FALL 2017

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Boston University College of Engineering

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SMART WINDOWS BRING THE LIGHT

TEAM BUILDING

ROBOTS LEARN TO WORK TOGETHER

BOSTON UNIVERSITY

Educating the Maker Generation for the Digital Economy

BY DEAN KENNETH R. LUTCHEN

Today, fully half of our graduates add a minor or concentration—including Technology Innovation, Nanotechnology and Energy Technologies, among others—to their foundational degree.

Today's engineering students are often referred to as the "Maker Generation." They are accustomed to applying their knowledge to hands-on projects even while still in high school, let alone when they enter college as freshmen. But the knowledge they need now and in the workplace is rapidly expanding beyond the scope of any single engineering major. As we move into the world of interconnected products, we have an obligation to give our students the tools and skills they will need to be successful in moving society forward.

That's why I believe the days of the single-discipline engineering degree have passed. While we will and should continue to award discipline-specific bachelor's degrees, we need to be sure all of our students are exposed to multiple engineering fields, regardless of their major.

When the College opened the Singh Imagineering Lab several years ago as a setting for extracurricular innovation, it was instantly popular and continues to be a place where our highly talented students can find an outlet for their impressive creativity. Later, we opened our extraordinary 20,000-square-foot Engineering Product Innovation Center (EPIC), a state-of-the-art facility where students could experience the entire concept-to-product process. Moreover, recognizing that the majority of real products integrate electrical, mechanical, computer and even biomedical engineering, we made knowledge of this product-design-to-distribution cycle part of every student's undergraduate curriculum.

It quickly became apparent that students are engaging multiple disciplines as they pursue innovation. Mechanical engineering students, for example, are delving into computer engineering, and vice versa. We responded to this by creating a suite of interdisciplinary concentrations accessible to all students. Today, fully half of our graduates add a minor or concentration—including Technology Innovation, Nanotechnology and Energy Technologies, among others—to their foundational degree. And while that number continues to grow, we are working on ways to ensure that every student has exposure to the skills engineers will need in the coming years.

For one, we want all freshmen to have the experience of making something, either in the Singh Imagineering Lab or in EPIC. By doing so, they will see how the challenging foundational coursework they are taking applies to actually engineering something. They will also get an initial look at how multiple engineering fields are integrated into the process of designing and making a product.

Programming and software are used in virtually all modern product design and manufacturing and are becoming increasingly relevant in our interconnected world, not to mention increasingly popular among our students. We require that all freshmen take a foundational course in programming and are modifying our curriculum to attract 75–100 percent of them to take more advanced programming courses later on.

Data science and analytics are rapidly emerging to drive virtually all future innovation in any field imaginable, from medicine to manufacturing to retail to organizational and urban function. Divining meaning from large data sets applies to all engineering fields and we are finalizing a transformation of our undergraduate curriculum to insure all students, regardless of major, take a course that provides some data science foundation, inclusive of statistics for large data sets and machine learning.

In addition to these requirements, we plan to offer an array of more advanced electives in areas like smart and connected systems, engineering data science and analytics, and robotics and automated systems. All will engage multiple disciplines and we believe they will be very popular. Adding these to our existing minors and concentrations will ensure that our students are prepared for the new economy, where virtually every new product interacts with the digital world in some way.

Several engineering schools have also begun to offer these kinds of courses and experiences, but, from what I have seen, most have done so at the individual department levels rather than as a broad foundation necessary for any engineering major. By this time next year, we will have fully designed and approved a more holistic and unique approach that opens all of these areas up to all undergraduates and will transform how we educate engineers to give them the depth they will need to innovate in the digital economy. ■

PHOTOGRAPH BY KALMAN ZABARSKY

PHOTOGRAPH BY MICHAEL D. SPENCER

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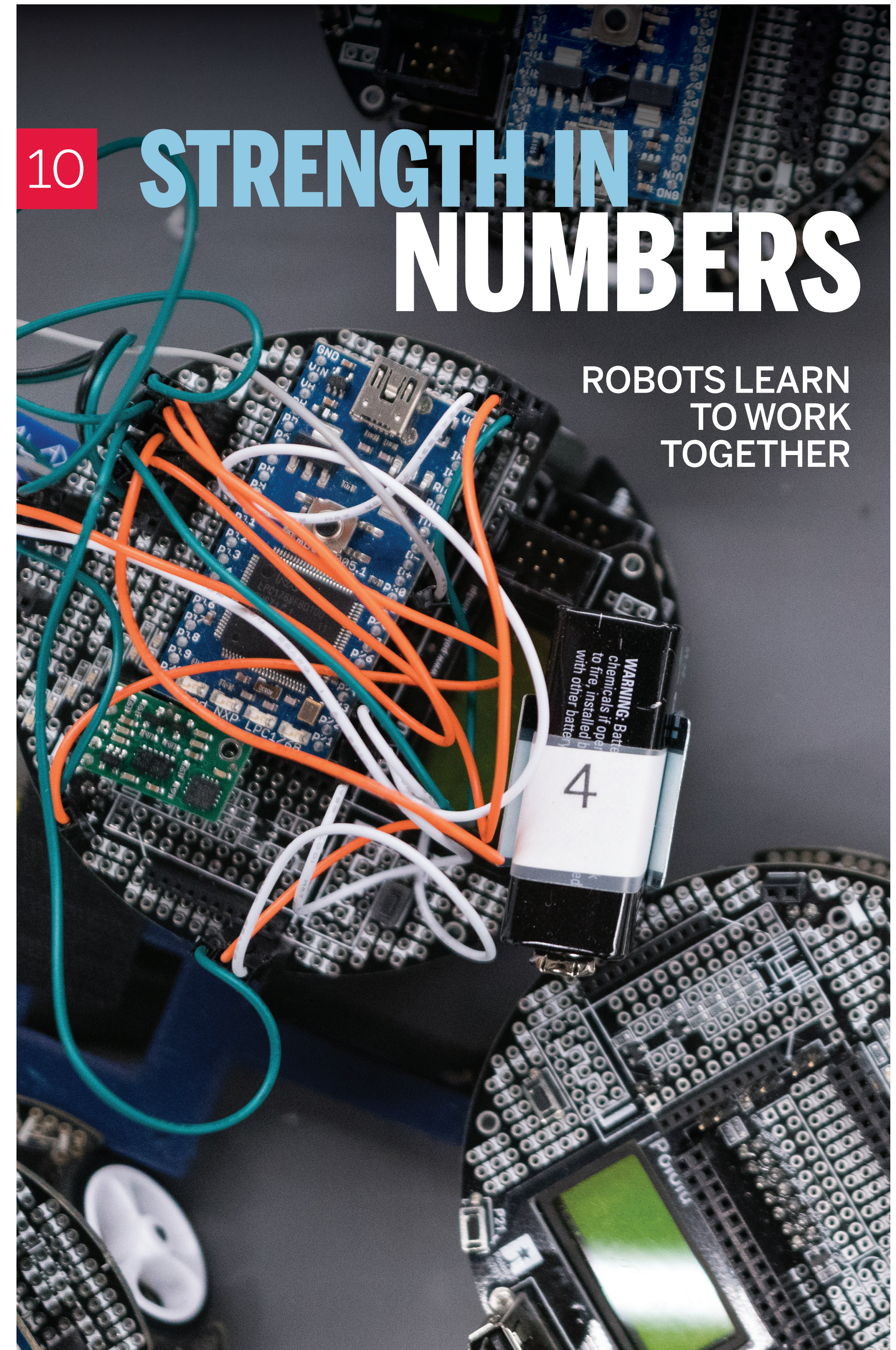

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BY SARA CODY

The new home of the Biological Design Center.

PHOTOGRAPH BY SARA CODY

Symposium Celebrates Grand Opening of Biological Design Center

KICKOFF EVENT HIGHLIGHTS MULTIDISCIPLINARY WORK IN BIOLOGICAL DESIGN

More than 200 researchers from industry, academia and healthcare gathered on campus June 1 to celebrate the formal launch of the Biological Design Center (BDC) and its new home, the just-completed, nine-story Rajen Kilachand Center for Integrated Life Sciences & Engineering.

According to Professor Christopher Chen (BME, MSE), founding director of the BDC, bringing together the community to explore synthetic biology—the engineering of living systems to understand, control and reengineer how biological components work—is a key portion of the mission.

"The purpose of the center is to build a new community, not just of faculty working on individual projects, but all of us working together," says Chen. "While not every BDC faculty member will be located there, having a central location acts as a catalyst for everybody to interact with each other and establish new collaborations."

The kickoff symposium, titled "Engineering the Future," featured an array of speakers from academia and industry who gave presentations on biological science and technology, as well as on their work with diverse aspects of biological design, ranging from molecular-scale investigations to tissue-level engineering and multicellular communities and communication. The community gathered in the Hariri Auditorium at Questrom School of Business to listen to the speakers before heading over to two poster sessions in the center's lobby, one at lunch and one in the evening, showcasing some of the research projects that BDC members have been developing. →

CONTINUED

Biological Design Center Opens

"Our vision is to use the center to branch out and make strong connections across the community, both in academia and in industry," said Chen in his opening remarks. "Connectivity across engineering, biology, physics, chemistry, medicine will be needed to make the vision a meaningful reality."

Deboki Chakravarti, a PhD student in the laboratory of Assistant Professor Wilson Wong (BME), was among the lineup of presenters during the morning session. She spoke to the audience about her research project focused on engineering T cells—an important component in the body's immune response—to provide the ability to tune the cells' behavior in the body. This would enable doctors to enlist the patient's own cells to fight against diseases like cancer.

"I've been in graduate school for a few years and the kickoff event was an exciting opportunity for me to have my first experience presenting my work in a formal setting," says Chakravarti. "It was great to interact with people outside of academia and in other industries, which I think is a key component of the mission of the BDC."

Professor Bonnie Bassler, chair of the Microbiology Department at Princeton University, presented the Charles Cantor Lecture, named in honor of Professor Emeritus Charles Cantor (BME), who pioneered a method for separating large DNA molecules, an important tool for biological research. Bassler's presentation focused on bacterial quorum sensing—the "languages" that bacteria use to communicate with each other to perform group tasks—and how to synthetically manipulate those systems to combat disease and improve human health.

"Charles' contributions to science are significant and his early support of synthetic biology helped to cultivate an environment of creativity, tinkering, unconventional thinking that we still maintain today and really helped put BU on the map," says Assistant Professor Ahmad "Mo" Khalil (BME), associate director of the BDC. "Bonnie's research spans everything from the science of a complex biological system to inspiring new tools that synthetic biologists use that she elucidated and all the way to human health implications. Her work speaks to the importance of team-based efforts and that synergizes well with the BDC."

Other presenters at the symposium included BDC faculty Associate Professor Douglas Densmore (ECE), Assistant Professor Allyson Sgro (BME), Associate Professor Pankaj Mehta (CAS), Assistant Professor Mary Dunlop (BME) and BDC laboratory team members, as well as distinguished speakers from academia and industry.

The Kilachand Center, which recently completed construction, boasts 170,000 square feet of space that brings together investigators in life science, engineering and medicine from both the Charles River and Medical Campuses. The BDC headquarters is located on the fourth and fifth floors of the center, which hosts six laboratories and the administrative offices, as well as collaborative space available to all BDC investigators. —**SARA CODY** ■

U.S. News Rankings

ENG EARNS HIGHEST-EVER RANKING IN *U.S. NEWS & WORLD REPORT'S* GRADUATE PROGRAMS LIST

The College of Engineering and several of its programs advanced and saw improved peer assessment scores in the latest *U.S. News & World Report* rankings of the nation's graduate engineering programs.

U.S. News now places the College 34th among the 198 engineering schools—all with graduate programs—that the publication ranked. This represents an 18-place advancement since 2006, the largest of any top-50 engineering school. The College's subjective assessment score among the nation's engineering deans climbed, as did its assessment by employers, both heavily weighted factors in *U.S. News & World Report*'s ranking methodology of engineering schools.

Among private engineering schools, the College ranks 15th nationally.

"The excellence of our faculty and their research continues to gain increasing recognition among our peers," Dean Kenneth R. Lutchen said. "This recognition is helping to fuel a virtuous cycle that attracts high-quality graduate students, who, in turn, help propel the College's research to ever-greater heights."

At 12th among 120 graduate BME programs and 6th among private schools, the Biomedical Engineering program continues to be ranked among the elite nationally. Its peer assessment score was the seventh-highest; a number of ties among higher-ranked schools edged it out of a top-10 spot. At the program level, subjective assessment by the respective department chairs nationally is the only factor used in ranking.

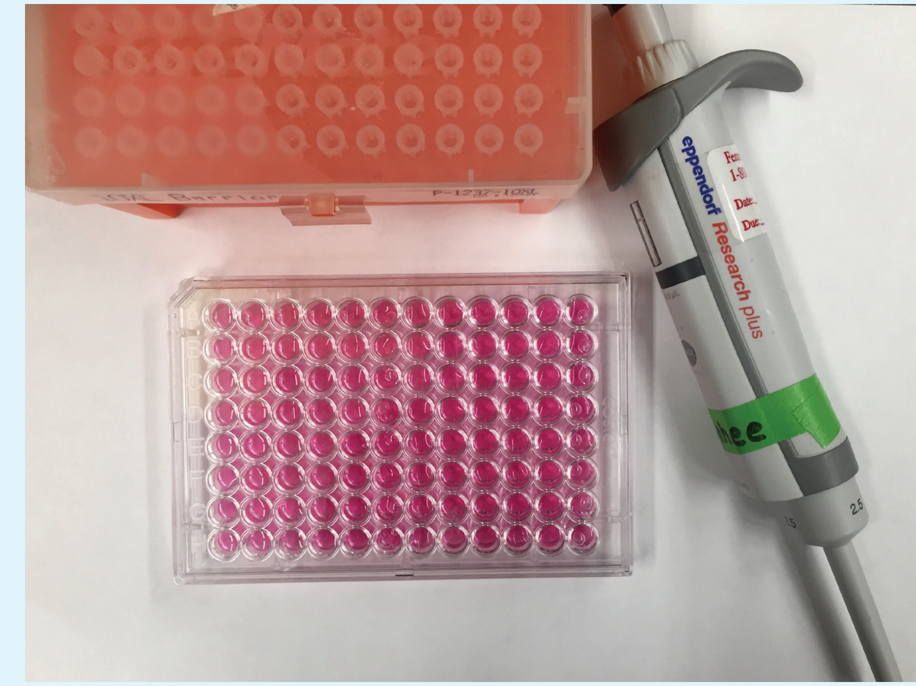
Other graduate programs significantly gained in this year's rankings. The Computer and Electrical Engineering programs recorded their highest-ever assessment scores and rankings—both placed 36th in their large categories—which represented jumps of six and seven places, respectively, over last year. The Mechanical Engineering program also notched a substantial advance—six places to 42nd in a field of 170 programs.

