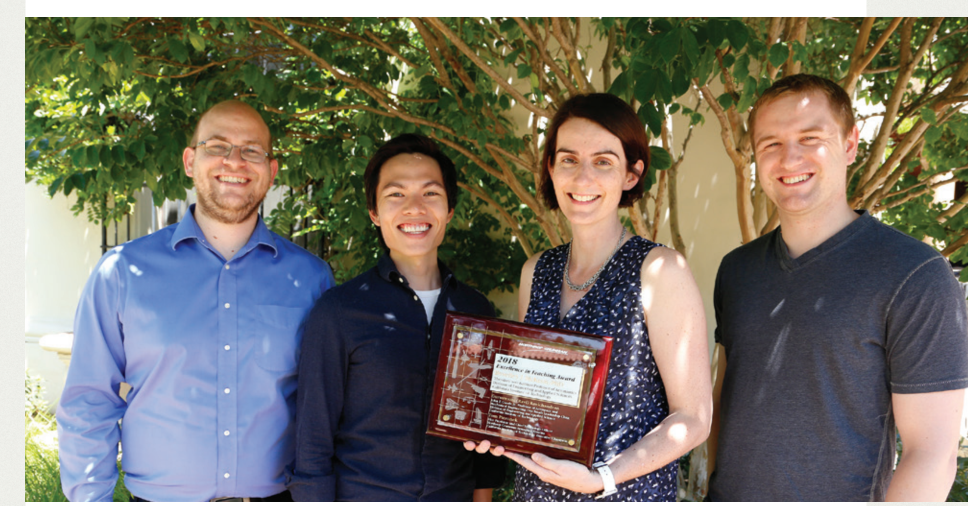
Learn more by searching #AI4Science.

Left to right: Professor Yisong Yue shared core machine-learning paradigms at the inaugural AI4Science Workshop.

Northrop Grumman Teaching Prize

Beverley McKeon, Caltech's Theodore von Kármán Professor of Aeronautics, is the 2018 recipient of the Northrop Grumman Prize for Excellence in Teaching. The prize is awarded to an EAS professor or lecturer who demonstrates unusual ability, creativity, and innovation in classroom or laboratory teaching. A nomination for Professor McKeon read, "She is a firm believer in the importance of having all students, regardless of their ultimate specialty, participate in laboratory coursework. Her courses serve as a solid foundation for research across disciplines. She takes tough subjects and uses her colorful approach to make the concept easy to comprehend."

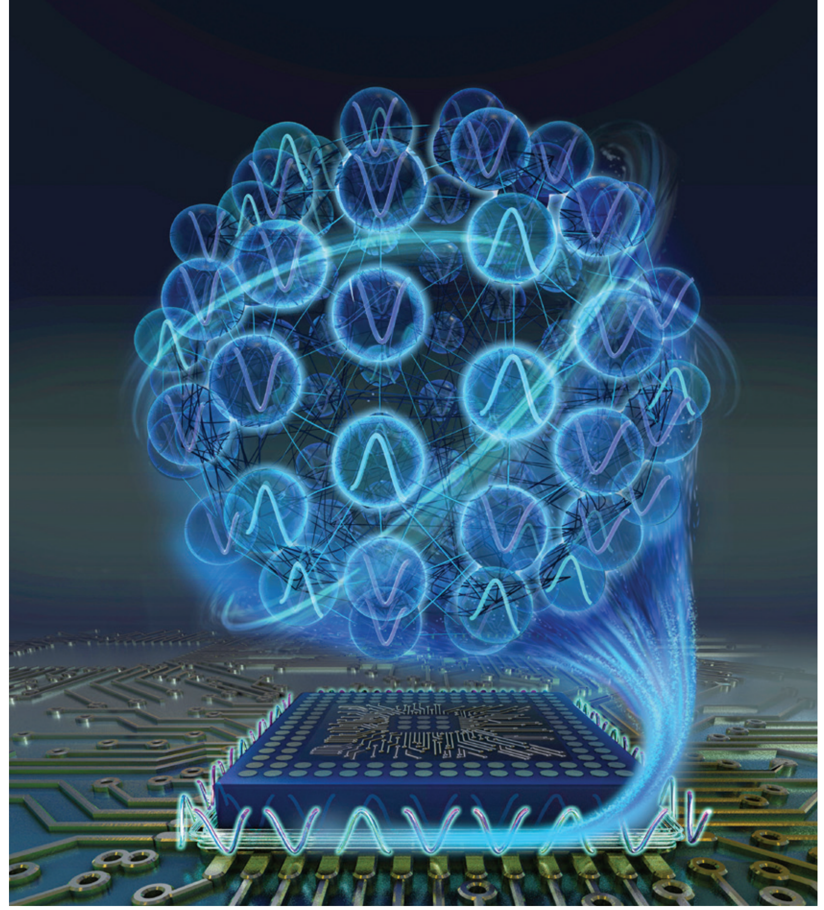
Learn more at eas.caltech.edu/teachingprize.



Left to right: Beverley McKeon with EAS students Kevin Rosenberg, David Huynh, and Sean Symon.

Who's New

To learn more about our new faculty's research and accomplishments, visit eas.caltech.edu/people.



Artistic illustration of an Ising machine—a special-purpose computer for optimization problems that uses short pulses of light

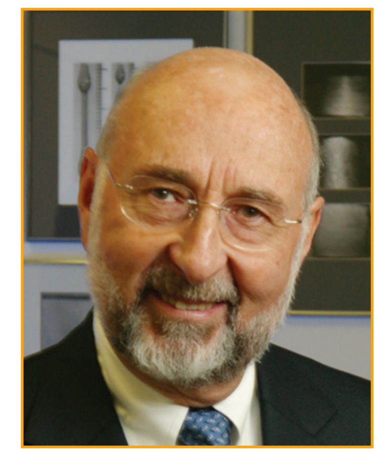
Alireza Marandi

Assistant Professor of Electrical Engineering

Alireza Marandi's research is focused on fundamental technological developments in nonlinear photonics. These technologies enable innovative, practical, and scalable solutions for challenges related to capturing information and its processing. His work explores the frontiers of ultrafast optics, optical frequency combs, quantum optics, optical information processing, mid-infrared photonics, and laser spectroscopy. His group uses state-of-the-art laser systems, micro- and nanofabrication techniques, numerical and theoretical techniques, and unconventional materials. Their main goal is experimental realization of novel nonlinear photonic systems, techniques, and technologies. In addition, they are working to advance the theoretical understanding of these systems and their applications, which range from sensing to unconventional computing and information processing.

Marandi received his BS from the University of Tehran, Iran, his MS from the University of Victoria, Canada, and his PhD from Stanford University, all in electrical engineering. Before joining Caltech as a faculty member, he was a postdoctoral scholar and research engineer at Stanford. He has also been a visiting scientist at the National Institute of Informatics in Japan and a senior engineer in the Advanced Technology Group of Dolby Laboratories, developing photonic technologies for high-dynamic-range display applications.

The Moore Distinguished Scholar program was established by Gordon and Betty Moore to invite researchers of exceptional quality who are distinguished at both the national and international levels to visit the California Institute of Technology for three to six months. There are no teaching or other obligations during the appointment, allowing Moore Scholars to focus on research. Visit eas.caltech.edu/people/moorescholars.

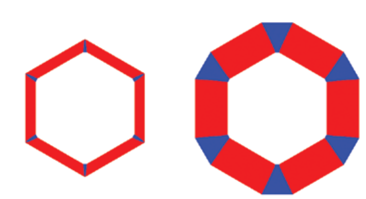


Stephen H. Davis

Professor of Applied Mathematics, Northwestern University

Stephen Davis is McCormick Institute Professor and Walter P. Murphy Professor of Applied Mathematics at Northwestern University. One of his research interests is fluid mechanics, with a specialization in interfacial dynamics, moving contact lines, thin films, and stability theory. Another research focus is in materials science: he explores solidification/fluid-flow interactions, rapid solidification, nanowire growth, cladding of nanowires, and island formation.

Davis received his BEE, MS, and PhD from Rensselaer Polytechnic Institute. Among his previous roles are research mathematician at the RAND Corporation, lecturer in applied mathematics at Imperial College London, and professor of mechanics at Johns Hopkins University. He is a member of the National Academy of Sciences, the National Academy of Engineering, the American Academy of Arts and Sciences, and the Academia Europaea. Davis has been awarded the G. I. Taylor Medal by the Society of Engineering Science, the Fluid Dynamics Prize by the American Physical Society, and the Humboldt Research Award for senior research scientists.



