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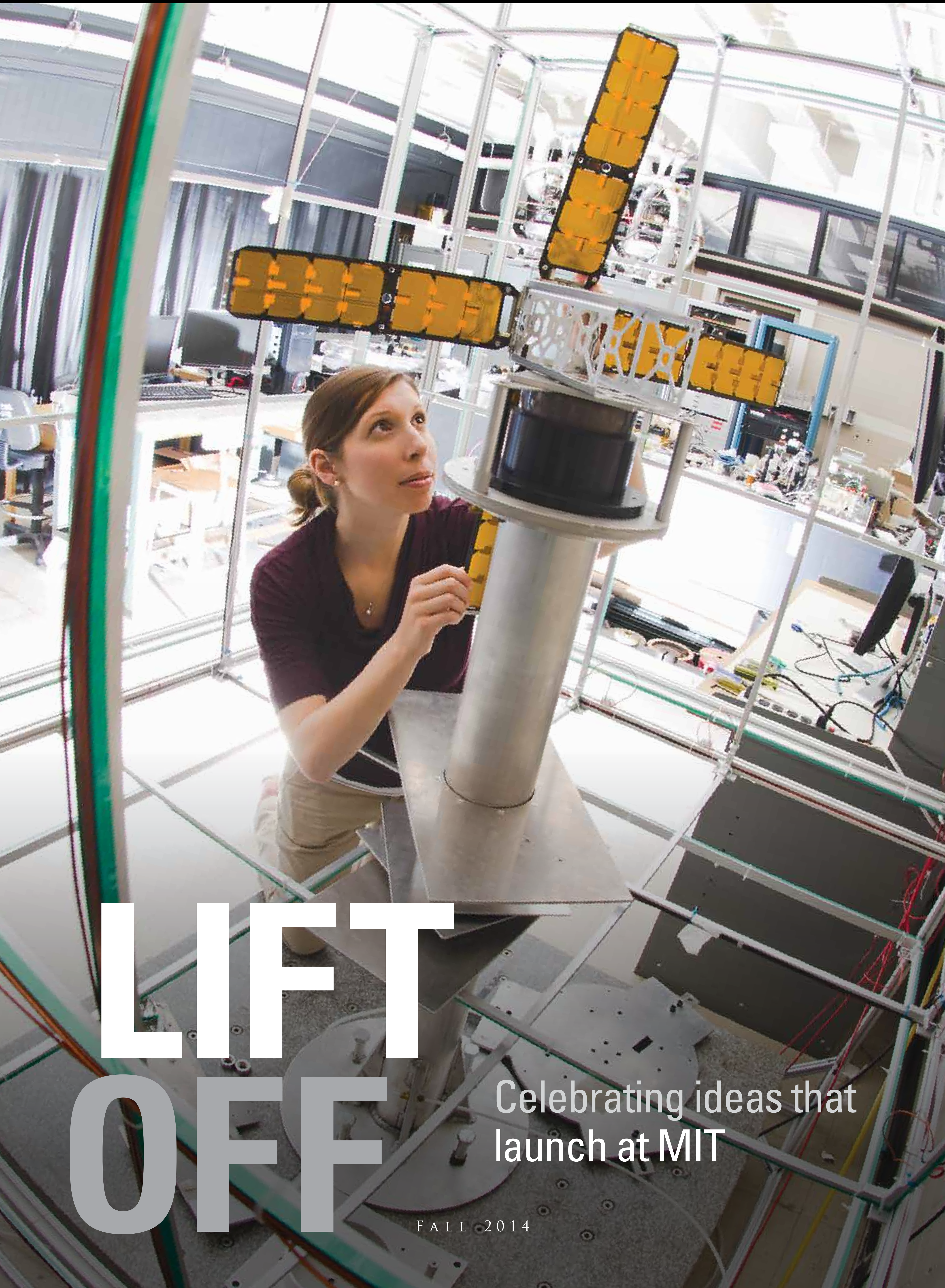
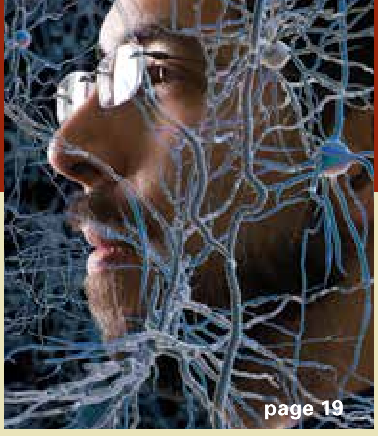


LIFT OFF

Celebrating ideas that launch at MIT

FALL 2014



FALL 2014

THE MIT SPECTRVM

is a newsletter distributed without charge to friends and supporters of the Massachusetts Institute of Technology by MIT's Office of Resource Development.