The relatively new Materials Science & Engineering program also recorded its highest score and rank since it started getting rated seven years ago with an 11-place jump into the 46th spot.

When comparing private universities only, every one of the College's programs is in the top 20.—**MICHAEL SEELE** ■

How to Hack a Cell

WONG'S NEW PLATFORM MAKES IT EASIER TO PROGRAM LIVING CELLS



BLADE, or "Boolean logic and arithmetic through DNA excision," will allow researchers to use different signals in one streamlined device to control the behaviors of the cells they target. Photo provided by Wilson Wong

The human body is made up of trillions of cells, microscopic computers that carry out complex behaviors according to the signals they receive from each other and their environment. Synthetic biologists engineer living cells to control how they behave by converting their genes into programmable circuits. A new study published by Assistant Professor Wilson Wong (BME), and co-authored by Research Assistant Professor Swapnil Bhatia (ECE), in *Nature Biotechnology* outlines a new simplified platform to target and program mammalian cells as genetic circuits, even complex ones, more quickly and efficiently.

"The problem synthetic biologists are trying to solve is how we ask cells to make decisions and try to design a strategy to make the decision we want it to," says Wong. "With these circuits, we took a completely different design approach and have created a framework for researchers to target specific cell types and make them perform different types of computations, which will be useful for developing new methods for tissue engineering, stem cell research and diagnostic applications, just to name a few."

Historically, engineered genetic circuits were inspired by circuit design in electronics, following a similar approach using transcription factors—proteins that induce DNA conversion to RNA—which are tricky to work with because it's hard to predict an entirely new strand of genetic code. Mammalian cells are especially difficult because they are a much more variable environment and express highly complex behaviors, rendering the electronics approach to circuit design time-consuming at best and unreliable at worst.

Wong's approach uses DNA recombinases, enzymes that cut and paste pieces of DNA sequences, allowing for more targeted manipulation of cells and their behavior. The result is a platform named BLADE, or "Boolean logic and arithmetic through DNA excision," referring to the computer language the cells are programmed with and the computations they can be programmed to carry out. BLADE will allow researchers to use different signals, or inputs, in one streamlined device to control the outputs, or behaviors, of the cells they target.

"The idea was to build a system simple and flexible enough that it can be customized in the field to get any desired outcome using one simple design, instead of having to rebuild and retry a new design every time," explains Benjamin Weinberg, graduate student in Wong's laboratory and first author on the paper. "Essentially, with BLADE, you can implement any combination of computations you want in mammalian cells. For this particular paper, we might not have built the particular behavior you need, but we wanted to illustrate that by using BLADE, you should be able to build the circuit you need to fulfill the behavior you are looking for."

The paper published in *Nature Biotechnology* outlines over one hundred examples of circuits that were successfully built using the BLADE platform. Weinberg notes that the researchers intentionally built complex circuits with complicated functions to illustrate the possibilities using their design, including some that program human cells to add or subtract numbers. He uploaded the design plans to an open-source online repository so that other researchers could begin downloading the tools to use in their projects immediately. Weinberg will continue to refine the technology and incorporate it into a software program to make it even easier to use, while Wong plans on using the platform to explore medical diagnostic applications.

"Before BLADE, any one of these circuits would have taken several years to build and make functional, and then you would have to use trial-and-error to make it work the way you want it to," Wong says. "I have been doing synthetic biology research for 15 years and I've never seen such complex circuits work on the first try like with this platform. We're excited to get it out there so people can start using it, and we're excited to see what they come up with."
—**SARA CODY**

College Creates New Precision Diagnostics Center

The road to commercializing medical technology is usually long, requiring the work of basic scientists, clinical researchers, engineers and eventually industry partners, with one group passing along knowledge to the next until a marketable version of the technology is finally realized. But what if the work of these groups could be combined, with each working toward a common goal simultaneously? Team science has the potential to make the process more efficient and bring medical innovations to the patient faster.

Professor Catherine Klapperich (BME, ME, MSE) hopes that the new Precision Diagnostics Center (PDC) she directs will do just that. She saw the potential that BU's diverse research portfolio offers and established the new interdisciplinary initiative that will capitalize on the synergy among faculty researchers to invent new medical diagnostic tools.

The PDC builds on the success, momentum and infrastructure of the NIH Center for Future Technologies in Cancer Care (CFTCC), which Klapperich also directs at BU and which will now fall under the umbrella of the new center. The PDC's mission will expand to include cancer and innovations that leverage point-of-care technologies to enable precision medicine across a wider swath of diseases. Researchers from the College of Engineering in collaboration with the BU schools of Medicine, Dental Medicine and Public Health will collaborate in the new center.

"This center comprises faculty across many departments of the University who are working on new ways to collect, measure and use patient data. We want to take the power of that data and put it into applications that can be patient facing either during an office visit or at home," says Klapperich. "After working on building the CFTCC for five years, a common refrain was 'Can we do this for other health-care areas?' We see the PDC as being one way to bring the engineering innovations we have developed in point-of-care diagnostics to the clinic earlier in the design process. Patient and provider input and acceptance are essential to the success of these technologies."

Point-of-care diagnostics allow clinicians, pharmacists and even patients themselves to conduct sophisticated molecular tests—like rapid strep throat tests, home pregnancy tests or blood-glucose monitoring in diabetes patients—in clinics and at home. The PDC aims to apply these innovations across a variety of areas using a three-pronged approach: developing new reagents and tests to make advanced patient monitoring possible; designing and creating the algorithms and devices that would house these technologies; and partnering with industry and government to translate innovations into the marketplace.

According to Klapperich, while there are other organizations and institutions that explore point-of-care diagnostics, this center is unlike any other effort in this space due to its unique research approaches. In addition to leveraging expertise from the Medical Campus, the PDC will also tap into the Photonics Center to explore using light-based technologies for noninvasive diagnostics and monitoring.

"The center will play to BU's unique strengths as a research university, including capabilities in infectious disease, expertise addressing healthcare disparities in underserved communities and our Photonics Center. We're excited to access those resources and expertise to make a global impact where it is most needed," she says.

Next steps for the PDC include hosting networking and professional development opportunities for faculty, students, postdocs and residents—such as workshops, seminars and symposia—to attract new members and continue building community. The other founding core faculty members of the PDC include: Professor Edward Damiano (BME), Professor Muhammad Zaman (BME, MSE), Professor Thomas Bifano (ME, MSE), Professor Mark Grinstaff (BME, Chemistry), Professor Thomas Little (ECE, SE), Professor Ioannis Paschalidis (ECE, BME, SE), Associate Professor James Galagan (BME, Microbiology), Assistant Professor Allison Dennis (BME, MSE) and Professor Avrum Spira (MED, SE).—**SARA CODY** ■

Neurophotonics Center Aims to Advance Understanding of the Brain

PHOTOGRAPH BY SCOTT NOBLES

David Boas, founding director of the Neurophotonics Center and an ENG professor, comes to BU from Mass General Hospital.

Efforts to understand the workings of the human brain have taken quantum leaps forward in recent years as researchers have developed noninvasive, light-based methods to observe its functioning in real time. Now, the College of Engineering is capitalizing on Boston University's interdisciplinary expertise in neuroscience and photonics to create the Neurophotonics Center, led by one of the nation's preeminent researchers in the field.

Professor David Boas (BME) is joining the faculty from Massachusetts General Hospital, where he has pioneered new technologies to see deep into the brain, in order to improve our understanding of the organ's healthy functioning and offer new pathways to understand how strokes, migraines, Alzheimer's disease and other neurologic maladies affect it. Boas, the center's founding director, is recruiting faculty from throughout the College of Engineering and across Boston University to pool expertise and further accelerate neurophotonics technologies.

"There are tremendous advantages to biomedical and photonics engineers working with neuroscientists," Boas says. "Neuroscientists have questions and problems that engineers want to solve. Those solutions advance the field and lead to new questions and new solutions. Boston University has a wealth of expertise in photonics, biomedical engineering and neuroscience that is excellent fuel for this virtuous cycle."

Many of the center's efforts will utilize multi-photon microscopy, a method that even 25 years after its advent is still accelerating in terms of its technological advances and impact in the neurosciences. In addition, the center will be developing and applying novel approaches to measuring human brain function with light.

Human functional brain imaging has been done for several years using fMRI scans, which produce sharp images of brain blood oxygenation and flow, key to seeing which areas of the organ are being stimulated at a given time. But fMRI scans require the subject to lay perfectly still in a confining machine for an extended period, not a natural state and a difficult procedure to use with infants, small children and others. They are also expensive.

Instead, Boas uses functional near-infrared spectroscopy, which penetrates through the scalp and skull as much as a centimeter into the brain, where it detects blood oxygenation, ultimately enabling the imaging of brain function. The images aren't as crisp as fMRI scans, but the wearable device allows the subject to move around naturally, engage socially and perform any number of activities while blood flow and oxygenation changes in the brain are observed in real time at a far lower cost. Furthering this research is expected to be one of the Neurophotonics Center's initial projects.

The Neurophotonics Center is expected to draw on the efforts of doctoral students through the new $2.9 million National Science Foundation Research Traineeship grant for neurophotonics, which awarded its first fellowships in summer 2017.

An array of faculty from the College of Arts & Sciences, Sargent College and the School of Medicine will join College of Engineering faculty in the center.—**MICHAEL SEELE**

New 3D Metals Printer Keeps EPIC on Cutting Edge of Product Design & Manufacture

GE DONATION GIVES STUDENTS, RESEARCHERS AN EDGE

More and more products—from custom-made orthodontic braces to hearing aids—are commonly made using 3D printing, and nearly every engineering school has 3D printers on which students can work. But virtually all of them print some form of plastic. With the addition of a metal-printing machine donated recently by General Electric (GE), the College of Engineering and the Engineering Product Innovation Center (EPIC) will remain on the cutting edge of education and research in this rapidly evolving field.

GE considered applications from 250 colleges and universities around the world before selecting just eight to receive a metals 3D printer. Boston University is the only engineering school in the Boston area to receive one.

As the range of materials used in 3D printing—or additive manufacturing, as it's known in industry—expands from plastics to metals, the commercial possibilities are expanding as well, says EPIC Director and Professor of the Practice Gerald Fine (ME, MSE). Students, as well as materials researchers and employers like GE, are eager to master the associated design and manufacturing challenges. Fine says the College's new Product Design & Manufacture master's degree program will particularly benefit from the addition of a metals printer, one of only about two dozen or so to be housed in engineering schools nationally.

"This will ensure that our new degree program is working with state-of-the-art tools in a rapidly evolving field," Fine says, adding that the machine will be integrated into the College's first graduate course in additive manufacturing.

"Adding metals to 3D printing changes the whole paradigm in design and manufacturing," he says. "The design rules are different. You are designing products differently." He notes that GE has begun 3D printing jet engine fuel nozzles. The nozzles used to be manufactured by assembling approximately 40 individual parts, but 3D printing reduces the part count to one.

The addition of metals to additive manufacturing also poses challenges for materials researchers, he says, noting that professors Soumendra Basu and Uday Pal (both ME, MSE) were involved in the effort to acquire the new machine.

"In additive manufacturing, the properties of metals can be different from what materials scientists are accustomed to. Also, the range of metals that can be 3D printed now is small, so there is interest in developing new materials."

The donation marks a further deepening of the relationship between the College, EPIC and GE. The company has been on EPIC's Industrial Advisory Board since EPIC's inception.

"They understand what we are trying to do and they've given us an understanding of their needs, which includes hiring more students who understand additive manufacturing and digital design. It's a win-win," Fine says.
—**MICHAEL SEELE**

3D-Printed Patch Helps Guide Growing Blood Vessels

NOVEL METHOD PROVIDES POTENTIAL TREATMENT FOR ISCHEMIA

Ischemia results when narrowed, hardened or blocked blood vessels starve tissue, often resulting in heart attack, stroke, gangrene and other serious conditions. Surgery can correct the problem in large vessels, but treatment is much more complex in vessels that are smaller or damaged by prior treatment. Professor Christopher Chen (BME, MSE), director of BU's Biological Design Center, is developing a method using 3D-printed patches infused with cells that offers a promising new approach to growing healthy blood vessels.

Chen—together with clinical partners C. Keith Ozaki, MD, FACS, a surgeon at Brigham and Women's Hospital who has expertise in leg ischemia, and Joseph Woo, MD, the head of cardiothoracic surgery at Stanford University—has developed a patch that fosters the growth of new vessels while avoiding some of the problems of other approaches. Their research is published in *Nature Biomedical Engineering*.

"Therapeutic angiogenesis, when growth factors are injected to encourage new vessels to grow, is a promising experimental method to treat ischemia," says Chen. "But in practice, the new branches that sprout form a disorganized and tortuous network that looks like sort of a hairball and doesn't allow blood to flow efficiently through it. We wanted to see if we could solve this problem by organizing them."

Chen and his colleagues designed two patches with endothelial cells—one where the cells were pre-organized into a specific architecture and another where the cells were simply injected without any organizational structure. In vivo results demonstrated the patches with pre-organized structure reflected a marked improvement in reducing the prevalence of ischemia, while the patches with no organization resulted in the "hairball" situation as described by Chen.

"This preclinical work presents a novel approach to guide enhanced blood flow to specific areas of the body," says Ozaki. "The augmented blood nourishment provides valuable oxygen to heal and functionally preserve vital organs such as the heart and limbs."

To 3D print vessels on such a small scale—100 microns, small enough for tiny blood vessels—Chen leveraged his connection to Innolign, a Boston biomedical technology company he helped found. The 3D-printing approach allowed researchers at Innolign and Chen's group to quickly change and test their designs, which helped them discern which patterns worked well. In addition, the 3D-printing technology allows for scalability, which will be helpful going forward as they move to test their designs in larger, more complex organisms and tissue environments.