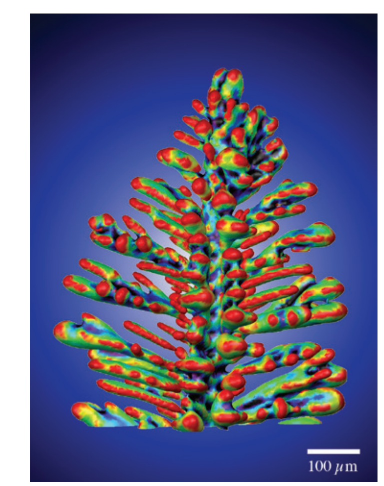
Cross section of the six-fold core-shell nanowire

Peter Voorhees

Frank C. Engelhart Professor of Materials Science and Engineering, Northwestern University

Peter Voorhees is the Frank C. Engelhart Professor of Materials Science and Engineering at Northwestern University. He is also the co-director of the Northwestern-Argonne Institute of Science and Engineering and co-director of the Center for Hierarchical Materials Design.

Voorhees's research focuses on the thermodynamics and kinetics of phase transformations in materials. He has a long-standing interest in coarsening processes that can occur in two-phase mixtures and has provided both theories for coarsening phenomena and experiments that test these theories. Voorhees's group also developed the first machine that automatically produces serial sections of a material, and they have created the computational tools needed to both reconstruct the three-dimensional structure and interpret the large data sets that are produced by such machines. Voorhees received his PhD in materials engineering from Rensselaer Polytechnic Institute. He has received numerous awards, including the ASM J. Willard Gibbs Phase Equilibria Award and is a fellow of several societies, including the American Academy of Arts and Sciences.



Three-dimensional reconstruction of an aluminum dendrite that was growing from an aluminum-copper liquid. In the image, the mean interfacial curvature is displayed on the interface of the dendrite, where positive mean curvature is red and negative mean curvature is blue. The challenge is to predict this morphologically complex dendrite and connect its morphology to the properties of an alloy.

FEATURE

Computational Thinking

How Computer Science Is Revolutionizing Science and Engineering

Computational thinking is becoming increasingly essential to the academic experience in the Division of Engineering and Applied Science and at Caltech more generally, with the challenges brought by a rapid increase in the availability and volume of data across disciplines and applications. The Institute not only has one of the leading computer science programs in the country, but it has also recently added a new major in information and data sciences to build on that area of strength and maximize its reach and impact. *ENGenious* sat down with a few of the faculty members who are leading this effort—one that promotes the cross-disciplinary perspective and collaborative research that are hallmarks of a Caltech education—to discuss the current state of the field, how it has evolved on campus, and what exciting opportunities await. Around the table were professors Victoria Kostina, Andrew Stuart, Thomas Vidick, Adam Wierman, and Erik Winfree.

Computational thinking is one of major research thrusts identified by EAS as the division looks to the future—and it's a complex one. Erik Winfree, professor of computer science, computation and neural systems, and bioengineering, explains that "it means different things to different people, but overall, computational thinking is the percolation of ideas from computer science into other areas of science." This has come

Left to right: Andrew Stuart, Thomas Vidick, Victoria Kostina, Erik Winfree, and Adam Wierman increasingly to mean chemistry, physics, and biology. Winfree's own research interests focus on "how molecules store information, how that information directs other processes, and how we can formalize and analyze that information." This sort of behavior can be precisely and mathematically defined, modeled, and analyzed using computer science.

Andrew Stuart, Bren Professor of Computing and Mathematical Sciences, remembers being taught from a young age that mathematics was the language of science. Now, he says, it's computational thinking that is becoming the basic language of all science and technology. "It is how we transfer ideas that were originally developed as the solution of one technological problem into a concept applicable to many other scientific ideas," Stuart says. "The final number is no longer the solution, but [the solution] is, instead, the algorithm itself." This shift from a more traditional mathematics-centric view to one based around computational thinking is especially conducive to collaboration and the translation of ideas to a variety of fields and problems.

Thomas Vidick, Professor of Computing and Mathematical Sciences, explains that with this shift has come a change in the order of inquiry, the approach to questioning. "In my field of quantum computing," he says, "we first started with quantum mechanics and its corresponding laws. Then came the machines. Now, we can ask a new question: What kind of machines can you build out of these laws of physics?"

Adam Wierman, professor of computing and mathematical sciences, executive officer of the Department of Computing and Mathematical Sciences, and director of the Information Science and Technology initiative at Caltech, also describes computational thinking in terms of framing questions. "When you look at a topic from a computational point of view, you want to know: What are the basic rules? What is a model for how molecules react? What are the capabilities of the model? What can it do or not do? Then, how do we use programming languages to represent the things a system can do?" These key questions are also of interest to strategic partners—such as Newport Beach–based investment firm PIMCO and Amazon Web Services—that are supporting the students, postdocs, and researchers who are pushing computational thinking forward at Caltech.

Victoria Kostina, Assistant Professor of Electrical Engineering, applies this mode of questioning to her work in the field of information theory. Kostina and her team always start with a model of a system. "This model is abstract and based on probability," she says. "Then we ask ourselves: What are the goals of the system? What are the tasks the model system should perform? And what are the fundamental limits that are achievable under the physical constraints of that system?"

Winfree sums up the influence of computational thinking and its potential to invigorate so many other fields. "In some areas of science, you look at what exists. In other areas, you look at what is possible. Computer science gives us a language for what's possible," he explains. "The resulting characterization of the design space allows us to look at the limits and think of things that may not have existed before. This design space lets us ask more interesting questions."

These faculty members, who apply computational thinking to topics ranging from economics to engineering to climate modeling, have collectively witnessed the growth of computer science at Caltech, from the days before an undergraduate CS degree was even offered (as when Winfree was appointed in 1999) to the exciting addition of the new major in information and data sciences this year. Given the close-knit nature of the scientific community here and the way the Institute promotes—even necessitates—true collaboration, Winfree argues that in a way, Caltech's undergraduates all become computer scientists by nature. "Because of the small size of Caltech, undergraduates get a feel for everything. Caltech is the liberal arts education for science," he says. Wierman agrees: the computer science program is designed for this kind of place and education, with an emphasis on fluid boundaries and the translation of ideas or approaches among disciplines.

Computer science gives us a language for what's possible.

In his teaching, Wierman gives particular attention to the many junior and senior students who take project sequences: three-term course sequences in either traditional CS or in networking and distributed systems, quantum computing, biological computing, robotics with mechanical engineering, or aeronautics—a setup that illustrates this integration of a computational approach across areas of study. "This is a 'CS + X' method, with the X being different areas of translation," he says.

Stuart also points to this model, noting that while one can find similar approaches at other schools, nowhere has it taken off quite like at Caltech. "The Department of Computing and Mathematical Sciences at Caltech is unique because we are a department of both continuous thinking and discrete thinking. We are one of a handful of programs in the U.S. that have applied math and computer science sitting under the same roof," he says. "Here we have traditional majors but also the opportunity for interactive degrees; courses are cross-listed and faculty conduct research in multiple departments. There is true collaboration. This is not something that is pressured to occur; it just happens because of the type of people and the environment that has been created." Winfree notes that the particular strengths that enable such a rich environment to develop at Caltech are not due solely to its small size. "One of my favorite attributes of Caltech is the diversity of students that take my class," he says. "They are trained as biologists, bioengineers, physicists, and computer scientists, but they come together. They educate each other."

At Caltech, students learn how to solve problems, how to think, how to not allow fears and obstacles to hinder the acquisition of knowledge. In an age of short attention spans and pressure for fast results that might keep others at a surface level, they are trained to go broad and deep. Kostina elaborates: "We are not sacrificing depth by offering breadth, because all our students have good foundations." Caltech forces you to challenge yourself, she says, by taking difficult and interdisciplinary courses. The unique new major in information and data sciences embodies this approach, providing a deep mathematical foundation for students while also requiring engineering courses with applicability to different fields. "If I were a Caltech undergrad today, I would take these classes!" Kostina says. "We are in a very exciting moment in history, and by creating this program, Caltech is responding to the great demand in data science." It is clear that the faculty members are eager to engage and encourage a variety of students—including those who may never have considered the interdisciplinary approach. "What we want to do with data science at Caltech is make our students connect the discrete view and the continuous view," says Wierman. The aim is to enable them to "incorporate this into scientific computing and model more data-driven artificial intelligence (AI) machine learning." And he is emphatic about this being the right place for this to happen: "Caltech is a balanced mixture of educators that excel at these areas and students who want to have such interactions and discussions."