ON THE COVER

Kerri Cahoy led a student team that built MIT's first CubeSat, called MicroMAS, the Microsized Microwave Atmospheric Satellite. MicroMAS supports an MIT LL instrument to observe Earth's weather and storm systems. It launched last summer to the International Space Station, and deployment into orbit is expected in early 2015. Cahoy is shown with a prototype CubeSat structure fitted with engineering model deployable solar panels.

CONTINUUM

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A PLACE OF NEW BEGINNINGS

In the distant future, the 20th century may be best remembered as the time that human beings set foot on the moon. The discovery of that new world depended on guidance — inertial and otherwise — from MIT, and as we celebrate the 100th anniversary of our Department of Aeronautics and Astronautics, the moon landing stands as one of many departmental milestones that speak to MIT's signature combination of boldness, rigor, and disregard for the status quo.

For example, in 1896, to study the effects of air movement on different surfaces, mechanical engineering student Albert Wells attached a tube to a campus ventilation system and created MIT's first wind tunnel — six years before the Wright brothers' famous flight. And in 1914, the first lab of any kind on MIT's then-new Cambridge campus was the prototype "aeronautical lab," constructed under the direction of Professor Jerome Hunsaker. He went on to found MIT's Department of Aeronautics and taught the world's first courses in aeronautical engineering. By 1959, the department had grown to include the burgeoning field of astronautics, and since then has produced a community of alumni who have collectively logged more than 10,000 hours in space and taken part in more than one-third of all US space flights.

In true MIT fashion, we see the department's centennial as an opportunity to envision the future. And as this issue of SPECTRVM makes clear, this focus on the future radiates through every field and discipline. From Peter Reddien's work in regeneration of body parts, to Edward Boyden's research in the repair of brain circuitry, to the steps Sanjay Sarma is taking to advance our educational principles in an increasingly digital world, MIT remains a community of pioneers.

The MIT campus pulses with an enthusiasm for discovery. Whether searching for answers to new problems or finding new ways to approach old ones, MIT remains a place of new beginnings. We are pleased to take this opportunity to celebrate the impact MIT has had on society, but our passion springs from considering the possibilities that lie ahead.

Sincerely,

L. Rafael Reif

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GIANT STEPS

Celebrating 100 Years of Flight

"Walking in space is the most amazing thing a human being can do," says astronaut Greg Chamitoff PhD '92."When you open the hatch, you have to do a flip to get outside, and you see the Earth flying by 250 miles below. You're hanging from a handrail, and then you look down at your feet and see the Earth floating in this vast sea of blackness; and it just feels like you, the space station, and the Earth are all floating in the middle of nothing, I mean, unimaginable nothingness. It's just unbelievable."

Aeronautics and astronautics has come a long way in the past 100 years. The Institute pioneered the nation's first aeronautical engineering course in 1914, and many say MIT defined the field. Today, the department is the top-ranked graduate and undergraduate program of its kind in the country, and faculty are preparing for a fantastic future of autonomous automobiles and aircraft, and visits to Mars and beyond to search for signs of life. In many ways, this future evolved from MIT's amazing history of leadership to the nation and the world, and this fall MIT celebrates it all with a three-day symposium honoring 10 decades of creativity in the Department of Aeronautics and Astronautics (AeroAstro).

The Wright Brothers Wind Tunnel was dedicated at MIT in 1938, and major aeronautics companies all tested there during World War II. After the war, MIT emerged as the nation's largest nonindustrial defense contractor. In 1953, Charles (Doc) Stark Draper flew from Boston to Los Angeles in the first long-distance inertially navigated flight, and Space Inertial Reference Equipment became a forerunner of today's autopilot systems. And in 1961, the MIT Instrumentation Lab (founded by Draper) developed the guidance, control, and computer systems for the Apollo program, making it possible for Neil Armstrong and Buzz Aldrin PhD '63 to become the first men to walk on the moon in 1969.