"One of the questions we were trying to answer is whether or not architecture of the implant mattered, and this showed us that yes, it does, which is why our unique approach using a 3D printer was important," Chen explains. "The pre-organized architecture of the patch helped to guide the formation of new blood vessels that seemed to deliver sufficient blood to the downstream tissue. While it wasn't a full recovery, we observed functional recovery of function in the ischemic tissue."

Chen notes that while the results of this project are promising, this approach is still in early stages. Going forward, his team will continue working on the scalability of the patches, while experimenting with different architectures to see if there is a structure that works even better than what they have tried so far.

"This project has been long in the making, and our clinical collaborators have been indispensable to the success of the project," he says. "As bioengineers, we were focused on how to actually build the patch itself, while the clinical perspective was critical to the design process. We look forward to continuing our partnerships as we move forward."

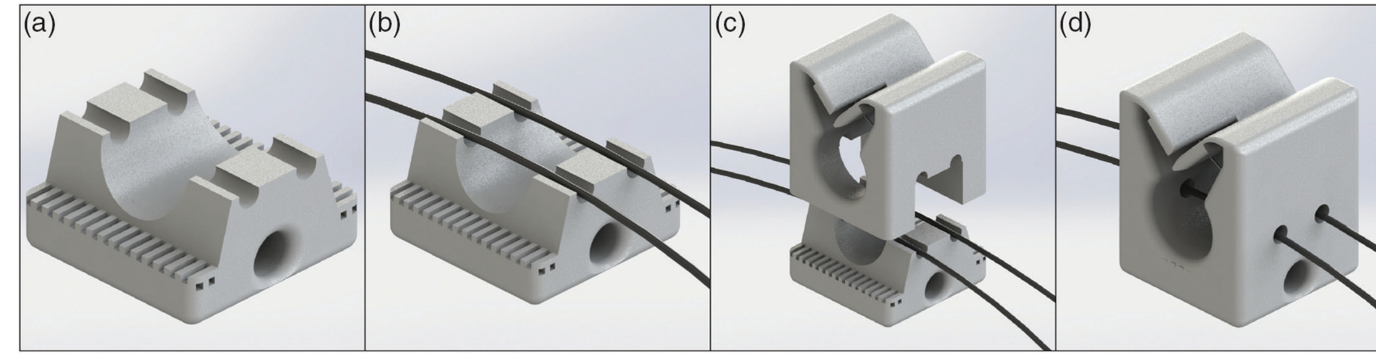
—SARA CODY

Dean Lutchen Visits Fifth-Grade Class to Inspire Students

Dean Kenneth Lutchen took a hands-on approach when he made a presentation to a fifth-grade class at the Joseph R. Dawe, Jr. Elementary School in Stoughton, MA. He's made the trip before—his daughter is the fifth-grade teacher there. He spent his visit showing the students how engineers invent new technologies that improve society and walked them through the invention process—from idea to patents to commercialization—that brings technologies into use, hopefully inspiring some of them to think about their future careers.

—MICHAEL SEELE

PHOTO PROVIDED BY DEAN LUTCHEN



The nanoclip printing process. a) The base is printed first and b) two CNTf conducting electrodes are manually inserted. c) The top half of the clip is printed. d) The final device contains two "trapdoors" on flexible hinges that allow the nerve to pass through and rest on the interior, locking it inside. Image from the Journal of Neural Engineering.

IMAGE FROM THE *JOURNAL OF NEURAL ENGINEERING*

Nanoscale 3D Printing Enables Bioelectric Medicine Research

When Professor Alice White (ME, MSE, Physics, BME) came to BU in 2013 as chair of Mechanical Engineering, she was keen to encourage the sort of cross-disciplinary research she had experienced as chief scientist at the storied Bell Labs. For her own research, she set up a powerful 3D-printing tool with nanoscale resolution—at the time, one of only three labs in the country with this tool. In addition to her personal projects, she hoped to attract collaborators whose research could be advanced using this capability.

An early realization of this hope came when, at the invitation of BU President Robert A. Brown, she gave a presentation to visitors from Singapore about her laboratory's ability to design and print on such a small scale. Afterward, she was approached by Professor Timothy Gardner (Biology, BME), who had also presented, about his research challenge in measuring nerve activity in songbirds. Their collaboration blossomed quickly. The fruit of their partnership, a nanoclip just twice the width of a human hair, is the focus of the cover article in the June issue of the *Journal of Neural Engineering*.

Gardner's research team was working on experiments to stimulate and measure electrical activity in tiny nerves in zebra finches, but they found the attachment they used was too big and stiff for the delicate nerve, causing damage that led to inaccurate measurements.

"Professor Gardner mentioned how the current technology for attaching to the peripheral nerve in a zebra finch was cumbersome and caused damage and scarring," White says. "We had a conversation in the morning about that challenge, came up with a solution, designed it that afternoon, printed it overnight and, the next morning, had the first version in Professor Gardner's hands."

"The nerve interface devices that are required to advance this emerging field must be very small but also must be very securely attached to a nerve for prolonged periods of time," Research Assistant Professor Timothy Otchy explains. "Though our lab had quite a bit of experience developing microelectrodes, we found that reliably making devices at that small a scale was extremely challenging." Otchy is managing Gardner's laboratory while Gardner spends a year as one of the first employees in Elon Musk's headline-grabbing new start-up in this field, Neuralink.

Birdsong is not only an important avian communication tool, it also provides a reliable platform to study nerve damage because of its high sensitivity to change and the easily quantifiable outputs it produces. One of the areas Gardner focuses his research on is the emerging field of bioelectronic medicine, or controlling nerves by blocking or stimulating signals, which could provide a better alternative to treat a variety of diseases, such as rheumatoid arthritis and chronic pain.

Charles Lissandrello (ME'09,'12,'15), working as a postdoctoral associate in White's laboratory, spearheaded the design of the device, working in tandem with Gardner's research team. Two initial designs proved ineffective or unwieldy, but the third design was successful.

"The design described in our paper had two 'trapdoors' with flexible hinges that would allow the nerve to pass through and lock the nerve inside, with a semi-cylindrical interior where the nerve could rest. Using our device, we were able to both stimulate and record neural activity successfully," says Lissandrello. "Ultimately, the nanoclip is a tool which addresses many challenges associated with interfacing with small-diameter nerves in the peripheral nervous system, and we hope it will enable others to conduct studies which would not have been previously possible."

According to White, while this technique may not lend itself to mass produce large batches of these tools, the fast turnaround time between design, production and implementation made it a great option for conducting science experiments, because they happen on a much smaller scale. White will continue to work with Gardner's research group to speed up the printing process so it could become scalable for manufacturing. She also intends on extending the nanoclip design to include optical sensing, where optical fibers are incorporated into the sensor for use in areas such as optogenetics.

"The feedback from the surgeon about the ease of use was quickly incorporated in the design, which had several iterations. Because we could run through the iterations quickly, it made this a successful experiment," says White. "It's a simple thing, but it fulfilled a need to move the science forward, and I look forward to more opportunities to collaborate with other faculty researchers in the future."**—SARA CODY**

STRENGTH IN NUMBERS

ROBOTS LEARN TO WORK TOGETHER

BY SARA CODY

Calin Belta

PHOTOGRAPH, LEFT, BY MICHAEL D. SPENCER; TOP, BY DANA SMITH

Agriculture. Automotive. Medicine. Biotechnology. Name an industry, and Professor Calin Belta (ME, SE, ECE) can tell you how the field of robotics will impact it—if it hasn't already. Robots are going to significantly aid in allaying some of society's greatest problems and stressors in a variety of ways, from performing automated tasks, to helping with housework to preventing dangerous situations. As they grow smarter, robots will also become more autonomous.

Many of the largest, resource-rich companies in the country—including Google, Amazon and Uber—are now investing in creating autonomous robots. Since it doesn't make sense for an academic institution to compete with these deeply resourced companies financially, BU researchers are taking a number of unique approaches to advance the field, namely, improving the systems to make them work better. →

Flying and ground-based autonomous vehicles of many types are being developed and tested in the Robotics Lab (left). Professor Christos Cassandras (ECE, SE) and research team members from a collaborative grant awarded by the Energy Department's Advanced Research Projects Agency-Energy NEXTCAR program display the vehicle they will turn into an autonomous smart car (right).

"My group brings in this kind of rigorous thinking that people use from computer science so we can use these platforms in dynamical systems and robotics to come up with smarter ways to control them," Belta explains. "We do this by bringing together two fields; one is machine learning and the other is formal methods, which is highly theoretical and seeks to prove the correctness of systems by developing mathematical algorithms to ensure what you make does what it's supposed to do."

The College of Engineering supports interdisciplinary research with resources like the Belta-directed Robotics Lab, located behind the Engineering Product Innovation Center (EPIC). His research group, the Hybrid and Networked Systems (HyNeSs) lab, focuses on making robots smarter and able to perform tasks autonomously. Improving upon machine learning—the mechanism that allows robots to become smarter as researchers track their progress—offers valuable insight that in turn helps to answer other questions.

Compared to developing an algorithm that predicts outcomes neatly, machine learning is messy because it does the exact opposite. Machine learning happens through trial and error, through which the robot learns from the data that is immediately available to it without any background or context. However, the process provides important insight into how neural connections are made as the machine learns, which can improve systems going forward. Belta seeks to improve this process by cleaning up the process of machine learning and making it more rigorous, or, as the industry refers to it, explainable.

"Understanding the 'how' of an idea working is crucial to improving it and making it smarter," Belta says. "It's one thing if an image algorithm that classifies between cats and dogs makes a mistake, and another thing entirely if a safety-critical system fails, like in a space application where lives depend on it working the way it's supposed to."

Funded by the Department of Defense, one of Belta's projects concentrates on persistent surveillance, where teams of robots are sent out to survey an area. Belta uses motion capture technology and floor projections in the Robotics Lab to run disaster relief scenarios, where the goal is to send a robot into a disaster zone and have it find its way through collapsed buildings and debris.

"The idea is to create heterogeneous robots both in the air and the ground that can go into an unknown or hostile environment," he says. "Instead of sending in people to survey an area, you can send in a robot to identify enemies, collect and interpret data, and move around this unknown environment so they don't collide into things."

Belta and his team plan to use robots to build a map, identify areas of interest and locate survivors. They want the robot to not only be

> **BELTA USES MOTION CAPTURE TECHNOLOGY AND FLOOR PROJECTIONS IN THE ROBOTICS LAB TO RUN DISASTER RELIEF SCENARIOS, WHERE THE GOAL IS TO SEND A ROBOT INTO A DISASTER ZONE AND HAVE IT FIND ITS WAY THROUGH COLLAPSED BUILDINGS AND DEBRIS.**

able to gather important data about disaster zones, but also demonstrate self-awareness in terms of knowing when it has to return to recharge. In addition to disaster relief and military applications, the technology could be used agriculturally to survey crops.

"Right now, we are working to address technical questions like how we track movement outside of a controlled environment, or even without GPS, which would be useful in military situations where activating GPS is dangerous," Belta notes. "Answering those fundamental questions about localization is important and helps answer other important questions like how we have the robots actually move around and collect data, or even recognize survivors in a disaster scenario."

Other engineering disciplines are also exploring this exciting field—faculty members in electronic and computer engineering, as well as biomedical engineering, are looking into ways we can use robotics and autonomous systems to benefit society in a variety of applications.

PHOTOGRAPH, TOP LEFT, BY MICHAEL D. SPENCER; TOP RIGHT, COURTESY OF CHRISTOS CASSANDRAS

PHOTOGRAPH BY CONOR DOHERTY

CONNECTED CARS

The driest period in California history began in 2011 with a drought that lasted until April of 2017. Prolonged, rainless periods resulted in vast expanses of forest land becoming kindling for fires, as the *Los Angeles Times* reported that firefighters were battling "larger and more aggressive wildfires as drought conditions [continued]." Unless caught quickly, in many cases the fires would grow so large and unwieldy by the time help arrived that they could not be contained. Fire does not discriminate in its path of destruction, and countless wildlife and human homes alike were destroyed.

Imagine a fleet of robots—hundreds of small, inexpensive machines equipped with sensors that survey a given area for incidents of extreme heat and temperature—deployed in a dried-out national forest. If one robot picks up on a major temperature fluctuation, it can call on two or three of its comrades to come and assess the situation (if the robots are mobile rather than stationary, and the collective data accurately representing the situation can be relayed back). And perhaps the robots can act on the information and begin the process of quenching the flames if the fire has already begun. According to Professor Christos Cassandras (SE, ECE), when it comes to autonomous systems, there is strength in numbers.

"Autonomy means that a device has the ability to not only guide itself without the continuing participation of an operator, but also to make decisions and change its behavior accordingly," he says. "Intelligence is part of autonomy, the ability to sense the environment and react to different conditions, above all to communicate and cooperate. But cooperation is also integral to autonomy as well.

What you don't want is one robot or one big computer to control everything. That leaves the system vulnerable to security breaches, it's expensive and it has a single point of failure. If that computer or robot goes down, you're done."

Cassandras and his research group, the Control of Discrete Event Systems (CODES) laboratory, are interested in Smart Cities; much of their research focuses on making teams of robots work together in order to address problems in society. One such project involves connecting autonomous vehicles wirelessly to create an "internet of cars" that can communicate with each other and their surroundings. Cassandras points out that humans are terrible drivers—we drive when we are tired and stressed; we can't see all around us at any given time; we get distracted; we don't react quickly enough to environmental stimuli. But computers thrive in this type of environment, which is why he seeks to create what is essentially an internet of autonomous cars to make driving safer, more efficient and less stressful.

"Most of the time when you develop new technology, there are a number of tradeoffs, but with autonomous cars, once the technology is in place, the result is a win-win-win," he explains. "You win because you cut down congestion and shorten travel times. You win because you save energy. You win by protecting the environment more by decreasing the amount of toxic emissions."