The excitement is palpable as Wierman discusses the way all this came about, as the outgrowth of a long process of innovation within traditional modes of inquiry. "When the concepts of 'computational thinking' or an 'algorithmic lens' were first developed, they were broad and ill-defined. It took a long time for these ideas to percolate into other disciplines and inform change. In the last 10 to 15 years, we have seen the meaningful emergence of this collaboration of computer science with different fields." Stuart adds, "Continuous, discrete mathematics has risen in importance as more people understand this model of thinking. At the same time, there is a need for continuous mathematics in computer science. One great example is machine learning. In the next decade, we will incorporate continuous mathematics into computer science." This integration will continue to be implemented at all levels of education, notes Wierman. "We are continuing to emphasize the importance of computer science, especially programming. This focus is even at the elementary and high-school level. My kids are learning recursive programming! This knowledge base and ease of interaction with computer science bodes well for the future of Caltech." ENG

Victoria Kostina is Assistant Professor of Electrical Engineering. Andrew M. Stuart is Bren Professor of Computing and Mathematical Sciences. Thomas G. Vidick is Professor of Computing and Mathematical Sciences. Adam Wierman is Professor of Computing and Mathematical Sciences; Executive Officer for Computing and Mathematical Sciences; and Director, Information Science and Technology. Erik Winfree is Professor of Computer Science, Computation and Neural Systems, and Bioengineering.

To learn more about Caltech's new major in information and data sciences, visit cms.caltech.edu/academics/ugrad_ids.

Left to right: Joel Burdick, Soon-Jo Chung, Yisong Yue, Anima Anandkumar, Aaron Ames, and Mory Gharib

FEATURE

Smart from the Start

Studying and Building Autonomous Systems

Drivers, pilots, and households are routinely able to set increasingly sophisticated systems on autopilot, thanks largely to the layering of multiple breakthroughs in separate domains like voice recognition, image classification, and sensors. The conversation about how to carry autonomous technology forward across disciplines and applications has had a natural place in the Division of Engineering and Applied Science. The question has been how to best approach autonomy from the start. The answer has meant identifying autonomous systems as a research priority for the EAS Division, creating a space for autonomy to come into its own and resisting the trend to treat it as an add-on to any other engineering discipline. Instead, EAS has managed to create a nexus between the departments of aerospace (GALCIT), mechanical and civil engineering, electrical engineering, and computing and mathematical sciences.

When considering the next generation of these technologies, Mory Gharib, Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering and Director of Aerospace and the Center for Autonomous Systems and Technologies (CAST), defines the emerging autonomy as post-navigator: "These are systems that do not require an operator, or any third party, to make decisions to successfully navigate and safely achieve their goal while negotiating dynamic conditions," he explains. Housed within GALCIT, CAST operates as an interdisciplinary center dedicated to the study of this new frontier: the emerging unknowns of the engineering of autonomous systems. The new center brings together researchers from EAS, JPL, and Caltech's Division of Geological and Planetary Sciences in a state-of-the-art, 10,000-square-foot facility where they can work alongside experimental machines—build and test robots and drones, for example—to advance bioinspired systems, autonomous exploration, and other related fields with a range of important potential applications.

Establishing a research program surrounding systems that do not yet exist requires a collaborative environment, with room for large teams to conduct research along with sophisticated testing facilities and a highly integrated educational model. "EAS has always pushed the boundaries of breakthrough research while educating the leaders of the future. The result is a culture that attacks the unknown with fundamental science," says G. Ravichandran, John E. Goode Jr. Professor of Aerospace and Mechanical Engineering and the Otis Booth Leadership Chair of the EAS Division. "By clearing a space and building a dedicated specialized home for autonomy, the aerospace department grows beyond itself, making way for more universal

Robot explorers working together to navigate unknown and complex terrestrial environments

applications of the systems it has influenced for decades." Gharib concurs. "Engineers and applied scientists from across Caltech and JPL now have a venue for collaboration that will have real and significant impact outside our immediate academic world," he says. "This research will undoubtedly affect science, culture, and society. Making sure research of this magnitude has a dedicated space is an important expression of the EAS Division's commitment to the exploding field of autonomous systems." This commitment also extends to Caltech trustees Lynn Booth and Kent Kresa, who recently endowed the Booth-Kresa Leadership Chair for CAST.

ENGenious brought together some of the key faculty collaborators of CAST to hear how they use this new space and its specialized testing facilities and how the evolving structure of that research is redefining what engineering education means at Caltech.

Research on autonomy within EAS is mission-driven and oriented around shared "moonshot" projects. Each of the moonshots—mapped out thematically as Explorers, Guardians, Transformers, Transporters, and Partners—is an ambitious, innovative, and interdisciplinary endeavor designed to capture broad tracts of fundamental research throughout its development. Like their namesake—the challenge of sending Americans to the moon in the 1960s—CAST's moonshot goals will require advances in engineering to accomplish currently impossible feats. Among these is the development of a robot that can walk from Mexico to Canada without assistance, other than being guided by a network of flying drone scouts; another project is the construction of a flying ambulance capable of delivering an injured person to first responders without a pilot.

The moonshots are fundamentally about helping: placing humans and machines on a team together to better navigate, monitor, survey, communicate, deliver, and assist in all manner of dynamic conditions. Under this model, the various engineering disciplines function democratically, with no one academic niche taking precedence. According to Gharib, this is the way to move past the traditional camps of hardware and software and set up systems more like the human body does. "It is a mind-body vision," he explains. "We are all critical, and each moonshot mandates the participation of multiple experts. The point of interface between the minds and the bodies of these systems is where the engineering will break out of one department and radiate throughout the Division and into our world." This potential for greater world impact is also recognized by the corporate and industry supporters of CAST, including Raytheon and AeroVironment.

Some of the faculty involved focus on the bodies of the machines, drones, and robots that will directly impact human experience. Aaron Ames and Joel Burdick from the Department of Mechanical and Civil Engineering and Soon-Jo Chung in the Department of Aerospace work on guidance and control. Yisong Yue and Animashree (Anima) Anandkumar from the Department of Computing and Mathematical Sciences develop the "brains" that enable learning, decision-making, and intelligence, with platforms that can discern, digest, and close the information loop for the bodies they serve. The collaboration of these teams is essential to the progress of the research, particularly beyond the lab. Aaron Ames, Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems, can take his robot bodies only so far without a mind: "To me, this step to autonomy means taking my robots out of the lab and into the wild. In order to do that, I cannot live in my silo, where the world is perfectly defined. I need expertise in dynamics and machine learning to make that happen. How else will my robots have the ability to handle unknown, unstructured events in a robust way?"

Joel Burdick, Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Bioengineering and JPL research scientist, recognizes that this kind of pioneering work brings challenge and opportunity alike, both of which necessitate collaboration. "It's not like we can open up an engineering textbook and say to our students, 'Go build an autonomous system.' We have to build that together, from scratch," he says. But it's worth it, says Bren Professor of Computing and Mathematical Sciences Anima Anandkumar, who underscores the great potential of their efforts: "I see right here, right now, the opportunity to shape the fundamental framework of this field—one that will come to define the theory of autonomy."

So how will they accomplish all this? If half the battle of successful engineering is asking the right questions—in this case, by way of the moonshot goals—then these teams have a great advantage in being able to frame those questions and seek the answers in the context of CAST and, more generally, the Caltech environment. According to Assistant Professor of Computing and Mathematical Sciences Yisong Yue, "There is consistent engineering serendipity at Caltech. You can count on it happening because we are small with strength in the fundamentals. Faculty and students interact and collaborate across the EAS Division and beyond organically. We all make the interesting and often unexpected connections that lead to the highest-impact research. CAST is a terrific example of this culture by design." Understanding and maximizing this strength was a critical part of the vision of CAST, with an emphasis not

> Autonomy really requires the mind and body coming together. We have to show intelligence and control. These are typically self-separate domains; at CAST it all comes together.
>
> Anima Anandkumar
> *Bren Professor of Computing and Mathematical Sciences*

just on collaboration but on the translation of ideas across academic disciplines—a very Caltech approach. "At Caltech, we all speak the language of mathematics, and that really makes the communication of different ideas much more efficient in terms of approaching a common problem from multiple angles," notes Yue. "This ability to jump in with a shared terminology, in combination with our small size, greatly reduces the friction that sometimes exists between disciplines at other schools. The result is an incubator culture for collaborative problem solving."