"Apollo changed the world," says Ian Waitz, Dean of the School of Engineering and the Jerome C. Hunsaker Professor of Aeronautics and Astronautics. "It became an icon of what we can accomplish through technology. A system that could navigate over that distance was unprecedented. And having to write the software and design the hardware so that it could fit inside that capsule was just a huge challenge."

"In the 1960s, the big issue was going to the moon," says Institute Prof. Sheila Widnall. "Bob Seamans, an MIT professor, former Secretary of the US Air Force, and Associate Administrator of NASA, basically presented to President John F. Kennedy the reasons why we should go. The stakes were so high," she says. "You can't go halfway to the moon. It's a go, no-go decision."

"Apollo was the largest, most notable technological project of the century," adds AeroAstro Prof. David Mindell, who's also the Frances and David Dibner Professor of the History of Engineering and Manufacturing. "It had an incredibly innovative digital computer at the core of that control system with a bunch of software that highly automated the moon landing. And the technology on board beautifully cooperated with the astronauts to accomplish the guidance and landing."

Waitz calls those who made it happen "technological rock stars," and says that a vast amount of Apollo-era technology developed at MIT shaped today's world. "Our engineers contributed to computing, autonomous systems, weather and communications satellites, GPS, space exploration, national security, and many earth processes that relate to climate change and the health of the planet. Many great advances at MIT, and beyond, trace their roots to the Apollo legacy."

Courtesy MIT AeroAstro Department

Greg Chamitoff spent six months aboard the International Space Station.

Sheila Widnall: Served as Secretary of the US Air Force. Photo: Len Rubenstein

Ian Waitz: Apollo changed the world. Photo illustration: Len Rubenstein

Air Travel Soars

"Up in space, you feel like Superman. You're flying. You're really flying. Not when you're dreaming, but while you're awake. The way you get around is you fly. It's really a special place. I mean, you discover that gravity is no longer a fact. It's an option." GREG CHAMITOFF

Maybe it's not human-powered flight, but air travel is a big, big business — the largest contributor to the gross domestic product. And the industry is exploding because flying is cheaper than ever before.

By 2050, the whole air transportation infrastructure will double, says Jaime Peraire, AeroAstro Department Head and the H.N. Slater Professor of Aeronautics and Astronautics. And not so much in the US, but in developing nations like India, China, Brazil. New airports are springing up by the dozens and old ones are growing larger and better than before. "In the next 20 years," Peraire predicts, "35,000 large new aircraft will be constructed."

Ready for the boom is Mark Drela, an AeroAstro professor, aircraft designer, and aerodynamicist, who a while back, designed the D8 aircraft concept for NASA's N+3 program. If built with future technologies forecast for 2035, it would use 70% less fuel than current planes while also reducing noise and emissions.

"We've made tremendous progress," says John Hansman, director of the International Center for Air Transportation and the T. Wilson Professor of Aeronautics and Astronautics and Engineering. "On a per flight basis, we're much safer, much cleaner, and we've tremendously improved fuel efficiency over the past 50 years. In fact, we're three times more fuel efficient today than at the beginning of the jet age in the 1960s."

Drela's D8 design will make aircraft quieter, cleaner, safer, cheaper, and more efficient. "If you burn 70% less fuel, you have 70% less pollution, so reducing fuel burn is an easy way to reduce emissions as well," he says, adding it would "certainly lower ticket prices, too."

And more good news: US transportation is the safest in the world, says Arnold Barnett, a professor at the Sloan School of Management and expert on aviation safety. "No country on Earth has demonstrated a better safety record than the US. In fact, if you took one domestic flight a day, every day of the week, odds are on average you could travel 63,000 years without dying in a plane crash."

Continued on next page

Mark Drela's D8 airplane uses 70% less fuel than current planes. Photo: Len Rubenstein

Paulo Lozano has a dream to democratize space. Photo illustration: Len Rubenstein

Fly Without the Pilot

We'll remember this in the future when transportation systems become autonomous.

"Because a plane is flown by a computer, the human doesn't actually have to be on the plane," says John Hansman, adding that's one reason for enormous growth in [Unmanned Aerial Vehicles] UAVs. "And miniaturization of this information technology allows us to have huge capabilities on a very small vehicle. Suddenly, with all this innovation, we can do things we couldn't even dream of 20 years ago.

"There's no question," he continues, "pilots will be shifted off the airplane, particularly for military applications, where it will happen first. The question is when — and how good do the systems need to be before people board a plane to San Francisco without a pilot?" It's a public acceptance issue, Hansman says, adding, "People once operated elevators, and now you happily get on an elevator without a person, right?"