Working with researchers at the University of Delaware, the University of Michigan and the Oak Ridge National Laboratory, and with Bosch as a corporate partner, the group received a $4.4 million grant from the Energy Department's Advanced Research Projects Agency-Energy NEXTCAR program. The project goal is to design a control technology that enables a plug-in hybrid car to communicate with other cars and city infrastructure, and act on that information. Cars

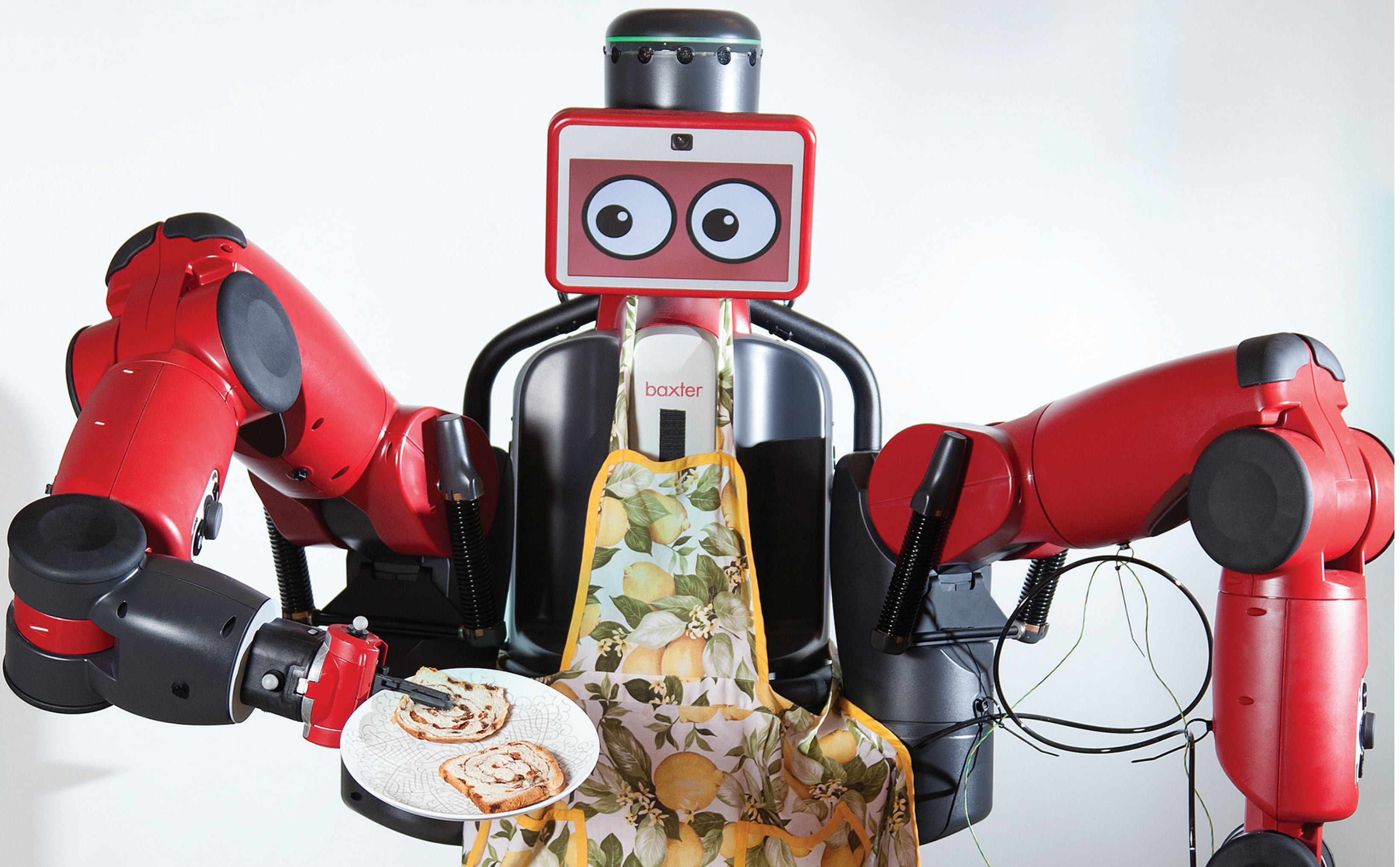
Christos Cassandras

> **THE PROJECT GOAL IS TO DESIGN A CONTROL TECHNOLOGY THAT ENABLES A PLUG-IN HYBRID CAR TO COMMUNICATE WITH OTHER CARS AND CITY INFRASTRUCTURE, AND ACT ON THAT INFORMATION.**

with situational self-awareness will be able to efficiently calculate the best possible route, accelerate and decelerate as needed and manage their powertrain.

"My vision is not the Google car, which is full of expensive hardware and software, because you don't need expensive computers to make autonomy possible," Cassandras says. "It's connectivity that we need to make it happen, GPS that can tell us where we are and our relative distance towards one another and our goals—and that's where it's really going to pay off. That will require new hardware, but not necessarily expensive hardware."

Currently, obstacles like stoplights, heavy volume and poorly designed infrastructure that causes bottlenecking contribute to heavy traffic. The constant stopping and starting not only wastes energy, but also expels the most harmful emissions into the atmo-



MAKING TOAST BY TRIAL AND ERROR

BY SARA CODY

His name is Baxter and today he's learning to make toast. Three feet tall and featuring red robotic arms and an animated face, the humanoid robot stands in front of the toaster in the experimental arena of the Robotics Laboratory, where he will teach himself—through trial and error—how to pick up a slice of bread, insert it into a toaster, turn the toaster on and remove the toast once it's done. This seemingly simple task is performed by the 300-pound, $30,000 robot from Rethink Robotics to demonstrate the process of machine learning.

"Baxter demonstrates machine learning with the toast experiment because he is going into an environment where he knows nothing about making toast, and after a long process of trying and failing, he learns how to do it," explains Robotics Lab Director Professor Calin Belta (ME, SE, ECE). "He is just one of many robots in the lab, and we are making him smarter by having him interact with his environment. It's one of many ways we work with robots in here."

Assistant Professor Roberto Tron's research in computer vision—a mathematical field that aims to enable computers to interpret and understand real-world images—also puts Baxter to work. Baxter allows Tron, who works in the Robotics Laboratory located behind the Engineering Product Innovation Center (EPIC), to research ways of making manufacturing and industrial processes more efficient using computer vision.

"Right now, there's a change occurring in industrial robotics," Tron says. "In the eighties, there was a big development wave of robots in industry, where you had really large robots in a long assembly line. The new wave is small-batch operations."

The Robotics Lab features an experimental arena that looks like a cross between a hockey arena and BattleBots ring and consists of a motion capture system containing more than 50 infrared cameras and several short-throw projectors that can create dynamic images on the floor. Reflective balls on the robots allow researchers to track their movements with infrared as the robots perform various tasks in the arena.

The BU Robotics Lab is also home to a workshop where lab members design and construct robots, an open-concept student workspace, and a soundproof, wireless conference room that makes it easy to work with colleagues off campus. Numerous whiteboards adorned with scribbled notes from brainstorming sessions are scattered throughout the lab, attesting to the collaboration that takes place within. The facilities also host graduate students conducting research in robotics, and three new faculty members will join the lab later this year.

"BU is really investing in this area and that is easy to see because we are attracting faculty members from prestigious institutions to join up with us," Belta says. "Robotics is set to impact many areas that involve repetitive tasks because they can do it better, cheaper, faster and with fewer safety limitations. The area is only growing hotter."

Rachel Riley also contributed information to this story.

PHOTOGRAPH, RIGHT, BY MELISSA OSTROW; LEFT, BY DANA SMITH

sphere. Traffic has a significant impact on lifestyle as well, as a long, rush-hour journey to work is hugely stressful for many commuters; anyone who has commuted to or around Boston can attest to the need for a new mode of transportation.

"Five years ago, this could have been considered science fiction, but we are already starting the culture shift towards acceptance," Cassandras notes. "And it will take work to address certain challenges, like the technology, security, privacy and other social challenges, like legal aspects of accountability. But it's an exciting time to be doing this work because BU is approaching this from every angle. It's very interdisciplinary, and that is a key takeaway."

HARNESSING AUTONOMOUS MICROBES

While robots and cars might seem obvious candidates for autonomous systems, Professor James Galagan (BME, CAS) envisions systems that can monitor our health on a much smaller scale. He is working toward harnessing the power of microbes, which he believes can be designed to home in on specific biological signals autonomously, offering a portable and inexpensive method to sense biology.

"Right now, our autonomous technology in biology is blind to a big chunk of the world because when it comes to being able to sense other biology with the level of specificity and sensitivity needed, we just aren't there yet," Galagan says. "When it comes to sensing things like biochemicals, the sensors themselves are the key because they are essentially the eyes for the entire system."

A biomedical engineer who spent 12 years working in genomics at the Broad Institute of MIT and Harvard mapping genomes, Galagan determined that since bacteria have been exposed to a diverse set of stimuli over millions of years, they have evolved a vast number of molecular mechanisms to sense and respond to their environment. Knowing that, he saw an opportunity not only to learn from microbes, but also to salvage them for parts to use in our technologies.

"We want to identify those parts, pull them out of the bacteria and embed them in our own devices by converting biological parts into electronic parts," he explains. "But how do we go into nature and essentially shop from nature's shopping list of parts that is written in a language we don't understand yet? The genes that we get from a microbe gives us access to the best recipe that three billion years of evolution has come up with and once we have the schematic of the microbe, we can tweak the recipe in order to improve it for our purposes."

While today's portable sensors are biased to physical and electromagnetic stimuli, Galagan wants to create sensors sensitive enough to pick up on biochemistry such as enzymes, proteins, DNA and other biochemicals that can be used to monitor health. His idea has precedent in the single most successful biological sensor available: the glucose monitor, used by diabetic patients to monitor blood sugar. The glucometer employs an enzyme, glucose oxidase, which evolved in microbes to help digest glucose. Much later, the enzyme was incorporated into a machine to do work for us. Galagan points out that this singular success is just the tip of the iceberg.

Current efforts to develop biological sensors depend on a limited number of molecular parts available in biochemical catalogs. "Our goal is to cut out the middle man and head straight into nature to identify parts of bacteria that would work well in sensors. We don't want to use the bacteria themselves because it would require keeping a living cell alive, which is hard to do, and I don't know many people who would want to attach different bacteria to our bodies," Galagan says. "Taking the parts out of microbes avoids this problem. And thanks to the glucometer, we know this idea can work. There is no reason to believe that glucose oxidase is the only enzyme that would work well in our sensors. It would be highly unlikely that we have hit the only jackpot on the first try."


James Galagan

THE CENTER WILL BRING TOGETHER A MULTIDISCIPLINARY GROUP OF ENGINEERS, SCIENTISTS AND MEDICAL PROVIDERS TO IDENTIFY NEW OPPORTUNITIES TO IMPROVE UPON DIAGNOSTIC PROTOCOLS.

Galagan is a founding member of the Precision Diagnostics Center (PDC), a research center that seeks to leverage point-of-care technologies to enable precision medicine across a wider swath of disease areas, building upon the success of the Center for Future Technologies in Cancer Care (which will now fall under the umbrella of the PDC). The center will bring together a multidisciplinary group of engineers, scientists and medical providers to identify new opportunities to improve upon diagnostic protocols. While this technology is poised to significantly impact the healthcare industry with the advent of surgical robotics and other healthcare-related systems, Galagan's vision is to incorporate a cultural paradigm shift that empowers people to think about their health before they get sick.

"These sensors are great for health applications, but I am keen on empowering the average Joe in terms of wellness. There will be a time in our lives when our technology will be able to beam much information about your biology at you, and this accessible information will impact how people make informed decisions about their lifestyles," he says. "It's not only about disease and only checking under the hood when you're sick. It's about enhancing overall wellness and lives." ■

WEARABLE WINDOWS INTO BREAST CANCER

DARREN ROBLYER IS DEVELOPING TECHNOLOGY TO HELP DOCTORS CHOOSE THE BEST THERAPIES

BY ELIZABETH DOUGHERTY

ILLUSTRATION BY HANNA BARCZYK

When Assistant Professor Darren Roblyer (BME) set up his Biomedical Optical Technologies Lab (BOTLab) at BU after arriving in 2012, he immediately started cold-calling doctors. He told them about a device he'd made, a new way of imaging tumors that could help cancer patients. It's worth your time, he told them.

His device uses diffuse optical spectroscopic imaging (DOSI) and Roblyer helped develop the technology while a postdoctoral fellow at the University of California, Irvine. The technology sends near-infrared light into tissue and measures what is reflected back, allowing doctors to peer several centimeters under the skin into breast cancer tumors and see their response to chemotherapy. Readouts are instantaneous, and preliminary studies offer hope that the technology may someday provide doctors with information that currently eludes them: an immediate alert when drugs aren't working.

"It's a window into the tumor. You can actually see what's going on biologically without taking a biopsy," says Professor Catherine Klapperich (BME, ME, MSE), associate dean for research and technology development.

Breast cancer is typically diagnosed with a biopsy after an abnormal mammogram; doctors rarely do additional imaging or biopsies to track progress. Rather, they prescribe a treatment plan, and for the most part, stick with it. The plan varies depending on the genetic makeup of the tumor, the tissue structure and the size. For some women, particularly those with large tumors that would be difficult to remove without taking the entire breast, doctors prescribe medicine to shrink the tumor first.

The medicine typically includes chemotherapy, which has a range of debilitating side effects. But most women respond extremely well to this therapy—five years later, 75 to 90 percent are cancer-free, according to Naomi Ko, a School of Medicine assistant professor of hematology and medical oncology and a breast oncologist at Boston Medical Center (BMC).

It's the remaining 10 to 25 percent Roblyer hopes his device will help. These women don't respond to the chemotherapy and spend months suffering its side effects without any benefit. Currently, says Ko, the best tool she has to determine if a patient is responding is to feel the tumor with her fingers and get a rough measure of its size using a ruler. "What you don't want is the tumor to grow, meaning the chemo is not working," she says. "That happens. I've had to send a patient emergently to the operating room for surgery."

If clinical tests over the coming years confirm his early results, Roblyer hopes his device will provide doctors with better information more quickly, so they can change a patient's treatment plan and avoid wasted time and emergency surgeries. "We'd like to prevent patients from undergoing months of ineffective treatment," he says. "The idea is to use optical feedback to personalize and improve treatment for each patient."