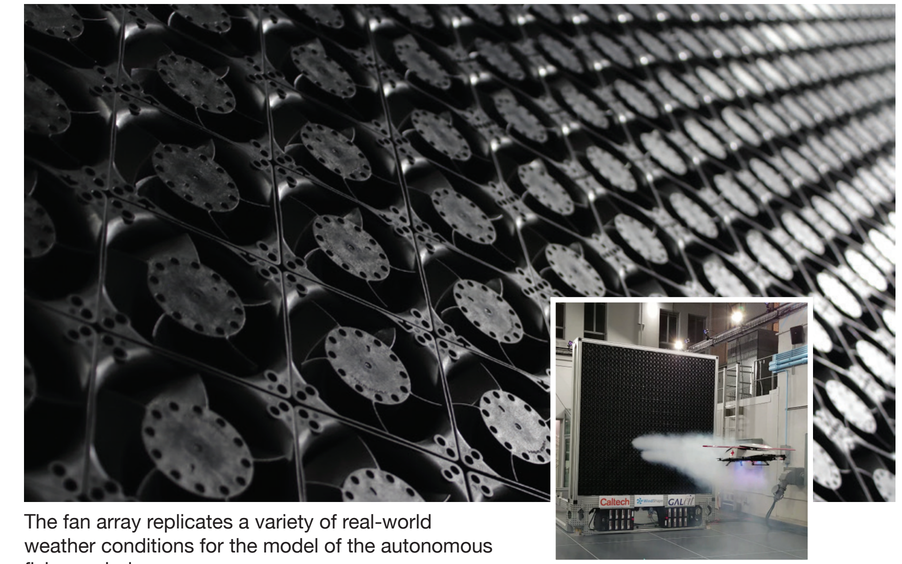
Answering big questions like those posed by the moonshots also requires careful planning and initial testing, which is the current stage of focus for the CAST researchers. "Now we are learning the math of the CAST moonshots," says Gharib. "We model heavily, and we ask ourselves, 'How do we design based upon the principles we see in the data?' We want to make sure from the beginning that no gadget is built before knowing it will be smart. It seems like a big question, but really, it requires great efficiency. You have to first have a good understanding of what is useful." The computing power required to achieve that level of understanding in the modeling and simulation phase is undeniably huge—an impressive learning problem, says Anandkumar, but one that can be approached systematically at CAST. "In many control problems, we already have algorithms designed by domain experts. However, these algorithms tend to be highly conservative," she explains. "Consider the example of landing a drone. That maneuver is slow and consumes a lot of battery power. We can learn better landing strategies in a data-driven way through two approaches: either by simulation or by the example of human experts. Human experts provide demonstrations of good landing, but we cannot rely uniquely on that modeling, as it takes too much time. On the other hand, the efficiency of simulators is convenient, providing lots of data quickly, with the added benefit of affording more mistakes that have no real safety implications. However, no matter how good the simulations are, there will always be a mismatch with the real world. Only when all of this real and simulated data is tested and refined do you gain the actual benefits. This is why a controlled testing environment like the drone lab here at CAST is so important."

This kind of learning requires a combination of high-level decision making and lower-level guidance and control. Their junction is the crux of CAST's initial testing. Associate Professor of Aerospace, Bren Scholar, and JPL Research Scientist Soon-Jo Chung says, "We teach our robots how to negotiate the unknown by creating the unknown using CAST's realistic simulation facilities, including the aerodrome and the space robotics lab. Aerial and space robots can better understand and negotiate uncertainty by predicting it in a way that encapsulates the top-level artificial intelligence *and* the low-level control." He adds: "The unique facilities here make that possible. We can set up unknown models, test the real-world conditions, collect data, collaborate, refine and improve our learning and control algorithms, then retest in-house. We can rapidly cycle through unknowns here because of these sophisticated facilities."

The state-of-the-art testing facilities amount to an important step forward in building that knowledge base. One key feature of CAST is its three-story enclosed aerodrome, an innovative reincarnation of the legendary wind tunnels of GALCIT's past. Chief project consultant David Kremers describes the flight arena as "the world's first real-weather wind tunnel, with the added benefit of being under a giant infrared microscope with a resolution of 100 microns, all in a space as unconfined as the Federal Aviation Administration will allow." The setup includes an elaborate fan wall—an array of 1,296 individually programmable fans—capable of creating a near-infinite variety of customizable wind dynamics, along with tiers of special cameras to capture all navigation and movement in the space as flying drones react. "There are universities building large spaces for flight," Kremers says, "but this fan wall and its capabilities are unique in the world for testing."

The Transporters moonshot endgame is the development of a fully autonomous flying ambulance. A flying machine capable of carrying a patient without any external information must be very stable and robust, able to compensate for everything from a mild breeze to the shears generated between skyscrapers. "The design and the developing autonomy of the flying ambulance are physics-driven," says Chung. "When we asked ourselves about the forces we had to negotiate and the degree of stability necessary, the question was: Rotors or wings? We decided the answer was both. We came to this platform design by incorporating aerodynamics, flight dynamics, and control theory. Actually testing our first model without the variety of conditions offered by the fan array would be extremely difficult if not impossible."

Another world-class physical feature of CAST is Chung's space robotics lab on the basement levels of the building. This near-frictionless environment allows his students to test physics-driven designs for spacecraft in three dimensions. This "flat floor"—the largest in academia, surpassed only by those held by NASA—is the kind of specialized facility that allows for advanced, efficient development and testing. Research currently underway in this lab, in partnership with JPL, will further the Transformers moonshot: A mini model asteroid, affectionately known as "the potato," is serving as the visual unknown target for a swarm of space drones that are learning to characterize the size, weight, shape, and motion of foreign objects using onboard sensors. A swarm offers the advantage of exponential improvement in the precision and speed of the characterization of the target object.



The fan array replicates a variety of real-world weather conditions for the model of the autonomous flying ambulance.

For the Caltech students working in these facilities, who invest energy and passion in these first projects informing the moonshots, the goal is to be broad but targeted in their scientific approach, according to Ames. "We are framing autonomy for our students in a way that grounds them in an underlying golden thread of scientific discovery. Our job here is to take out all of the noise," he says. "The range of things students are going to have to know in order to study autonomy is immense. We are teaching what threads them together and optimizing the coursework so they receive just the right amount of information along that spectrum without being too tangential." That might seem daunting, but with the right attitude and collaboration, the learning happens horizontally and vertically, says Yue. "We cannot expect our students to be experts in every field. However, we do encourage them to be collaborative, just as we are as faculty," he explains. "Aaron Ames and I have students in control and machine learning who are working together. It is a very fruitful partnership because they're learning from each other by doing together."

The study of autonomy is also a healthy arena in which to nurture the student-advisor relationship, Yue adds, particularly in the CAST setting. "I am very honest with my students. If I make assumptions about strategy that end up falling flat, then I say so, and we learn together," he says. "Questions like the ones we're posing in CAST help students realize that they really need to take the initiative for their own career development, which is beyond any advice I could ever give them." Joel Burdick—who, as senior faculty, is familiar with the complex relationship between risk and reward—likewise makes sure that his students understand he's not exempt from making mistakes, especially in relation to his CAST projects for the Guardians moonshot. He says, "I tell my students, 'I don't know any more than you do, I've just been at this game longer. Let's make the mistakes together, and let's all keep an eye out for where the opportunities are.' There is huge opportunity in autonomy right now."

Each of the CAST moonshots aims to augment or improve the human experience. With that comes a particular awareness of the anxiety associated with shifts in the economy, labor market, and society that will accompany the future proliferation of autonomous systems.

Yue reminds us that adjusting to autonomy is not new: "It just gets refined every five to ten years. What used to be an autonomy milestone is now routine and would be more defined as 'automation'—not autonomy as we think about it at CAST, but the idea is the same. We do not stop progress, and progress has always produced anxiety and debate about how to best integrate and adapt in a new tech era." Many of the coming transitions will be complicated, but the researchers are optimistic. "Human creativity is one thing we can count on," Yue offers. "As some jobs go away, new ones take shape. It's up to our whole society to align educational training and experience to the job market that will emerge in a more autonomous world."

And there will be a wide range of beneficial improvements in that more autonomous world. Caretakers and families stand to gain considerably from the advances that may emerge from the Partners moonshot. Achieving the Partners goal of having a robot walk the dirt, snow, and mud of the Pacific Coast Trail will propel the work of Ames and Burdick as they develop prostheses and exoskeletons for the paralyzed. The prospect of smarter prostheses and vastly improved mobility is a big driver for both researchers. "Christopher Reeve had a devastating injury, and he lived for a long time with a good quality of life. That is wonderful, but you shouldn't have to be wealthy to get that level of care and assistance," says Burdick. "Aaron Ames and I both work on new technologies coming online that will enable services for patients living with severe injuries in a more affordable way, which will directly improve life for some of our most vulnerable citizens and their families." Ames's enthusiasm is palpable when he talks about the progress being made and the possibility it brings. "It's really incredible and powerful to see," he says. "We are working with a startup that uses our walking controllers on their exoskeleton device to realize the first dynamic walking for paraplegics—paraplegics who walk, dynamically, without crutches. You can see how, with these collaborations, with Joel's work on stimulation of the spinal cord and interfacing with the device, and with Yisong's on providing some of the flexibility of machine learning for robotics, the potential gets seriously exciting."