Autonomy is a giant step into the future, Peraire says. "We can use autonomous aircraft for security, monitoring forest fires, inspecting power lines, delivering packages in remote areas, transporting cargo, monitoring agricultural activities, weather forecasts, pollution. There are countless applications. First we'll see autonomous cars, then autonomous airplanes. The challenge is how to make those vehicles intelligent enough to operate safely. It all will happen gradually," he says, "but in 10 years, we're going to be seeing both."

Space Travel for All

Another powerful thrust in the future will be small satellites, says Paulo Lozano, who has a dream to develop the first interplanetary small satellite, a way to democratize space.

"Outer space exploration is currently limited," he says. "You can't go to space unless you're NASA, Russia, or a large private space agency. You can count on one hand the number of countries that have access to interplanetary space who are capable of investing funds to explore," he says, adding that an interplanetary mission costs about $1B, but small satellite missions cost just $1–5M.

Lozano, associate professor of AeroAstro and director of the Space Propulsion Lab, is now designing propulsion systems for small satellites. Called CubeSats, they're the size of a jack-in-the-box and once in space can take off for another orbit or planet. Thanks to advances in nanotechnology, they run on solar power, and sending up satellites in clusters could increase the amount and value of the data.

"And what about if a group of students put together a mission?" says Lozano, who's now advising 50 students from several universities on how to make that happen. The mission is *Time Capsule to Mars*, the first crowd-funded, student-led, interplanetary mission, set to launch in 2017. "Only when we give many access beyond low-Earth orbits, can the field of space exploration grow exponentially."

Kerri Cahoy, the Boeing Assistant Professor of Aeronautics and Astronautics who holds a joint appointment in Earth, Atmospheric and Planetary Sciences, leads a student team that built MIT's first CubeSat, set to take thermal measurements of Earth's weather systems. Launched last summer to the International Space Station, it will be deployed into orbit next year. In addition to work in optical communications, weather sensing, and radiation, Cahoy also focuses on imaging of exoplanets — a planet that doesn't orbit Earth's Sun, but orbits a different star. She's now part of a NASA team designing a space telescope to hold an instrument that will photograph exoplanets, where one day scientists hope to identify signs of life.

New Generation of Leaders

"In space, I took more than 22,000 pictures of the Earth. I will never forget seeing Saudi Arabia in the brilliant light of the sun. It's not a shape on the map. It looks curved, like a potato chip. I saw Morning Glory, a giant roll cloud across Australia, and in China, I saw clouds in the mountain valleys form fingers and branches that look like leaves of a tree. The Earth is so beautiful. You never get tired of looking at it. I'll never forget that." GREG CHAMITOFF

Scores of students are now flocking to the field of AeroAstro, because it's just plain exciting, says Department Head Jaime Peraire. "We're seeing a 50% increase in our enrollment in the last two years."

It's good news in a field where people who helped win the Cold War and Space Race are long gone. And even the current workforce of aerospace engineers is now retiring in large numbers.

And yet, says David Mindell: "The field has a lot of vitality. It's not Silicon Valley. It doesn't have the get-rich-quick connotation that you get in a lot of the computer fields. But aviation and space flight have always been fields driven by enthusiasm. People get involved because they love it."

"Students get excited about aerospace because it is so hands-on, so visual. There's an energy around it," says Widnall, the Abby Rockefeller Mauzé Professor of Aeronautics and Astronautics, who in the '90s served as Secretary of the US Air Force. "You see an F-16 flying, and it's just plain exciting."

In fact, she says, to determine one's love of the field, Jim Mar, a former department head in AeroAstro, developed a test: "When you're walking across a parking lot and a plane flies overhead, do you look up?"

Widnall, who always looks up, says educating the next generation of AeroAstro leaders will define the future of the field, one now soaring in new directions.

AeroAstro once involved studying materials and structures, fluid mechanics, thermodynamics. Today, it involves computational engineering, energy, autonomous systems, aerospace software, and complex systems. A future education, Peraire says, will also include online technologies and innovative educational technologies like Conceive-Design-Implement-Operate (CDIO), which was initiated by AeroAstro in 2000, and which has been adopted by 100 universities worldwide.

Also key to the future, Peraire says, are private industries providing access to space — commercial space flight companies like SpaceX and

Continued on next page

David Mindell: Aviation and space flight are fields driven by enthusiasm. Photo: Len Rubenstein

Dava Newman designed the MIT BioSuit™, a spacesuit that offers better mobility and reduced mass than modern gas-pressurized spacesuits.