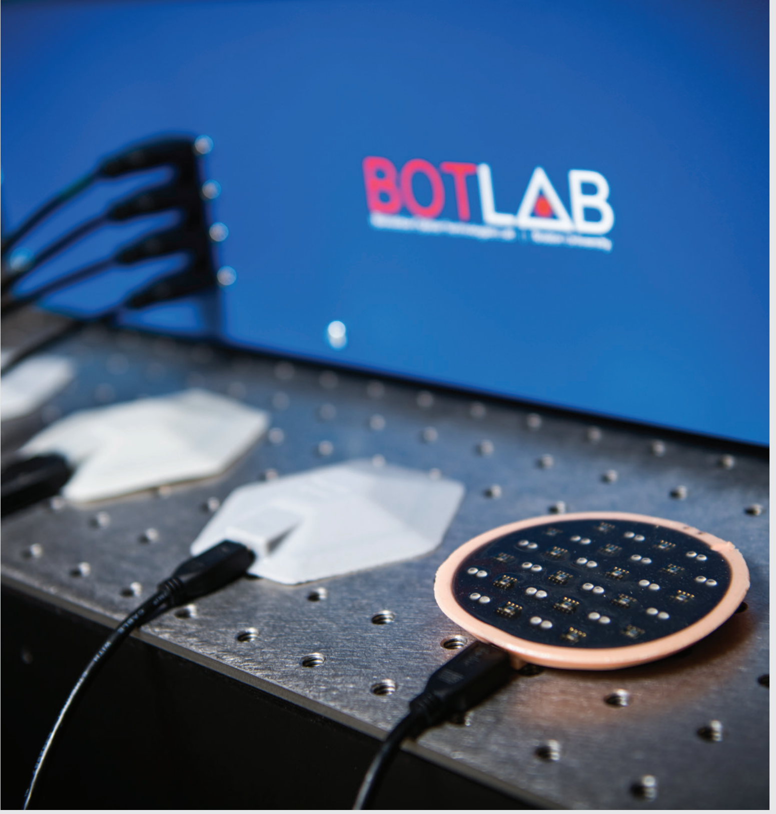
BREAST CANCER IS TYPICALLY DIAGNOSED WITH A BIOPSY AFTER AN ABNORMAL MAMMOGRAM; DOCTORS RARELY DO ADDITIONAL IMAGING OR BIOPSIES TO TRACK PROGRESS.

At UC-Irvine, Roblyer and his colleagues used DOSI to measure several dozen breast cancer patients, all of them treated with chemotherapy to shrink tumors prior to surgery. Roblyer analyzed the data, looking for signals that might be connected with a good outcome—and he found one. In women whose tumors responded to chemotherapy, the DOSI images revealed a flare, a data spike that occurred early in treatment. The flare appeared within 24 hours of infusion with chemotherapy and represented an influx of oxygenated red blood cells into the tumor.

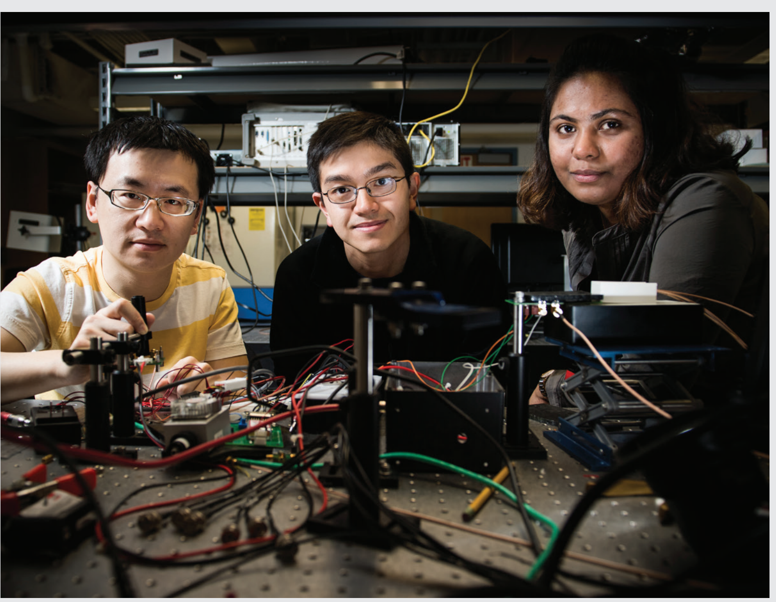
It isn't clear yet exactly how the flare contributes to tumor shrinkage. When Roblyer came to BU, his priority was to start larger studies to validate his findings about the flare. He had reduced the size of the DOSI equipment needed to take measurements and wanted to get his new technology into a clinical trial. Earlier versions of the back end of the device, the part that produces the laser light, were the size of a refrigerator, but his current versions can be carried like a briefcase. "It gives us access to patients in new places, like the infusion suite at a cancer center," he says.

His phone calls and emails to BMC oncologists led him to Ko, who agreed to run a clinical trial with him to test his technology. At this point, the tests involve collecting data from patients as they undergo chemotherapy prior to surgery. Roblyer and Ko will analyze that data to determine if his earlier findings hold up in a larger group of women. If so, it will add to the evidence that the device could help doctors improve care for patients who don't respond to chemo.

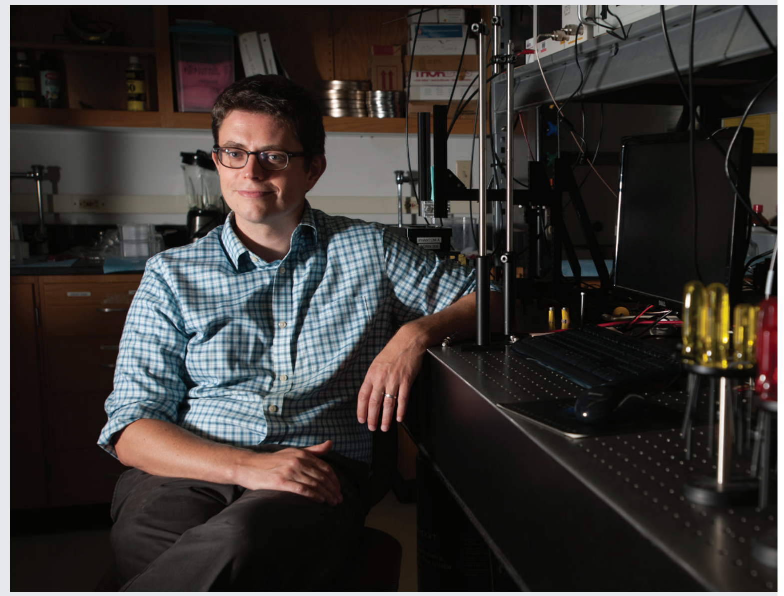
The probe used in the study with Ko is handheld and about the size of a brick. To get a full set of measures requires a few hours with the patient, and for this reason, it has been hard to convince patients to sign up. "A lot of these patients are already anxious about their first chemo, so to ask more of them is a lot," she says.



Darren Roblyer's wearable sensors conform to the breast and use an array of LEDs and optical sensors that can noninvasively monitor a breast cancer patient's response to chemotherapy over time. Photo by Jackie Ricciardi

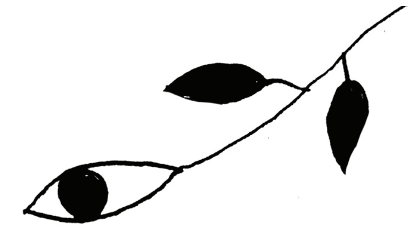


A team of graduate students in the BOTLab, Fei Teng (ENG'18) (from left), Kavon Karrobi (ENG'19) and Syeda Tabassum (ENG'18), is continually developing smaller and more sensitive optical devices and testing them in the lab. Photo by Jackie Ricciardi



Biomedical engineer Darren Roblyer set up his Biomedical Optical Technologies Lab with the goal of making new devices that not only shine a light on cancer biology, but also help improve treatment for patients. Photo by Janice Checchio

Before testing the wearable sensors on patients, Roblyer tests early designs of his devices on the wrists of healthy volunteers to see how well it measures blood flow and water and fat content. Photo courtesy of Darren Roblyer



THE MORE ROBLYER UNDERSTANDS ABOUT THE CELLULAR AND MOLECULAR PROCESSES HIS DEVICE DETECTS, THE MORE VALUABLE THOSE SIGNALS BECOME.

But she does ask, and she is grateful when they agree. "We do it because we believe that this will further our understanding of breast cancer and how it responds to chemo," Ko says. "I don't know what doors it will open, but there's great potential to learn."

Until now, cancer researchers could see only snapshots of tumors from mammograms or examine tumor tissue after it's removed from the body. "With this device, we can see a living tumor reacting to the medicine being infused," says Klapperich. "The technology is opening up the potential to answer new biological questions that couldn't have been answered before."

The ability to see dynamic changes is one thing. But to understand how that biological process might be linked to the shrinking of tumors requires more extensive digging, the kind of digging that isn't possible to do in human patients.

So Roblyer also studies mouse models of breast cancer using the BOTLab's imaging technologies. To launch this effort, fifth-year graduate student Syeda Tabassum (ENG'18), who works in the lab, confirmed that it was possible to use a form of imaging called spatial frequency domain imaging, or SFDI, to image breast tumors in mice. SFDI uses near-infrared light and measures oxygen saturation, water and fat content. SFDI also allows imaging of the tumors at multiple depths, so it is possible to create, for example, a map of oxygen saturation across the entire tumor.

In new studies, graduate student Kavon Karrobi (ENG'19) is using SFDI in combination with another form of imaging, called multiphoton microscopy (MPM), which creates images of much higher resolution. Using MPM, Karrobi can image a cross section of the tumor and get a detailed look at the blood vessels, tumor cells and structure of the tissue. It's a bit like taking a slice of the tumor and inspecting it under a microscope, but without touching the tumor.

Combining these tools, Roblyer's team can image the tumor throughout a course of treatment and see how it changes. The work is just beginning, but one observation so far is that tumors don't change uniformly in response to treatment. "There are pockets within a tumor and we're trying to understand how they relate to growth or resistance to therapy," Karrobi says.

Such heterogeneity within a tumor is common and well known, but Roblyer's tools are allowing his team to visualize them in a completely new way. For instance, Karrobi plans to overlay detailed images of tumor vasculature onto maps of oxygenation. "One provides context for the other and could give us an idea of what is happening inside," he says. "We're still very much in the exploration phase."

This research is helping Roblyer's team learn more about how tumors behave and also what the signals they see with the imaging tools they are testing mean. The more Roblyer understands about the cellular and molecular processes his device detects, the more valuable those signals become. "We're interested in what's going on in a tumor over time," he says. "We can image things other people can't, so we're learning a lot. It could go in many different directions."

Meanwhile, Roblyer's lab continues to advance the DOSI technology. Last year, they created the first wearable DOSI device, improving upon the brick-sized probe. The wearable device is flat, star-shaped and flexible so it can conform to the shape of the breast and be worn during a chemotherapy infusion, making it more convenient for patients.

To shrink the technology, however, Roblyer had to alter its function. His older probe collects absolute measures, but the new one detects only relative changes. It's a bit like having a heart rate monitor that shows how much faster the heart beats during exercise but cannot tell the starting or maximum heart rate.

Roblyer is also improving speed and resolution. For instance, he recently completed a second wearable design that has many more light sources and sensors, allowing it to probe more deeply and take a series of images at different depths throughout the tumor tissue, potentially revealing pockets of response or nonresponse to therapy in a patient's tumor.

He and his team of two postdoctoral fellows and seven graduate students have managed to create these new designs in less than two years. The seed money to create the first wearable probe came from the BU Center for Future Technologies in Cancer Care, directed by Klapperich. Roblyer also received a grant to support collaboration with the Fraunhofer Center for Manufacturing Innovation at BU, which helped create the flexible circuit board and skin-safe material in the wearable device. In addition, he has received funding from the American Cancer Society as well as a $4 million, five-year grant from the US Department of Defense Breast Cancer Research Program.

He wants to take these newer devices to the clinic. He's already at work on his next version: a wearable design that can collect absolute measures of oxygenated blood, fat and lipids. All of his efforts must move forward in parallel, with his team learning from studies of patients and laboratory animals and adjusting their technology each step of the way.

"The most important thing," says Roblyer, "is to figure out if this is the right technology and if it will help people." ■

THE LIGHT STUFF

ALUMNA'S START-UP AIMS TO IMPROVE HEALTH THROUGH LIGHTING

BY SARA CODY

The invention of the lightbulb paved the way for humans to conquer the darkness, effectively severing dependence on the sun to provide productive working hours. Recent advances in materials research are now providing new ways to render light that are healthier, more satisfying and more energy efficient. Jessica Morrison (PhD'16) aims to change how people use light with her new start-up company, Helux Lighting, by using these materials advances to tailor light color, intensity and direction to meet personal needs.

"Light is something we take for granted and generally ignore because it seems like a fixed resource instead of something we can shape our lives around," says Morrison. "What I want to do with the company is move forward with state-of-the-art light technology that will allow for more personalized environments by directing it where it is needed." Adding directional controls to a light source would provide users with the option to redesign workspaces to align with their personal preferences, inherently improving productivity and reducing energy consumption with targeted task lighting.

Morrison first learned about microelectromechanical systems (MEMS) working as a PhD student under Professor David Bishop (ECE, MSE). As a postdoctoral researcher in Professor Thomas Little's (ECE, SE) laboratory, and as part of the NSF Engineering Research Center for Lighting Enabled Systems & Applications (LESA), she integrated MEMS with advanced light sources. Her company, Helux Lighting, has created an innovative system using next-generation light sources, including LEDs and laser diodes, and a deformable mirror, a device that uses microscopic actuators to change the mirror's shape. She applied this technology to lighting by creating a device that electronically adjusts light position, brightness and illumination with the goal of creating healthy, energy-efficient environments.

"Dr. Morrison has been at the center of efforts to enable the directional control of lighting using MEMS within LESA and is the lead inventor of this enabling technology," says Little. "Her technology involves a variable focus, lotus-shaped mirror that can tilt, tip, focus and 'piston.' These degrees of freedom can be computer controlled and thus allow integration into low-cost steerable lighting devices."

Today's typical office building is filled with rows of cubicles illuminated by fluorescent light, computer screens glaring. With Morrison's technology, she envisions a work environment that incorporates task lights that disperse light where it's needed automatically. This could decrease the cost for consumers, save energy, increase consumer well-being and productivity and alleviate light pollution that is harmful to plants and animals in the environment.