It is important to pair this optimism with a focus on inclusion, participation, and education to ease the coming adjustment to a more autonomous world, says Anandkumar. As a scientist, she believes that communicating the power of partnership is the only way to handle this transition responsibly. Corporations, civic leaders, policy makers, scientists, and educators have to work together to shape the economy of the future and create an informed, engaged citizenry and a more resilient society. "We must all do a good job explaining the benefits of new technologies to the general population. This will help policy makers be as mindful as possible in the coming transition," she says. "It is important that we welcome all people, at every level of the economy, to participate. You do not have to be a computer scientist to learn about the benefits of artificial intelligence; a lot of the time you just have to be willing to engage with new technology. Let's design curricula for non-science majors that teach the important skills of exposure, adaptation, and retraining so the next generation can be comfortable with change. It's the one thing we can count on." ENG

Aaron D. Ames is Bren Professor of Mechanical and Civil Engineering and Control and Dynamical Systems. Animashree Anandkumar is Bren Professor of Computing and Mathematical Sciences. Joel W. Burdick is Richard L. and Dorothy M. Hayman Professor of Mechanical Engineering and Bioengineering and Jet Propulsion Laboratory Research Scientist. Soon-Jo Chung is Associate Professor of Aerospace and Bren Scholar and Jet Propulsion Laboratory Research Scientist. Morteza Gharib is Hans W. Liepmann Professor of Aeronautics and Bioinspired Engineering; Director, Graduate Aerospace Laboratories; and Director, Center for Autonomous Systems and Technologies. Yisong Yue is Assistant Professor of Computing and Mathematical Sciences.

> "CAST represents physics-driven autonomy in which scientists and engineers work together to solve open problems that involve complex physics such as fluid flows and fast dynamics."
>
> Soon-Jo Chung, *Associate Professor of Aerospace and Bren Scholar; Jet Propulsion Laboratory Research Scientist*

Left to right: Dr. Issa Nesnas, Professor Soon-Jo Chung, and students Rebecca Foust and Yashwanth Kumar Nakka in the near-frictionless environment at the CAST space robotics lab

Alumna Jennifer Dionne Reflects on Her Caltech Graduate Journey

Jennifer (Jen) Dionne was a graduate student in the research group of Harry Atwater, Howard Hughes Professor of Applied Physics and Materials Science, and obtained her PhD in applied physics in 2009. She is now an Associate Professor of Materials Science and Engineering at Stanford, where her focus is on developing new optical materials and microscopies to observe chemical and biological processes as they unfold, with nanometer-scale resolution. Dionne's research and academic achievements have been recognized with a Moore Inventor Fellowship (2017), the Adolph Lomb Medal (2016), and the Presidential Early Career Award for Scientists and Engineers (2014).

ENGenious sat down with Jen Dionne to discuss her story: her experiences at Caltech, her path to an academic career, and the in-between.

ENGenious: What inspired you to become an applied physicist?

Dionne: I was a very curious child and would frequently ask my parents questions about how the world worked. As my questions became more complicated, they would guide me toward the World Book Encyclopedia. From reading nearly every page of the 22-volume set, I became drawn to problems in physics, especially optics and quantum mechanics. A summer undergraduate research experience in oceanography confirmed my love of "waves" but, more importantly, my love of research—especially research that can positively impact the environment. When I applied to graduate school, I was torn between Caltech's nanoscience and oceanography programs. I took a chance on nanoscience, and it was a very good move. I have stayed in nanoscience throughout my career.

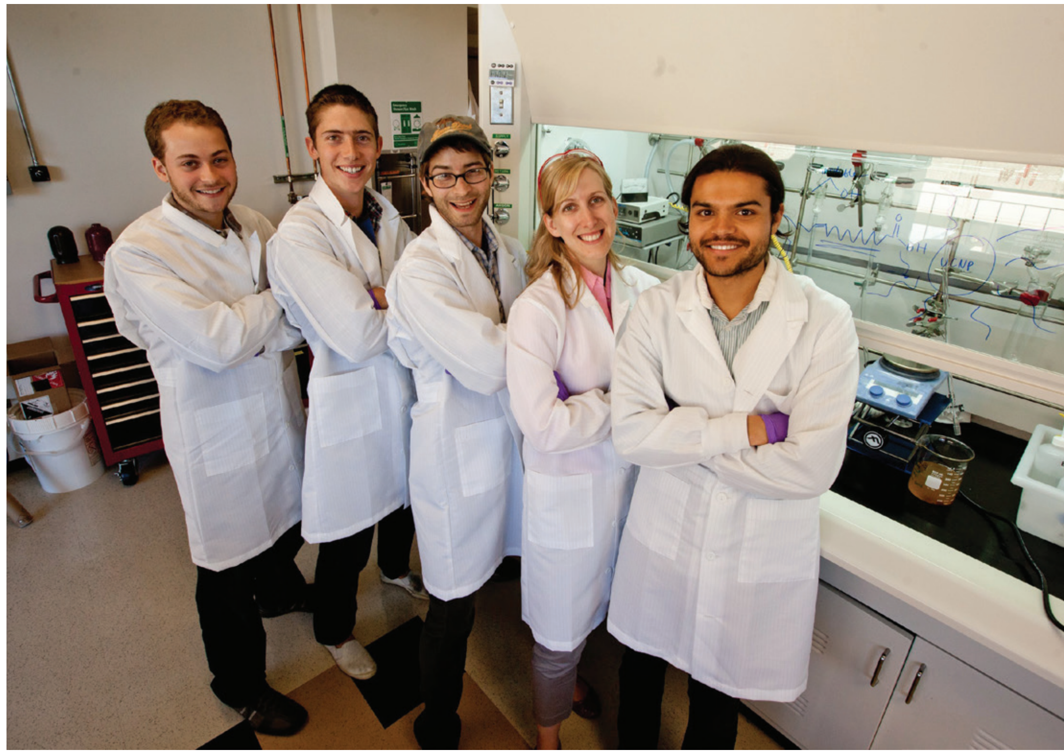
ENGenious: How has Caltech influenced you?

Dionne: In so many ways! The community at Caltech has turned out to have the most influential and lasting impact from my Caltech education. For example, my classes at Caltech were small, with exceedingly bright professors and classmates. Many of my Caltech classmates became my closest friends, and it has been amazing to watch their careers unfold and learn from them. Beyond the classroom, Caltech fosters a very close-knit community of scholars that seems to extend beyond any temporal bounds. Since graduating from Caltech, I have learned from and benefited from interactions with Caltech alumni of all ages. The Caltech community inspires me and has been a major influence on my approach to science.

ENGenious: What are some of your favorite memories at Caltech?

Dionne: One favorite memory involves working in the Kavli Nanoscience Institute (KNI) before it was the KNI. At that time (2005 or so), most of the nanofabrication and characterization tools were in the basement of Steele. To get into the clean room, you had to walk through an unfinished basement with pipes and beams exposed everywhere. Not many people used the facilities, so I could often set up fabrication runs that would run overnight. One night, I set up a fabrication process that would require my input around 4 a.m. I walked over to Steele from my Catalina apartment in my pajamas, not expecting to see anyone. To my surprise, nearly all of Axel Scherer's lab was there, preparing for a big conference. Amazingly, everyone there was very supportive and welcoming, even as I donned clean-room attire over my pajamas. That memory is a perfect example of what sets Caltech apart: it is an incredibly supportive and creative community of scientists, working in the lab at any and all hours of the day, trying to make tomorrow's next big discovery a reality today.

Another favorite memory involves my very brief time on the Caltech gymnastics team. My roommate was an elite gymnast who convinced me to join some of the Caltech team's practices. Since I had done gymnastics as a kid, I thought it would be fun. I was surprisingly okay, probably due to muscle memory, but I ended up breaking my foot after just a few sessions. My advisor, Harry Atwater, was among the first to call me to see if I was okay, and he even took me to the hospital to get an X-ray and crutches. This is just one example of what a great mentor and friend he has been; his combination of incredible scientific creativity and kindness is a true inspiration for me.



Left to right: Dionne lab members Jonathan Scholl, Justin Briggs, Sassan Sheikholeslami, Professor Jen Dionne, and Ashwin Atre

ENGenious: As a woman at Caltech, was your educational experience different from that of your male counterparts?