Photo illustration: Len Rubenstein

Jaime Peraire: 35,000 large new aircraft will be constructed by 2035. Photo: Len Rubenstein

Orbital Sciences, which are hiring MIT students for internships and summer jobs. "And," he says, "the hope is that as new commercial applications develop, we'll see further expansion in private hands."

Space Exploration, World Collaboration

"Religious or not, going into space is a spiritual experience. When you look at Earth, it's so vast; it doesn't match up with our usual reality. It exists on such a different scale of size and time. You feel that the Earth will continue its journey around the sun, and what's happening on Earth at any particular place or time doesn't really matter. You're overwhelmed with questions: 'Why is this here? How did it come to be?', yet you feel the answers will never come." GREG CHAMITOFF

The next giant step is sending humans to Mars, says Dava Newman, co-director of MIT's Man Vehicle Lab and Professor of Aeronautics and Astronautics and Engineering Systems, who's currently designing space-suits for the trip.

It will likely happen in the next few decades, she says, because we already have the technology; it just depends on political will and committing the resources.

"Human space exploration is at a pivotal historical juncture," she says. "We have the technology and know-how to explore the solar system, but how do we make it a high national and international goal?" says Newman, adding that space flight could help bring peace.

Much like the successful International Space Station, which is the size of a football field, and which was built by 15 countries over 12 years at a cost of $100B, "There's a grand opportunity to make future space exploration a prime example of peaceful international collaboration.

"NASA, China, and Russia can now all send humans to low-Earth orbit. But to get to Mars with humans we need to do it globally," she says. "Let's go as humanity. Let's explore with pooled resources and collaborating internationally. That's the dream."

Life Beyond Earth

"I can't imagine that the only place there's life is Earth. The number of stars and planets are uncountable. Why would this be the only place with life? The real question is if our nearest neighbors are just too far away to ever meet them." GREG CHAMITOFF

"One thing likely to change consciousness in the world is finding life on other planets, and we are poised to do that in our lifetime," says David Mindell. "If we do find life on other planets, it will be bacteria, microbes, or signatures of organic activity. It won't be little green men, but it will be so dramatic."

Newman adds: "This is a remarkable age of exploration, and the space science data coming in shows that there are potentially habitable planets. Getting more and more data every day keeps us searching."

Meanwhile, life on Earth goes on, for us and for Greg Chamitoff, who after spending six months on the International Space Station with a dozen astronauts, is now back on Earth, and who on this day is sitting on a bench in Cambridge in the brilliant sunlight.

So what do you do for thrills after you've been shot into space?

He laughs. "Save my money to go back again on a commercial flight. I want to celebrate a future birthday with my family in space."

Chamitoff, who flew on the last space shuttle flight of Endeavour, tells of his two seven-hour spacewalks and says that it was so breathtaking, so overwhelming, he didn't want to come back inside.

"I'd love to go back," he says. "See, it was tough for me, very tough for me to leave."

— LIZ KARAGIANIS

FIRSTS:
PROGRAMS LAUNCHED AT MIT

ARCHITECTURE
The first formal architectural curriculum in the US was developed at MIT in 1865, and provided professional academic instruction to Americans for the first time. The Department of Architecture enrolled its first students in 1868: four full-time degree students and 12 students in a special two-year program. Though the curriculum borrowed elements from the classical European training model, MIT's program differed by offering more structured classes and courses in construction, architectural history, and fine arts.

ELECTRICAL ENGINEERING
The nation's first curriculum in electrical engineering was established within MIT's Department of Physics in 1882. Recognizing that the nation was on the verge of an electricity revolution with inventions such as the telegraph and America's first commercial power plant, Charles Cross, a member of MIT's third graduating class and chair of the physics department, developed the curriculum almost single-handedly. Within just 10 years, electrical engineering students comprised 27% of MIT's student body.

CHEMICAL ENGINEERING
MIT played a key role in establishing chemical engineering as both a discipline and distinct profession. Course X, the world's first four-year chemical engineering curriculum, was created at MIT in 1888. In 1891, the Department of Chemistry granted seven bachelor's degrees in chemical engineering—the first such degrees to be granted anywhere. In the early 20th century, a School of Chemical Engineering Practice was established, and in 1907 MIT became the first school to grant PhD degrees in chemical engineering. The Department of Chemical Engineering continues to lead the nation in awarding graduate degrees.