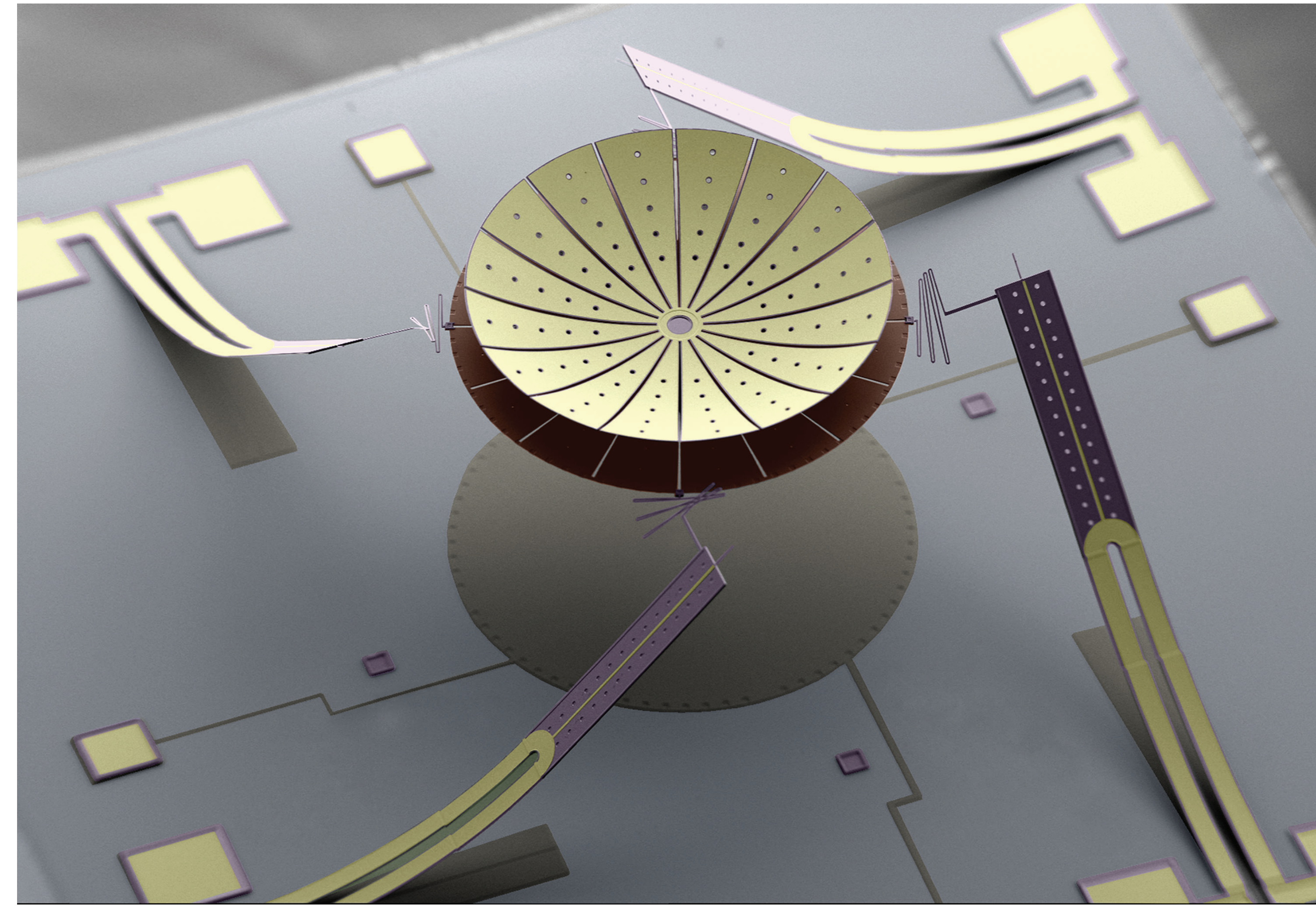
Jessica Morrison (PhD'16)

PHOTOGRAPH COURTESY OF JESSICA MORRISON

"Currently, people are willing to put on a coat when they are cold but wouldn't necessarily be willing to shell out extra money for a special light, even though it could improve their health or their environment, because they aren't aware of the significant role that it plays," she says. "Ultimately, we want to shift the conversation to get people thinking about the overall impact of light and provide options to improve their consumption of it."

It wasn't until she attended the Advanced Research Projects Agency-Energy Innovation Student Summit, a career opportunities and professional development summit, that Morrison realized commercialization would be the best path to get her technology out into society, and there were resources that would help her do that.

"After completing my PhD, I was looking for alternatives to a career in academia, and after talking to a few people at this event, it was suggested to me that I keep going because I had something that could really help people's lives," she says. "I was hesitant at first, because I never imagined myself starting a company, but once that seed of an idea was planted, it grew and now I can't wait to dive in."



Right: *Combining a deformable mirror with a lighting system will allow the user to control light position, brightness and the illumination area electronically.*

PHOTOGRAPH BY JESSICA MORRISON

HER COMPANY, HELUX LIGHTING, HAS CREATED AN INNOVATIVE SYSTEM USING NEXT-GENERATION LIGHT SOURCES, INCLUDING LEDS AND LASER DIODES, AND A DEFORMABLE MIRROR, A DEVICE THAT USES MICROSCOPIC ACTUATORS TO CHANGE THE MIRROR'S SHAPE.

Last spring, Morrison headed to Lawrence Berkeley National Laboratory to join Cyclotron Road, a highly selective incubator program focused on hard science innovation. The two-year fellowship, located in the heart of Silicon Valley, provides financial and logistical resources—like laboratory and office space, staff scientists and program mentors—for new technology companies, as well as opportunities to attend industry conferences and other networking events.

"The Cyclotron Road program is such an incredible program that is such a perfect resource for me, at first I wondered if it was too good to be true," she says. "But their goal is to invest in technologies that are in the gap between blue-sky research and the ones that are 'shovel-ready.' Helux is based on research foundations that will need effort and expertise to shape into products; this expertise will be available through specialized resources offered at Cyclotron Road. I am very excited to get started."

Helux Lighting is still in the research application phase, which means Morrison will continue to refine the technology in the Cyclotron Road program to make it more efficient as she learns the business side of running a company. Initially, she plans on focusing on the architectural and artistic lighting industry to gather information about market needs, which will shape her approach in terms of research and development. ■

A ROOM WITH A VIEW

ENG ALUM SHAKES UP THE COMMON WINDOW

RAO MULPURI ('92,'96) CREATES BETTER, HEALTHIER SPACES

BY SARA CODY

View CEO Roa Mulpuri ('92,'96) says his company's dynamic glass can lower a building's energy consumption by about 20 percent and can be controlled from an app.

PHOTOGRAPH COURTESY OF RAO MULPURI

For centuries, windows have remained largely and functionally unchanged. But a BU alum saw the opportunity to improve something we see and use every day and formed his company, View, with the goal of reengineering the window to make it smarter.

"We have this everyday object, the window, that was completely under-optimized and we've just been living with problems like heat and glare while missing out on highly desirable things like natural light and a beautiful view," View CEO Rao Mulpuri ('92, '96) says. "Light is required to live a healthy, happy and productive life. We aren't using windows well and because of it, we are also losing a lot of energy. It was a compelling idea for us to build a business around redesigning the window from the ground up."

Natural light is important to health and wellness, and a well-placed window can go a long way in improving the environment both at home and at work. Blinds and shades can help manage the discomfort caused by the glare of direct sunlight, but we use them at the expense of the natural light and views that add to our well-being. View has completely reengineered the window by being the first company to commercialize large-scale, dynamic glass. The company uses semiconductors and software that automatically eliminate glare while letting in natural light and allowing access to views—it's like putting sunglasses on buildings. Windows with View Dynamic Glass also lower building energy consumption by about 20 percent, and adjust themselves automatically (though users can also control them from a smart phone app).

"People spend 90 percent of their time indoors, so first and foremost we want to help create better, healthier, more productive spaces for those who live and work inside buildings," Mulpuri notes. "Our goal wasn't so much to create this beautiful piece of technology, glass, sensors or software; it was to use these as a mechanism to create delightful human environments."

From an early age growing up in India, Mulpuri knew he wanted to be in the business world. Inspired by his father's steel fabrication business—which he built from the ground up as a mechanical engineer—Mulpuri became an engineer with the expectation that he would eventually take it over. But after he decided to pursue his master's degree at Boston University in the manufacturing engineering program, these plans changed.

During his time at BU, Mulpuri worked closely with Professor Vinod Sarin (ME, MSE) who had come to academia from industry and was using his real-world experience to do a lot of applied work in his laboratory. Mulpuri decided to stay at BU to complete his PhD, where he continued to work with Sarin as well as Professor Soumendra Basu (ME, MSE) and Associate Professor Michael Gevelber (ME, MSE, SE), who advised him on his graduate thesis. In a twist of fate, Mulpuri even met View's current Chief Technology Officer, Robert Rozbicki ('92, '99), a teaching assistant at the time; they've now worked together for more than 27 years.

"I never thought I would pursue a PhD because I never considered myself a traditional academic—I'm not a lab guy, I'm a business man. But I came to BU for my master's degree and stayed for my PhD—and I'm so glad I did," Mulpuri reflects. "While nanomaterials and materials science is a fascinating field and you become sort of an expert while solving original problems, what I really learned at BU is how to learn, which prepared me well for my career."

After graduating from BU, Mulpuri worked for 12 years at Novellus, a semiconductor equipment company. Beginning as a technologist and working his way up to an executive role, he eventually moved his family to Japan to oversee operations. As the company grew, so did he.

"The semiconductor industry taught me how to do rapid development and use technology to quickly advance outcomes in a disciplined fashion, which allows you to sort through and address technical challenges that ultimately lead to success," he explains. "That approach created a natural segue to look at other areas in the world that were untapped opportunities so we could fundamentally change for the better something that people take for granted every day. And that is what led me to View."

Not only has View changed the functionality of glass, but also the form. Multiple nano-scale layers of metal oxide form the electrochromic ceramic coating on the inside of a window, and when a small electric voltage is applied, the ions move between the layers, causing the tint that is automatically controlled by software that connects to sensors located in the building. So far, this technology has been implemented in more than 350 buildings in North America, including commercial offices, healthcare facilities, universities, airports, hotels, government buildings and multi-family residential complexes (while View has not tackled single-family homes yet, that is certainly on the horizon as the company continues to expand).

Mulpuri says that building the company—from the technology to the business plan—from the ground up and scaling it to mainstream has been the most rewarding part of his career. "As a business leader, at the end of the day you have to deliver results, and as an engineer you apply what you have learned to something that is real and useful and benefits society," he says. "When you peel everything back, I am a family business guy at heart and that is the mindset that has governed the way I built this company."

He remains actively involved in the BU community as a member of Dean Kenneth Lutchen's Advisory Board and received the Distinguished Alumnus Award in 2012. ■

VIEW BY THE NUMBERS

- MORE THAN 500 PATENTS FILED
- MORE THAN 100 PATENTS ISSUED
- MORE THAN $600 MILLION DOLLARS INVESTED
- 600 EMPLOYEES
- MORE THAN 500 BUILDINGS ACROSS NORTH AMERICA, EUROPE, MIDDLE EAST, AND INDIA, WITH 350 ALREADY COMPLETED AND ANOTHER 150 IN PROGRESS
- MORE THAN 20 MILLION SQUARE FEET OF REAL ESTATE USING VIEW DYNAMIC GLASS
- 20,000 BUILDING OCCUPANTS ENJOY THE BENEFITS OF DYNAMIC GLASS EVERY DAY

27  NEW SENSORS FOR SMART LIGHTING

Professor Joyce Wong delivers the DeLisi Distinguished Lecture.

PHOTOGRAPH BY DAVE GREEN PHOTOGRAPHY

Joyce Wong Presents DeLisi Distinguished Lecture

HIGHLIGHTS COLLABORATION AND RESEARCH IN BIOMATERIALS TO TREAT DISEASE

Standing before a packed ballroom of colleagues and friends on April 25, Professor Joyce Y. Wong (BME, MSE), recipient of the 2016 Charles DeLisi Award and Distinguished Lecture, presented "Biomaterials to Detect and Treat Disease." The award recognizes faculty members with extraordinary records of well-cited scholarship and outstanding alumni who have invented and mentored transformative technologies that impact quality of life.

Wong recounted the experiences in her life that informed her career, from her parents—both chemists—inspiring her at an early age to pursue a career in science to a sabbatical she took in 2011, when she participated in a surgical observership in the cardiology department at Boston Children's Hospital.

"There is a high, unmet clinical need because eight out of every thousand infants are born with congenital heart defects, and the current solutions have a lot of problems," she says. "Multiple surgeries result in scarring, limiting the tissue surgeons can work with and biological implants calcify over time. More importantly, synthetic grafts can't grow with a child, so that's why multiple surgeries throughout a patient's lifetime are needed."

After observing the herringbone pattern of collagen under a microscope, Wong thought she could create a patch that would grow with the child by patterning and layering the collagen into sheets. Working in tandem with BU's Center for Regenerative Medicine and a laboratory in Japan, she developed a patch made of collagen sheets derived from induced pluripotent stem cells—adult stem cells that have been reverted to undifferentiated stem cells so they can be induced into any cell type.

"The environment at BU presents a lot of opportunities for collaboration and provides resources to push your research forward," says Wong. "Next, we want to transition to translation to get this into a clinic. We recently incorporated into a company where we will produce these patches as 'Band-Aids' that can help restore blood vessels that have been damaged from procedures like angioplasty or stenting."

Wong also discussed her latest project, which focuses on finding a better way to locate and treat the fibrin adhesions that sometimes develop after surgery. The adhesions stick internal organs together, causing abdominal and pelvic pain, as well as infertility in women. Wong is working on a noninvasive approach that uses ultrasound and tiny bubbles that can both enhance the ultrasound image and deliver drugs to the adhesion sites.

"Using ultrasound, we want to be able to image using one frequency and to destroy them (the adhesions) with another, so we can essentially 'see and treat' surgical adhesions," she says. "Currently, we are collaborating with a laboratory in France to use their multichannel microfluidics technology to streamline the delivery of microbubbles, which would allow us to move forward with the technology."

The importance of collaboration—particularly on an international scale—was a common thread throughout Wong's lecture. She noted, and thanked, her collaborators, mentors and family who hail from a wide array of countries.

"Science is global and the projects like the ones I have highlighted today are possible because of the collaborators from all over the world," she says. "Working together allows research to move from basic science to applied research and provides a foundation for innovation. It's critical that we keep this in mind as we move forward."