Dionne: Caltech is a supportive and diverse environment, and during my time there, I didn't notice any specific gender biases. In fact, the Atwater group probably fostered more gender diversity than most labs. At one point, I think the lab was almost half female. That said, I was the only female member of my applied physics cohort. I would work extra hard to deeply understand concepts being taught in class or researched in the lab. To a certain extent, I lacked confidence, but I figured I could tackle that by being as prepared as possible. Thankfully, everyone at Caltech was very willing to help me learn.

ENGenious: What has been a pivotal or magical moment in your professional life so far?

Dionne: One of my scientific highlights was observing negative refraction as a graduate student at Caltech, working with Harry Atwater and Henri Lezec. This experiment required many, many long hours designing and fabricating devices and conducting optics experiments. When we finally got the experiment to work, it was a true eureka moment. This experiment laid the foundation for my love of developing new microscopies and imaging techniques. Another highlight occurred in my lab at Stanford, visualizing photocatalytic transformations in real time with atomic-scale resolution. My group members (especially Michal Vadai, Fariah Hayee, Andrea Baldi, and Tarun Narayan) and I worked together for years to combine optical and environmental electron microscopy to image dynamic processes in situ. It was incredibly exciting to get the experiments finally working, and I think there is remarkable potential for this nascent field.

ENGenious: How has your Caltech graduate degree been viewed by colleagues in academia and industry?

Dionne: I think it is viewed very highly and with great esteem. Caltech has consistently delivered some of the brightest scientific minds, along with some of the nicest people. I try to uphold that tradition as best as possible.

ENGenious: Was anything lacking in your Caltech education?

Dionne: Caltech is a magical place, and I don't see much that is lacking. There is very limited bureaucracy—which is a good thing! With limited bureaucracy, you have a lot of freedom to work on topics that you are passionate about. It certainly helped that Caltech could quickly and efficiently obtain new, state-of-the-art facilities. Also, as a student in Harry's lab, I had the ability to travel to conferences and meet top researchers in my field. It was a fantastic five years. As a graduate student, I sometimes wished there were a nearby medical school. Though, since I graduated, Caltech has introduced a medical engineering program. This program seems like a great fit for the school, helping to bridge Caltech and top nearby medical researchers and physicians.

ENGenious: What advice do you have for the next generation of Caltech students?

Dionne: First of all, take advantage of all the opportunities you have on campus. Caltech is small enough that graduate students can acclimate themselves and figure out what resources exist, but [they have to] do it quickly because graduate school flies by. Try to serve on a colloquium committee. I served on the KNI colloquium committee and got to meet some great scientists, including Carlos Bustamante, John Pendry, Naomi Halas, and Stan Williams (while having some very nice dinners too!). I learned a lot about their research and enjoyed the networking opportunity.

Caltech holds an incredibly special place in my heart. In a nutshell, here is my advice: Use Caltech as a strong foundation for learning science and engineering. Make as many friends as you can and learn from your advisors. Also, know that when you leave, there's no such thing as goodbye. It's only "Until next time." Despite being miles away from Caltech, the community remains close and available if I need help or advice. E N G

Jennifer Dionne is Associate Professor of Materials Science and Engineering at Stanford University.

The Milton and Rosalind Chang Career Exploration Prize

The Milton (PhD '69) and Rosalind Chang Career Exploration Prize encourages and supports recent Caltech graduates who would like to explore careers outside of academia through a career gap experience project.

This prize provides action-oriented alumni with the freedom to intentionally explore career opportunities or transitions outside of academia, and it helps alumni build and enhance their skills as leaders and advocates, such as in government and journalism. Projects could include volunteering, either within or outside their degree or field, or the pursuit of a bold, compelling, and innovative project that has the potential to make a positive impact on society.

The Chang Career Exploration Prize can provide up to $65,000 in financial support for a career gap experience, a finite period of time (six to twelve months) during which an individual deliberately takes a break from his or her current academic or professional path in order to explore other interests, have a diversity of experiences, and develop new skills with the goal of optimizing career pathways.

In this first year of the program, the intent is to award the Chang Prize to one undergraduate and one graduate Caltech alumna/alumnus. Prizes are awarded at the discretion of Caltech and administered by the Office of Alumni Relations.

Eligibility

Caltech alumni who have received their BS, terminal master's, or PhD from Caltech within the past 10 years, with a preference for those who are five years or less from graduation, are eligible to submit their project proposal for the Milton and Rosalind Chang Career Exploration Prize. Current Caltech students who will receive their degree by the submission deadline are also eligible to apply.

For more information, visit www.alumni.caltech.edu/learn-more-chang-prize.

Alumna Julie Eng Reflects on Her Caltech Undergraduate Journey

Julie Sheridan Eng currently serves as the Executive Vice President and General Manager of 3D Sensing, a business segment of the global technology and engineering leader Finisar. Eng holds a BA in physics from Bryn Mawr College and a BS in electrical engineering from Caltech, and she earned her MS and PhD in electrical engineering at Stanford. She has published over a dozen papers and holds seven patents.

ENGenious editor Trity Pourbahrami visited Julie Eng at Finisar to learn more about her Caltech educational experience and her path to industry.

ENGenious: What inspired you to become an electrical engineer?

Eng: It was a somewhat nontraditional pathway. No one in my family was in engineering or high tech, but I was good at math and science. In junior high, my school required us to take county-sponsored math exams. I did very well and starting winning cash prizes. I realized [that taking these exams] was an easier way to make money than babysitting or mowing lawns, so I kept doing it. When I was a senior in high school, I did so well that I was invited to a banquet for the people with the top math scores, hosted by the American Society of Mechanical Engineers. I was told that engineering is a field that typically lacks women but is also a great major to get a good job straight out of undergrad, which was important to me.

I decided to try out engineering, but since I didn't know many engineers growing up, I decided to do what is called a 3:2 program. A 3:2 program is a partnership between a technical/engineering school like Caltech and a liberal arts college in which you complete three years of a science degree at the liberal arts school along with all its liberal arts requirements, then transfer to the engineering school for the final two years of study and complete all the additional classes required for an engineering degree. At the end of five years, you get two bachelor's degrees—one from the liberal arts college in science and one from the technical school in engineering. This helps the technical school add to and diversify its student body, and it helps students who aren't sure a technical school is the right choice for them have a broader educational experience before specializing. I don't think it's widely known, but Caltech has this program with a number of liberal arts colleges. I learned about it from my dad, who found it in the brochure for Bryn Mawr College. For me, it was perfect. I attended Bryn Mawr, an all-women's college 10 miles west of Philadelphia, as a physics major. I studied there for three years and then transferred to Caltech for the final two years. When I came to Caltech, I chose to study electrical engineering (EE), mainly because I had done an internship at Bell Labs in fiber optics and EE was the most relevant engineering discipline for fiber optics.

ENGenious: Were there any EAS faculty who made a specific impression on you?

Eng: Definitely Amnon Yariv, my senior thesis advisor. He was in applied physics and electrical engineering. He had written a well-known book called *Optical Electronics* that I had studied at my Bell Labs summer internship, and I wanted to do a senior thesis with him. I talked to him, and he agreed to let me do my thesis in his group. That had a major impact on me.

I also remember Kerry Vahala. I took quantum mechanics from him. Kerry is a great teacher and very approachable. That is a great combination: someone who is very good at what they do, and good at explaining it, and approachable for students.

I remember Bill Bridges. I remember him because I knew he had invented the argon ion laser, which I thought was really cool, and was on the board of a famous laser company—but yet, he was so approachable and friendly.

ENGenious: How has your Caltech education influenced you?

Eng: One of the biggest influences my Caltech undergraduate experience had on me was that it set me up to get into a great graduate school. Caltech was instrumental in this because I had access to many excellent technical courses. In addition, I had the opportunity to do research in a world-renowned group as an undergrad, which is an opportunity not everyone has. And because of the small size, you really get to know the faculty and interact with them. All these things helped me to have opportunities at the best graduate schools in my field. And probably the biggest influence Caltech had on my life was that I met my husband, Lars, at Caltech!

ENGenious: What are some of your favorite memories of Caltech as a student?

Eng: The people were great. Meeting Lars was, of course, a highlight. My thesis experience in Amnon Yariv's group was very positive.

Also, I have many fond memories of the Caltech Y. I was the activities chair of the Caltech Y. I remember Julie Bolster, who was leading the Caltech Y at that time. She was someone you could always go and talk to, which I always appreciated. As the activities chair, I planned events such as parties and spring-break trips to Mexico. It was a great way for me to get involved with campus life and meet people whom I otherwise would not have met because we were in different majors and in different years.

I also remember Jack Roberts, who was a chemistry professor I met through the Caltech Y. He was very friendly and genuinely interested in student life on campus. It was not until later that I learned how famous he was in his field. To me, he was just a friendly face on campus who cared about students.