The DeLisi Lecture continues the College's annual Distinguished Lecture Series, initiated in 2008, which has honored several senior faculty members. The previous recipients are professors John Baillieul, (ME, SE), Malvin Teich (ECE) (Emeritus), Irving Bigio (BME), Theodore Moustakas (ECE, MSE), H. Steven Colburn (BME), Thomas Bifano (ME, MSE), Christos Cassandras (ECE, SE), Mark Grinstaff (BME, MSE, Chemistry, MED) and M. Selim Ünlü (ECE, BME, MSE). **—SARA CODY**

Getting Power to the People

CARAMANIS AWARDED SLOAN FOUNDATION GRANT TO IMPROVE ELECTRICITY DISTRIBUTION NETWORKS

While the use of clean, renewable energy is rising nationally, its growth is being restrained by an imbalance between the consumption and generation of power. Wind and solar power are clean and cheap, but their availability varies widely depending on location, season and time of day. Fossil fuel–generated power is available anytime but is expensive and carbon-intensive. Utility companies average out the cost difference and charge consumers accordingly, leaving little economic incentive for consumers to adapt to cost differences and increase the use of renewable sources.

Professor Michael Caramanis (ME, SE) is working to change that by developing algorithms that will enable consumers to choose when and how they use electricity. Recognizing the potential of this approach, the Alfred P. Sloan Foundation has awarded Caramanis a $420,000 grant to pursue it.

"In a distribution network today, you pay an average price whether you consume in the morning or at night, on a hot or cold day, and regardless of the location of the grid that you are connected to," says Caramanis. "This practice results in an electric power system that operates very inefficiently and provides perverse incentives for inefficient investments by all parties involved."

He is developing algorithms that take a number of generation and usage factors into account and derive dynamic prices. Smartphone apps that incorporate these algorithms could enable users to take advantage of the emerging Internet of Things and pursue their preferences at the lowest cost or highest benefit.

"Knowing how electricity prices will change over time, and in particular their locational granularity, will be very important information to consumers," Caramanis adds. "For example, in midday, prices are high in commercial areas but low in residential areas where everyone is away at work; the opposite trend is true in the evening. We want to empower consumers by giving them information and financial incentives to do the right thing."

Consumers might, for instance, specify when they expect to plug in electric vehicles to charging outlets and when they expect to depart. The consumer's smartphone would then monitor the cost of electricity at that charger's location and implement a charging schedule that takes advantage of low-cost times and avoids high-cost times. Using price information sharing, a smart thermostat might precool or preheat a suburban home and a grid-friendly dishwasher could be run at a time of day when electricity prices are low. Micro-generators could even be used to provide reserves.

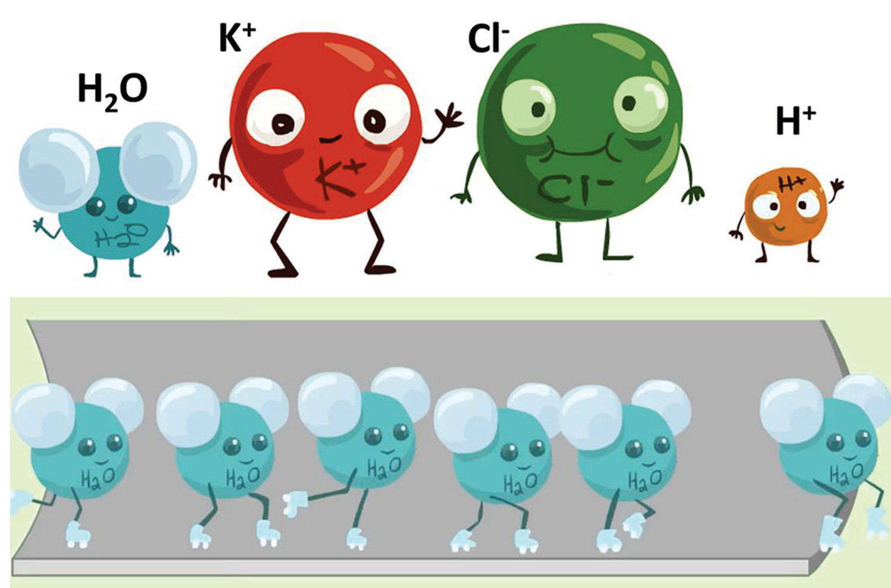
Such usage would allow utilities to optimize their distribution networks, reducing their costs and allowing them to pass along savings to consumers. It would also facilitate more efficient use of solar and wind power, much of which is underutilized in the current system. Taken together, Caramanis believes his proposed dynamic price discovery and sharing market will contribute to lower energy costs and increased adoption of clean, renewable energy sources.

Caramanis and his research group have already conducted computer simulations that demonstrate the potential for significant benefits of optimal spatiotemporal electricity pricing. The Sloan Foundation grant will facilitate pilot studies using actual networks to evaluate the impact of spatiotemporal pricing, and Caramanis expects the results to boost confidence in the technology. A wide range of utilities, including National Grid, have expressed strong interest in participating.

"Building confidence is the key prerequisite to establishing a new market. Although we have already simulated benefits in computer studies, demonstrating bilateral benefits for utilities companies and consumers in actual pilot studies can provide invaluable momentum," says Caramanis. "The Sloan Foundation grant will allow us to verify these benefits by key participating stakeholders, including distribution companies, practitioners, regulators and consumer advocates. Should applicability and societal benefits be documented, barriers to the adoption of efficient distribution markets will have been significantly overcome." **—SARA CODY**

Duan Receives NSF CAREER Award

RESEARCH AND OUTREACH WILL FOCUS ON CARBON NANOFLUIDICS



Duan will use animated characters to teach carbon nanofluidics to K–12 students. Image provided by Chuanhua Duan

Assistant Professor Chuanhua Duan (ME, MSE) netted a prestigious National Science Foundation (NSF) Faculty Early Career Development (CAREER) award in recognition of his outstanding research and teaching capabilities. He will receive more than half a million dollars over the next five years to pursue high-impact projects that combine research and educational objectives.

Duan's research will focus on developing an understanding of the fundamental mechanisms that affect the flow of water and ions through nanoscale graphene conduits.

"This exciting project is at the intersection of fluid mechanics, nanotechnology and materials science," says Professor Alice White (ME, MSE), chair of Mechanical Engineering. "It will inform the design of novel nanoporous membranes with impact on some of the world's largest challenges."

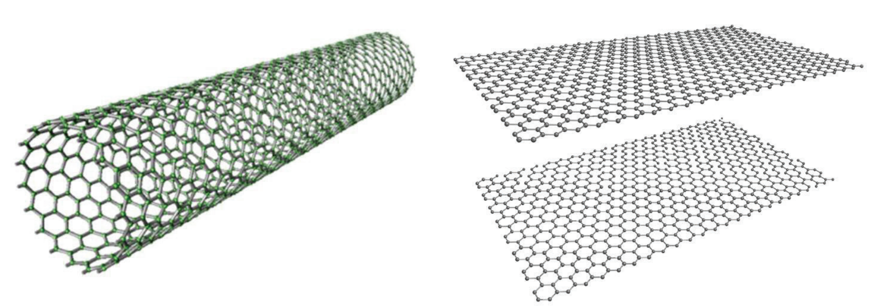
Graphene, a flexible sheet of pure carbon one atom thick, is a material that allows surprisingly easy passage for liquids and ions with high selectivity. Graphene sheets can be stacked horizontally to form channels, called graphene nanochannels, or rolled into carbon nanotubes. These structures could potentially be used for water desalination, improving the efficiency of batteries and fuel cells, lab-on-a-chip technologies and other biomedical applications. However, when researchers have tried to repeat experiments, large discrepancies in the data attributed to variables such as curvature, ion density and membrane structure have resulted.

To address this challenge, Duan will use his NSF CAREER award to study water and ion transport in single graphene nanochannels and single carbon nanotubes with different sizes, surface properties and substrate materials. He will also perform molecular dynamics simulations to elucidate underlying mechanisms revealed by his experimental studies. Using this combined experimental-computational approach, he expects to achieve a complete understanding of mass transport in carbon nanofluidic conduits.

"My lab has developed a novel technique, inspired by capillary flow, to accurately measure water and ion transport in a single carbon conduit," says Duan. "To fully understand the affect that each variable has on the process and resolve discrepancies in previously reported results, this level of accuracy is key."

In addition to the research component of his CAREER project, Duan will fulfill the educational objectives by creating a module to teach carbon nanofluidics to K–12 students for the Technology Innovation Scholars Program. In addition, Duan will work with an animator to develop a cartoon that depicts fast-mass transport in carbon nanofluidics using anthropomorphized molecules.

"For example, in one scene we will show water molecules wearing ice skates to demonstrate how easily they slip down the smooth walls of the carbon nanotubes," says Duan. "Since I know the transport process well, if I can help them visualize that process with something that is familiar, it makes learning about it more accessible." **—SARA CODY**



Graphene sheets can be stacked horizontally to form channels, called graphene nanochannels, or rolled into carbon nanotubes. Image provided by Chuanhua Duan

New Sensors for Smart Lighting

Imagine a student sitting in a secluded corner of a college library, writing a last-minute paper. Just as she reaches the final paragraph summing up her argument, the lights go out, prompting her to get up and wave her arms around. In an energy-efficient room, these lights may be controlled by motion sensors that turn them on only when they detect that someone is moving. However, if everyone is quietly working, the lights can't register their presence—which doesn't always serve the students well.

Now, a team from the Lighting Enabled Systems & Applications Engineering Research Center (LESA ERC)—a collaboration including Boston University, the University of New Mexico, Thomas Jefferson University, and Rensselaer Polytechnic Institute (RPI) faculty and graduate students—is tackling the issue. Funded primarily by the National Science Foundation, the center researches and designs smart lighting: lights, sensors, and controls that can adapt to better support human productivity, energy efficiency and wellness. The team was awarded a US patent titled "Sensory Lighting System and Method for Characterizing an Illumination Space" for a system of LED lights and sensors that can detect the location and poses of occupants in a room without using cameras. (While occupancy sensing is not a new idea, it is novel to interpret the reflected light in a room using low-cost sensors built into the lights, without using cameras.)

"The lights in a space are strategically located," says Professor Thomas Little (ECE, SE), associate director of the LESA ERC, referring to his office overhead lights. "They're in a good position in these indoor environments to interact with us." Rather than completely overhauling lighting design, Little wants to make what's already there smarter. He and his colleagues have been working on a system of responsive LED lights called luminaires, which they have designed to be energy efficient, increase productivity and improve health by responding to the needs of people in the room. Sensors embedded in the luminaires, called "time-of-flight" sensors, can detect people and objects and change lighting intensity, turn lights on and off and even adjust color. For example, the system could change the balance of red and blue light to mimic sunlight in a room without windows, rather than relying on fluorescent bulbs.

The sensors measure location by emitting a brief pulse of light and timing how long it takes that light to reach the people and objects in the room, a process that is also used in some types of radar or sonar. By combining time-of-flight data from multiple sensors throughout a room, it is possible to differentiate between people, pets and furniture, and to classify actions such as sitting, standing, or writing on a whiteboard. For example, a speaker at the front of a classroom could use arm movements to change the lighting settings in the room or to advance the pages of a PowerPoint presentation.

Researchers also hope that the luminaires can positively affect human health. According to the Mayo Clinic, certain types of depression, such as seasonal affective disorder and circadian rhythm disorders, can improve with exposure to different levels of light.

LESA ERC's patented lighting system can potentially change the landscape of smart lighting, and the researchers are also exploring commercialization opportunities. Right now, most people rely on passive sensors that don't respond to human needs. "If I sit at my desk and don't move, after 15 minutes the lights go out. All the offices are like that," Little says. But it's good to know that in the near future, a "smart building" with responsive luminaires could turn on the lights for us, set themselves up for our school or work purposes, and maybe even make us healthier while they do it. **—CAITLIN BIRD**

PHOTOGRAPH BY JACKIE RICCIARDI

Little (second from right) and his colleagues at LESA recently received a patent for a system of smart LED lights and sensors that can detect the location and poses of occupants in a room without using cameras.

WE WANT TO HEAR FROM YOU! SEND YOUR CLASS NOTES SUBMISSIONS TO ENGALUM@BU.EDU OR VISIT WWW.BU.EDU/ENG/ALUMNI.

PHOTO BY DAVE GREEN PHOTOGRAPHY

Remember Your Roots

GRADS TOLD TO WORK HARD, ENGAGE WITH THE WORLD

All eyes were on the Class of 2017 as 364 graduates gathered at Agganis Arena for commencement exercises on May 20 to celebrate their accomplishments as they begin the next chapter of their lives. Throughout the day, graduates were urged to remember their roots as they moved forward in their new careers.

"Many of the attributes that we attempt to begin instilling in you are beyond your degree so you can become successful Societal Engineers. But it turns out there is one attribute that may be the single most important ingredient to success in life. And that is the ability, the willingness, the desire, the passion to work really hard," said Dean Kenneth R. Lutchen during the ceremony. "It's difficult to become an engineer, and not everyone can do it. But you can."

Next, student speaker Lauren Etter (ME'17) shared her connection to the College's mission of creating the Societal Engineer as she recounted her experience designing a water filtration system for a community in Zambia while participating in Engineers Without Borders. A majority of the system was built in Boston and brought to the developing country for implementation, however, when she arrived, she realized the tools that were so readily available in the United States were no longer at her disposal in the field, and she had to improvise, using the limited resources available. With help from the community elders, she and her classmates worked together to devise a simple solution that allowed the system to be implemented successfully.

"The Societal Engineer is the bold idea of having an awareness of your surroundings and being able to contribute positively through problem solving," said Etter. "We have an obligation to engage with our world. We have the technical foundation and the moral obligation to make a difference. Through our education here at BU, we've come to realize that being Societal Engineers means being dynamic in our solutions."

Colin Angle, CEO and co-founder of iRobot Corp., gave the commencement address, which focused on his experience building a company and advised graduates moving into the working world.

"Most of you are about to enter the workforce and you want a job that you will enjoy at an employer that will value you in return. Companies, like people, have personalities and there are ones that you will like and some that you will not," he told the graduates. "Your longer-term happiness in any job and your career is based on being a part of something you believe in and that aligns well with who you are."

Angle described the values and culture that he has built at iRobot and how his company provided aid to Japan to mitigate the Fukushima nuclear disaster after a tsunami-triggered meltdown. His company donated half a million dollars' worth of robots and sent engineers to train the disaster team in how to operate them. The robots were deployed into the reactors to create radiation maps to seek out the safest pathway, and allow an operator wearing protective clothing to reach the control room and shut down the reactor without receiving a fatal dose of radiation.

Lutchen presented Department Awards for Teaching Excellence to Associate Professor Michael Smith (BME), Senior Lecturer and Research Assistant Professor Tali Moreshet (ECE) and Senior Lecturer Caleb Farny (ME), who also received Outstanding Professor of the Year. Associate Professor Tyrone Porter (ME, MSE) was recognized with the Faculty Service Award.

Later that afternoon, more than 280 master's degree and 59 PhD graduates were celebrated in the Fitness & Recreation Center while their friends and families looked on.

"When you go for a PhD or master's degree, you have chosen your profession and that obligates you to continuously question the central tenents of your discipline and your field," Lutchen told the graduates. "Therefore, you constantly advance the forefronts of knowledge and translate that new knowledge into discoveries and innovations for society."

Professor Daniel Beard (BME'93), Department of Molecular and Integrative Physiology and Carl J. Wiggers Collegiate Professor of Cardiovascular Physiology at the University of Michigan, addressed the crowd about his career and how it started when he was an undergraduate at BU, crediting his experience with inspiring him to follow a career in academia.

"Having a career in academia means you get paid to learn. You get to think, to design, to try, to dream, to build things and break things and you fail and you learn, and I never knew this was possible until I came here," said Beard. "Now, it's time to follow your potential and get to work."

—SARA CODY

ENG Alum Bob Hines Is a NASA Astronaut Candidate

ELITE GROUP OF 12 CHOSEN FROM 18,000-PLUS WHO APPLIED

PHOTOGRAPH BY NASA/ROBERT MARKOWITZ

BU has many alumni in high places, but Bob Hines is bound for even greater heights—he is one of only a dozen people chosen this year by NASA to be an astronaut candidate.

Hines (ENG'97) survived a selection process where the odds against making it were, well, astronomical: a record 18,300 people applied for the astronaut slots. The Air Force combat veteran and lieutenant colonel in the Air Force Reserve has been a research pilot at the Johnson Space Center in Houston for five years.

Hines' possible assignments range from the International Space Station to commercial spacecraft to journeying into deep space as part of NASA's Orion project, which has an ultimate goal of reaching Mars.

"We are going to be thrilled to do whatever mission they put in front of us," says Hines, adding that his generation of space explorers is surfing an expanding wave of opportunity. When he started working at NASA five years ago, the agency's mission "was probably at the bottom of the bathtub," as the space shuttle program ended. "The parking lots were pretty empty."

But with the range of upcoming missions, he says, "The space world is our oyster right now."

Hines' course of study as an aspiring astronaut will combine a Trekkie's wildest dreams with rigorous intellectual requirements. "Spacewalks are the hardest thing, physically and mentally," NASA said in announcing its new class, so candidates must demonstrate their prowess in a giant pool that simulates weightlessness, training in spacesuits to master life support systems, handle emergencies and make space station repairs.

Learning the International Space Station's advanced technological systems, including its robotic arm, as well as Russian (along with English, one of the station's two international languages) are also part of the regimen.

Before he graduated, Hines had done independent research with Associate Professor Sheryl Grace (ME), who wrote him a recommendation for the Air Force. For his part, he credits BU, and particularly Grace, with teaching him the "foundation of engineering and engineering discipline" undergirding his career.

Born in North Carolina and raised in Pennsylvania, the 42-year-old Hines majored in aerospace engineering at ENG and earned a master's degree from the US Air Force Test Pilot School. He also holds a master's in aerospace engineering from the University of Alabama. →

CONTINUED

Alum Is a NASA Astronaut Candidate

Commissioned in 1999 by the Air Force Officer Training School, he has served 18 years on active duty or in the reserves. In those capacities and as a research pilot, he has logged more than 3,500 hours of flight time in 41 types of aircraft, according to NASA.

Hines also flew 76 combat missions for the Air Force, most in Iraq and Afghanistan. Often assigned to suppress attacks on American ground forces, he recalls, he would be gratified to be in radio communication with US soldiers after dropping a bomb and hear the background noise of enemy fire suddenly stop.

During the execution of deposed Iraq leader Saddam Hussein in 2006, he flew combat patrol over Baghdad, "a pretty bizarre thing," he says, for a man who'd first heard of Saddam as a high school sophomore during the first Gulf War in 1991.

Hines has numerous NASA and military honors, including two Air Medals for meritorious achievement during aerial flight and Iraq and Afghanistan Campaign Medals. He and his wife, Kelli, have three children.

The astronaut candidates—seven men and five women—reported in August to begin two years of training. When they graduate, they will join an astronaut corps that currently stands at 44 and a tradition dating back to the first US astronauts 58 years ago. **—RICH BARLOW**

NEWS BYTES

FACULTY

Assistant Professor **Ahmad "Mo" Khalil** (BME) was elected to take part in the National Academy of Engineering's 23rd Annual US Frontiers of Engineering symposium, which brings together young engineers nominated by their peers or organizations for performing exceptional engineering research. Khalil also received the College's 2017 Early Career Excellence Award and his research, which focuses on using synthetic biology to rapidly test for antibiotic resistance, was the subject of the National Institutes of Health Director's blog in June.

Assistant Professor **Stormy Attaway** (ME) received a 2017 Textbook Excellence Award (or "Texty") for *MATLAB: A Practical Introduction to Programming and Problem Solving, 4th Edition* from the Textbook and Academic Authors Association. The Texty awards recognize excellence in current textbook and learning materials each year.

Harvard Business Review published an article by Professor **Yannis Paschalidis** (ECE, BME, SE). Titled "How Machine Learning Is Helping Us Predict Heart Disease and Diabetes," the article explores how machine-learning algorithms can potentially improve patient outcomes in chronic illnesses such as heart disease and diabetes.

ALUMNI

Francis O'Hearn (ENG'88) of Bethesda, MD, was named chief technology officer for the US Department of Treasury.

Jane Kepros (ENG'03) of Boston was honored as one of *Building Design + Construction* magazine's "40 under 40" in the publication's October 2016 issue. Jane is a lab planner at TRIA, a boutique architecture firm in Boston's Innovation District.

Timothy Wolfe (ENG'11) of Albuquerque, NM, writes that since graduating from BU and commissioning from US Air Force ROTC Detachment 355 (BU's AFROTC), he's had an eventful US Air Force career. Timothy has served as a developmental engineer, earned a master's in electrical engineering from the Air Force Institute of Technology in 2015, published journal papers in *IEEE Transactions on Plasma Science* and presented conference papers in IEEE and Directed Energy Professionals Society events. He's currently a deputy program manager at the Air Force Research Laboratory Directed Energy Directorate and is working on a PhD in electrical engineering at the University of New Mexico. Recently, he briefed the Scientific Advisory Board on his program's research portfolio.

Qi Zhao (ENG'12,'16) of Long Island City, NY, is a research scientist at 84.51°, a customer science and marketing analytics firm and a subsidiary of the Kroger Company.

Lauren Ouellette (ENG'09,'11) and **George Daaboul** (ENG'09,'13) of Watertown, MA, married on October 1, 2016; they met freshman year on the engineering floor of Myles Standish Hall. Alums in the wedding party included bridesmaids **Angela Giannopoulos** (COM'09) and **Megan Fessenden** (ENG'09), and best man **Rahul Vedula** (ENG'09). Other Terriers in attendance were **Else Vedula** (ENG'09), **Brian Trautman** (ENG'09), **Roshan Kalghatgi** (ENG'09), **Dave Freedman** (ENG'10), **Julie Kulak** (ENG'08), **Kim** (ENG'11) and **Michael deMello** (ENG'10), **Cara** (CAS'08) and **Kyle Willis** (ENG'08) and professor John Connor.

STUDENTS

Summer Mundon (ME'17) won the grand prize in the College's Sixth Annual Imagineering Competition with her modular hydroponics system that uses water reservoirs and UV light in a glass tank to grow organic vegetables. In addition to a cash prize, Mundon will receive assistance on patent submission and market analysis from College faculty members.

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Dear Friends,

As I look over the past nine months that I have been the assistant dean for development & alumni relations at the College of Engineering, I am inspired and grateful for the many wonderful relationships that have been built over the years between the College's leadership and our alumni, parents and friends. These connections are essential resources to the dean, faculty and students, and include advisory boards, corporate partnerships, career networking opportunities, philanthropic support, mentorship roles and, importantly, a sense of community and purpose.

Fiscal Year 2017 was another banner one for fundraising achievements. The College of Engineering's Annual Fund and Societal Engineering Fund were at all-time highs, with increases in both dollars and donors. The College is well on the way to reaching its portion of the University's Choose to Be Great Campaign: ENG's fundraising goal is $100M by 2019, and we reached $80M by the close of the fiscal year. There were also a number of well-attended social and educational outreach events this year that took place on both coasts, as well as in London, where I had the opportunity to meet many of you. Perhaps the most noteworthy campaign achievement to recognize is **the record number of ENG students who have benefitted from your philanthropy**. Many have participated in "outside the classroom" experiential opportunities such as the Technology Innovation Scholars Program, as well as undergraduate research, or in student club experiences such as Engineers Without Borders. Highlights over the past several years include:

- **120 Technology Ambassadors** have reached over 22,000 K–12 students, inspiring and educating them on the positive impact engineers can have on society.
- **30 ENG students** participated in the Summer Term Alumni Research Scholars (STARS) program, working in faculty research labs and gaining hands-on engineering experience.
- **15 Distinguished Summer Research Fellowships** were awarded to some of our top students, giving them an opportunity to work on cutting-edge research projects with faculty mentors.

Your ongoing generosity drives the College's quantum leap in excellence and recognition. It is because of your leadership, support and engagement that the ENG student experience is enriched year after year and the College continues on its upward trajectory. On behalf of the Development & Alumni Relations team, we thank you for your partnership and commitment to advancing the mission of the College of Engineering.

Best wishes,

Lisa Drake

Lisa Drake
ENG Assistant Dean for Development & Alumni Relations

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Giving Back to Provide a Strong Foundation

Binoy K. Singh, MD (BME'89) and Dean Kenneth R. Lutchen at the grand opening of the Binoy K. Singh Imagineering Laboratory, known colloquially as the Tinker Lab, in 2011.

PHOTOGRAPH BY VERNON DOUCETTE

As a cardiologist, Binoy K. Singh, MD, (BME'89) fills many roles—provider, problem solver, educator, communicator and manager among them. Whether he is educating patients about care, managing his team or trying to diagnose a problem, Singh utilizes the skills he learned and honed during his time as a BU ENG undergraduate.

"The biomedical engineering program is notably rigorous," he says. "You weren't just memorizing facts. You were analyzing data and solving problems, applying scientific methods and mathematical modeling to address challenges in real time. With this experience, I am a more effective physician. I feel that I have a more thorough and fundamental understanding of disease states and can appreciate, implement and utilize technology and process to address them. My experience at BU has made every other life endeavor easier."

Singh, who spent much of his childhood moving around the country, liked the fact that when it came time to choose a college, Boston University offered a diverse, metropolitan setting and a strong biomedical engineering degree program to develop his skills and interests in math and science, and Boston was the perfect place to pursue his interests in the sciences, medicine, culture and sports.

During his undergraduate years, Singh participated in an internship with Haemonetics in Braintree, MA. "The opportunity to work on quality control for one of their systems and to learn how the work impacted operations in hospital operating rooms was incredibly rewarding. I developed a deep appreciation for teamwork, discipline and responsibility. The experience was one of many while at BU that served to set the foundation of my career," he says.

Another hallmark of Singh's BU experience was the BME Senior Design Project, when he had the privilege to work with Professor H. Steven Colburn (BME) and his team on a large binaural hearing research project. Singh's project focused on the effects of different variables—such as sound frequency, source position and source distance—on sound perception. "To work with a professional team, contributing to understanding and advancing the field of auditory research and technology, was invaluable. The entire experience was the ultimate culmination of a challenging and rewarding undergraduate curriculum," he says.

Now, as he serves as associate chief of cardiology at Northwell Health-Lenox Hill Hospital in New York, Singh's relationship with the College has evolved into a deeper connection over the years. He joined the Engineering Dean's Leadership Advisory Board, where he provides support and guidance to help develop strategic priorities and improve the curriculum for undergraduates and graduates.

In 2011, Singh made a gift to the College that established the Binoy K. Singh Imagineering Laboratory, known colloquially as the Tinker Lab, which provides resources and space for students to tackle extracurricular engineering initiatives and think about new ways to address society's challenges. Singh feels privileged to be able to give back to the institution that provided so much to him. "It's an honor to work with Dean Lutchen, the Advisory Board and the Boston University College of Engineering to innovatively support, and positively impact, the educational experience of our next generation of Societal Engineers," he says. —**SARA CODY**

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Established in 2011 as a makerspace for students' extracurricular projects, the Singh Imagineering Lab provides memorable learning experiences for students like Summer Mundon (ME'17). She took home the top prize in the 2017 Imagineering Competition for her creation, an autonomous hydroponics system that can be used to grow a variety of plants and was built entirely in the lab.

"I've been working in the Singh Imagineering Lab since my sophomore year and I learned basically all of my skills that I put into this machine from that experience," says Mundon. "As an engineer, your main job is to be a problem solver, so even though you have a specific major, it's helpful to learn skills outside of that and you have to be able to apply it wherever you can."

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My research focuses on trying to understand how objects change shape. Studying how skin wrinkles, roots writhe in soil and leaves curl as they grow enables us to design new materials. These topics are connected by geometry and mechanics, and they all rely on structural instability. Not long ago, a structure losing stability led to failure and disaster; instability makes rigid materials useless, so engineers had to design around it.

Now, the resilience of soft materials has enabled engineers to rethink the role of stability in the design of new materials. In the Mechanics of Slender Structures (MOSS) laboratory, I study the instabilities of thin structures in order to aid in the design of wearable electronics, smart needles, soft robots and ultra-lightweight mechanisms.
My research is interdisciplinary, bringing together ideas from physics, mechanics, mathematics, biology and materials science. BU's culture of collaborative research makes an ideal environment for my work. I often find myself pursuing a research question out of curiosity, only to realize its potential applications much later. I love that the College of Engineering encourages the freedom to pursue curiosity-driven research.

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