ENGenious: How was your experience as a 3:2 student at Caltech unusual?

Eng: It couldn't have been more different, because Bryn Mawr is all women, but Caltech was probably only 10 percent women at the time. Plus, there is the difference in location. Bryn Mawr is East Coast, Caltech is West Coast. I also took a lot of liberal arts classes at Bryn Mawr, but when I got to Caltech, it was all technical courses. At Caltech, I got top-notch technical skills and training, course work, and exposure to high-level research. But I couldn't have made that decision [to go to Caltech] straight out of high school, so the 3:2 program was ideal for me. I would recommend it to anyone who has interests in both liberal arts and technical fields, or who wants to start with a broader education and then have an excellent technical education. It made me well rounded, and I gained excellent opportunities in my field of engineering.

ENGenious: How would you describe your professional life and contributions thus far?

Eng: I started off in fiber optics in the late '80s with an internship at Bell Labs. They were literally putting the first fiber-optics networks into the ground. After graduate school, I went back to AT&T and took a full-time job. After a few years, I realized I liked interacting with customers and being on the product side of things, so I moved into product development and began managing groups of engineers. After working on fiber optics at AT&T/Lucent/Agere for eight years, I moved back to California to work for Finisar and run engineering for their data-communications business.

Now I've been with Finisar for 15 years, which is very rare in Silicon Valley. During this time, we've grown our revenue from $130 million to $1.3 billion and moved from being number eight in optical components to number one. We made some acquisitions, but most of the revenue growth was from our own product ideas and hard work. Today, we are the market leader in fiber-optic components, and we manufacture approximately 30 percent of the world's fiber optic transceivers. What that means is that if you use the Internet to search or send email three times, it's likely that your signal has gone through Finisar equipment. I'm very proud of helping to grow the engineering team at Finisar into one of the best and most respected teams in our industry and of helping the company become one of the top vendors in this field.

Most recently, I was asked to lead the 3D Sensing business, a new area for the company. This is a general management role, which is new to me. In this role, I manage engineering, marketing, and operations. I'm responsible for the profit and loss of the business. 3D Sensing is very interesting; it uses technology similar to the technology we use for fiber optics but applies it to new applications such as facial ID, which is being deployed in mobile phones, and in-cabin driver monitoring in automobiles. In the future, it can be used to aid in driver-assist or autonomous driving.

ENGenious: What have been some defining moments in your career so far?

Eng: One of the big moments was the summer I spent at Bell Labs after my junior year in college. That was my first experience with fiber optics and research. Another defining moment was when I made the decision to attend Bryn Mawr, and then Caltech, and then Stanford for graduate school. Going to AT&T right after graduate school was also a pivotal decision. I learned a lot about fiber optic technology there, and also how to make real products.

ENGenious: How is a Caltech education viewed by your industry colleagues?

Eng: A Caltech education is viewed very favorably. Most people know that Caltech is a difficult school to get into and also that it is a preeminent research university at the scale of a college. If students seek out the opportunities, they can conduct research at a very high level. If a Caltech resume comes across my desk, I view that very favorably because I know this person had a great education, they are smart, and they have had great opportunities.

ENGenious: Did you find anything lacking in your Caltech education?

Eng: Sometimes it was not easy to be there when it was only 10 percent women. Really, it isn't easy to be anywhere where you're different from other people. Bryn Mawr was all women, but men from other nearby colleges could take courses there, and for them, I don't think it was that easy either sometimes. When there's a small number of people who for whatever reason feel different, you run the risk of missing opportunities for all students to engage. Also, [at Caltech] there was a sort of unspoken hierarchy of disciplines—specifically that science and engineering are much harder and more worthy majors than business or liberal arts. But if you've ever taken a philosophy course with a class full of philosophy majors, you realize that can be as hard as any engineering course you'll ever take! I think students would benefit from a more-balanced view of the worth of all fields. This could provide a wider diversity of experiences and help students grow into broader-minded people.

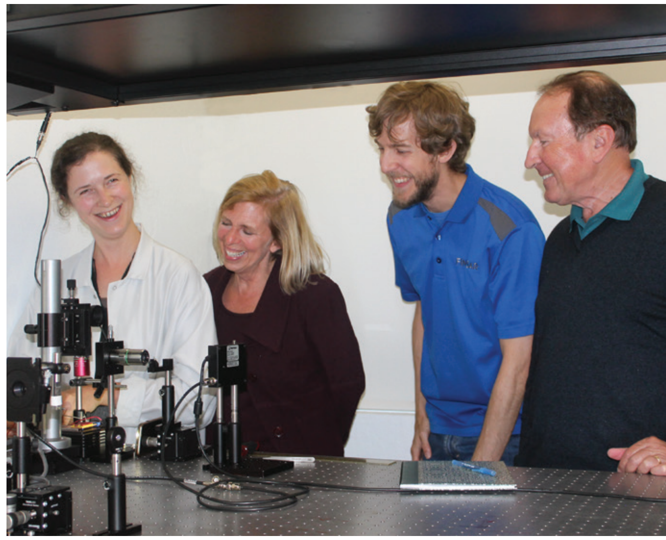
ENGenious: Was your educational experience different as a woman at Caltech?

Eng: Coming from a women's college, I had [learned to have] no fear of taking initiative, because at an all-women's college, the women do everything. So, of course I'm going to ask a question in class, of course I'm going to go get involved with the Caltech Y, of course I'm going to seek out a well-known professor if I want to do my thesis with him. I think I got out of Caltech as much as I would have independent of my gender. However, I think that if I had come in as a freshman, it would have been a lot harder. My parents were not scientists, but many other students had that sort of scientist upbringing. I probably would have felt intimidated by them, or out of place. It really helped to have done a 3:2 program and come in as a junior.

ENGenious: What advice do you have for the next generation of undergraduates?

Eng: You are lucky to be at Caltech! It is a world-class research university on a college scale. Take advantage of the world-class course work and research opportunities and get to know the professors. I would also encourage students to take part in internships. My first internship was at Fermilab, where I realized I didn't want to be a particle physicist. But when I did my internship at Bell Labs, I loved that there was an application for my work. Learning what you do and don't like in a real work situation is very important, and you can meet people who can be influential in your life. Also, I'd suggest that students try to broaden themselves. Don't be too narrow. The workplace of today involves interacting and working with different types of people and across disciplines, and you need to have a broader view to do this well. For women, I'd give the same advice but add that when you are looking to join a company or a university, look to see if there are any women in high-power positions. If there are, that's probably a positive sign. ENG

Julie Sheridan Eng is the Executive Vice President and General Manager of 3D Sensing at Finisar.



Left to right: Finisar members Anna Tatarczak, Julie Eng, Patrick Gregg, and Chris Kocot

The Caltech Associates

Making Science More Accessible

The members of the Caltech Associates have played a vital role in the life of the Institute since the organization's founding 92 years ago. Their annual membership dollars provide unrestricted support for faculty, students, and researchers to create new knowledge, lead innovation, and shape a better future for us all.

The past few years have been transformative for the Associates. *ENGenious* sat down with Executive Director Catherine Reeves and Associate Director Nicola Wilkins-Miller to better understand where the organization has been and where it's going.

The story of the Caltech Associates began when co-founders George Ellery Hale, Robert Millikan, and Arthur Noyes wanted to build an academic institution to rival prominent East Coast universities such as MIT. Millikan, with the help of Caltech Trustee Henry Robinson, sought 100 members of the greater Pasadena community to pledge $1,000 a year for 10 years to build this emerging scientific center. "As a thank-you to these investors," explains Reeves, "a series of Associates dinners that featured distinguished scientists and cultural leaders were organized. In just a year, the goal of 100 Associates was reached, and Henry Huntington, who was one of them, invited the Associates to hold their first meeting at his home—the now-famous Huntington Library. A few years later, thanks to two of the Associates' founding members, Mr. and Mrs. Allan C. Balch, the ornate Athenaeum was built to create a gathering place for Caltech faculty and Associates members. The first speaker in the Athenaeum's Hall of Associates was visiting professor Albert Einstein. Today, Millikan and Einstein are memorialized at the Athenaeum with guest rooms named in their honor."

Caltech Associates group at Bartolome, Galápagos Islands, August 2018

The Associates program continues to use the same basic model. In recent years, however, events organized by the Associates have expanded from individual faculty presentations to panels that may also include students and/or alumni with expertise in particular fields. For example, Associates recently heard from EAS faculty members Aaron Ames, Anima Anandkumar, Soon-Jo Chung, and Yisong Yue—who are making technological leaps and shaping our autonomous future—at a panel discussion called "Robots, Drones, and Machine Learning."

Approximately 25 percent of Associates members are alumni, while the remaining 75 percent are primarily non-alumni who live in the greater Pasadena region. Wilkins-Miller notes that being part of the Associates is a unique experience, one that offers a combination of travel, networking, mentorship, and the opportunity to connect on a deeper level with Caltech's dynamic, multifaceted community. Associates events and activities cover a range of regions and relevant topics, from finance and gene editing for East Coast members to startups, technology, and Mars 2020 for those in Northern California. There are chapters in New York City, Northern California, West L.A., and Orange County in addition to the Pasadena campus. The level of engagement varies in these chapters; alumni members, alongside members of the community, can serve on the Associates board and influence program development and travel ideas.

Left to right: Jessica Lee, Lelia Marshall, Nicola Wilkins-Miller, Catherine Reeves, and Cathy Axibal-Cordero

The Associates partnered with the Alumni Association on a recent trip to the Galápagos Islands—a prime example of how the organization integrates faculty, alumni, and the broader community. Rob Phillips, Caltech's Fred and Nancy Morris Professor of Biophysics, Biology, and Physics, accompanied the group to illuminate the untouched landscapes and habitats of this legendary volcanic archipelago and share his expertise on island biogeography and paradoxes in animal evolution.

Among the organization's aims is to encourage lifelong learning in the Caltech community and to serve, as Wilkins-Miller put it, "as a portal for the community to connect with the Institute"—especially since Caltech's small size allows for intimate interactions and an unusual degree of access to all Caltech offers. Membership isn't just for those who attended Caltech; it's open to anyone. "If you join the Associates, you become a donor," Reeves says. "You are investing in the future of the Institute." The Associates' philanthropic mission includes an increasing emphasis on funding student scholarships and graduate fellowships. They encourage the kind of interaction between faculty, students,

Panel discussion including Caltech professors Aaron Ames, Soon-Jo Chung, Yisong Yue, and Anima Anandkumar

alumni, and non-academic community members that can lead to interesting collaborations and research support.

The Associates' efforts are guided by the goal of making science more accessible through the discussions, networking events, and travel opportunities they organize for their members. Upcoming programs include a panel on what the future holds for Earth's climate with Tapio Schneider, Theodore Y. Wu Professor of Environmental Science and Engineering; as well as a dinner event with Yu-Chong Tai, Anna L. Rosen Professor of Electrical and Medical Engineering, which focuses on how Caltech's Andrew and Peggy Cherng Department of Medical Engineering is leading the way in designing systems for translational medicines, technology, and devices to be used now or in the near future by patients and doctors.

"Caltech has a Nobel Prize-winning history of leading at the forefront of scientific inquiry, from how atoms bond to advances in human genomics to detection of gravitational waves," says Associates board president Stephen Rogers. "Being a member of the Associates brings a person closer to those achievements. It promotes access to learning more about how science can positively affect the human condition. My family and I have been members for almost 30 years, and we continue to be impressed and amazed at the incredible research taking place here in Pasadena."

The Associates continue to create two-way opportunities for their members to play a vital role in the life of the Institute and for Caltech faculty and students to share their innovative work. "It's such a privilege to be able to give our faculty the opportunity to showcase their research, their divisions, and the future as they see it," says Reeves, "and this kind of intimate conversation with our community often yields great benefits for all involved." Wilkins-Miller explains that "it is not unusual for an Associates member to attend a faculty talk, a lab tour, or an event and be inspired to give of their own time and resources." One such example is the support of mechanical engineering undergraduate student Hana Keller, who has received an Associates-funded scholarship to work in the Advanced Mechanical Bipedal Experimental Robotics Laboratory with Professor Aaron Ames.

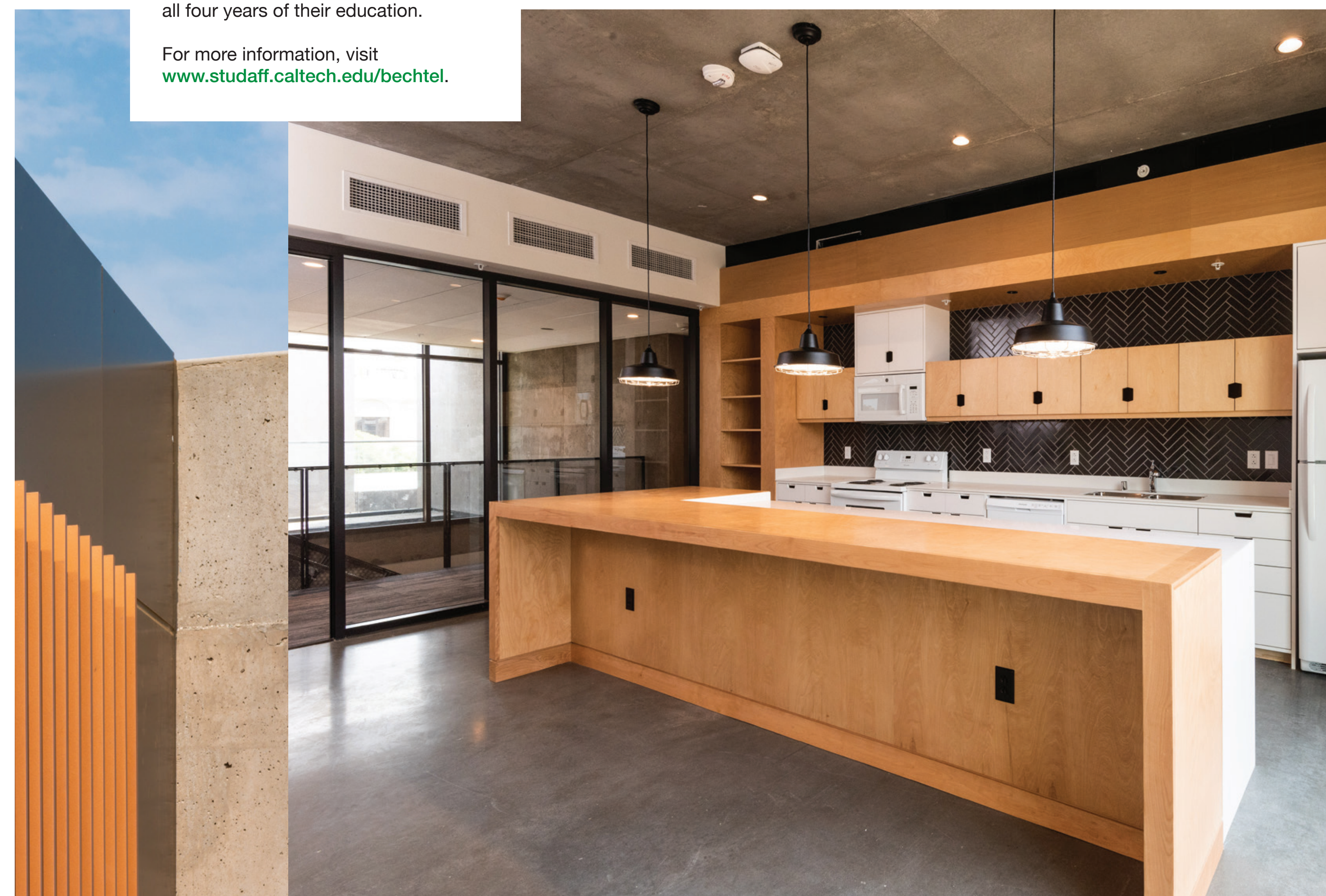
Top priorities for the Associates as the organization looks ahead to the next few years include improving and deepening the experience of members and amplifying efforts to showcase the transformative research being done at Caltech, such as work in EAS to make megacities more resilient. ENG

Cathy Axibal-Cordero and Marisa Demers are Assistant Directors. Jessica Lee is Program Support and Production Coordinator. Lelia Marshall is Membership and Services Coordinator. Catherine Reeves is Executive Director. Nicola Wilkins-Miller is Associate Director.

Visit associates.caltech.edu to learn more, or email caltechassociates@caltech.edu to subscribe to the Associates mailing list.

Caltech's newest undergraduate residence, the Bechtel Residence—named for Caltech life trustee Stephen D. Bechtel Jr.—officially opened its doors to students on Monday, September 17, 2018. Bechtel is a 211-bed multi-use residence that houses undergraduates from all class levels along with two faculty-in-residence, a half-dozen graduate resident associates, and a residential life coordinator. This 95,000-square-foot residence has six distinct but interconnected structures arranged around an expansive interior courtyard that is designed to promote serendipitous interactions. The number of beds in Bechtel have made it possible for Caltech to offer all of its undergraduate students the opportunity to live on campus throughout all four years of their education.

For more information, visit www.studaff.caltech.edu/bechtel.



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