SANITARY ENGINEERING (PUBLIC HEALTH)
The first curriculum in sanitary engineering was launched at MIT in 1889 thanks to William Thompson Sedgwick, known as the architect of public health and sanitary engineering. Sedgwick's lectures in bacteriology introduced the principles of public health to civil engineering practice. He went on to become one of three founders of the nation's first public health school, the Harvard-MIT School for Health Officers, in 1913.

METEOROLOGY
Weather forecasting was transformed from an art to a rigorous science when the nation's first meteorology program was founded at MIT in 1928 by associate professor Carl-Gustaf Rossby. His analysis of upper-atmosphere data led to the 1939 discovery of "Rossby waves"— slow-moving waves of air hundreds of miles long that are now considered the basic building blocks of weather. He also mapped and named the jet stream, and he was the first to use blue and red to indicate warm and cold fronts on weather maps.

EXECUTIVE EDUCATION
Established in 1931, the MIT Sponsored Fellowships Program was the first in the US to provide engineers with executive potential, a chance to gain advanced academic and professional expertise in management. The program was renamed the MIT Sloan Fellows Program in 1938, in honor of Alfred P. Sloan Jr. 1895, for his longtime support of leadership education. Today, the program is recognized around the world for educating visionary business leaders.

CENTER FOR REAL ESTATE
MIT's Center for Real Estate (CRE), established in 1983, offered the first-ever Master of Science in Real Estate Development degree program in the US. The Center was founded by real estate investor Charles (Hank) Spaulding CE '51, to improve the quality of the built environment and to promote a more informed professional practice in global real estate. Uniting the disciplines of architecture, urban studies, civil engineering, economics, and management, the CRE has become a model for programs across the country.

NANOSCALE WORK YIELDS BIG RESULTS

An avid amateur astronomer during her childhood in Vukovar, Croatia, Silvija Gradečak, Thomas Lord Associate Professor in Materials Science and Engineering, was not content observing the physical world only from a distance: "I discovered what I really liked about science were experiments, and having the ability to make something with my hands," she says.

Today, handling the smallest elements in nature, Gradečak is generating large-scale results that may transform energy production, storage, and lighting. Her enthusiasm for both basic and applied research will help to power MIT.nano, the Institute's $350 million nanoscale laboratory now under construction. Gradečak looks forward to working "with people from different backgrounds, advanced nanofabrication tools, and the seamless integration of the technologies needed to work on these problems."

At the Swiss Federal Institute of Technology, where Gradečak pursued her doctorate, an electron microscope revealed a new terrain ripe for exploration and manipulation. "I saw individual atoms for the first time, and came to realize that having the ability to arrange them on the nanoscale is a powerful tool," she says. "There were so many new problems available to work on. All kinds of possibilities emerge when you have the capability to develop materials with unique structure and properties not found in nature."

Teasing out these properties becomes possible when examining materials at the nanoscale (a nanometer is one-billionth of a meter, and nanoscale materials run one to 100 nanometers in size). During graduate school, Gradečak zeroed in on gallium nitride, GaN, a synthetic compound used by the semiconductor industry that turned out to feature some extraordinary optical properties: If the composition of GaN is altered at the nanoscale, the compound can produce light ranging from the ultraviolet to the infrared.

As a young researcher investigating nanoscale defects in GaN that changed the compound's behavior, Gradečak "opened up a new world," she says. "We all have to find a niche, our passion, and learning that I could design materials, tune their properties and emissions — this ability was amazing to me."

Gradečak was especially fascinated by the wealth of potential optical and electrical applications for these nanoscale materials. GaN and similar semiconducting compounds are capable not just of emitting light at a range of wavelengths, but of conducting electricity and heat more efficiently, too.

Gradečak set about harnessing the power of nanoscale compounds. She developed a unique repertoire of laboratory methods that involve manipulating compounds in their vapor phase in a growth chamber. Inside, atoms take root on substrates in particular configurations based on Gradečak's desired outcomes.

In one venture, Gradečak created nanowires, slender, solid fibers composed of nanoscale semiconductor materials, that can be grown on varied surfaces such as silicon or flexible polymers. Of infinitesimal diameter, these nanowires are essentially one-dimensional objects, and because they can be millions of times longer than they are wide, they are ideally suited for transmitting energy in the form of electricity, heat, and light.

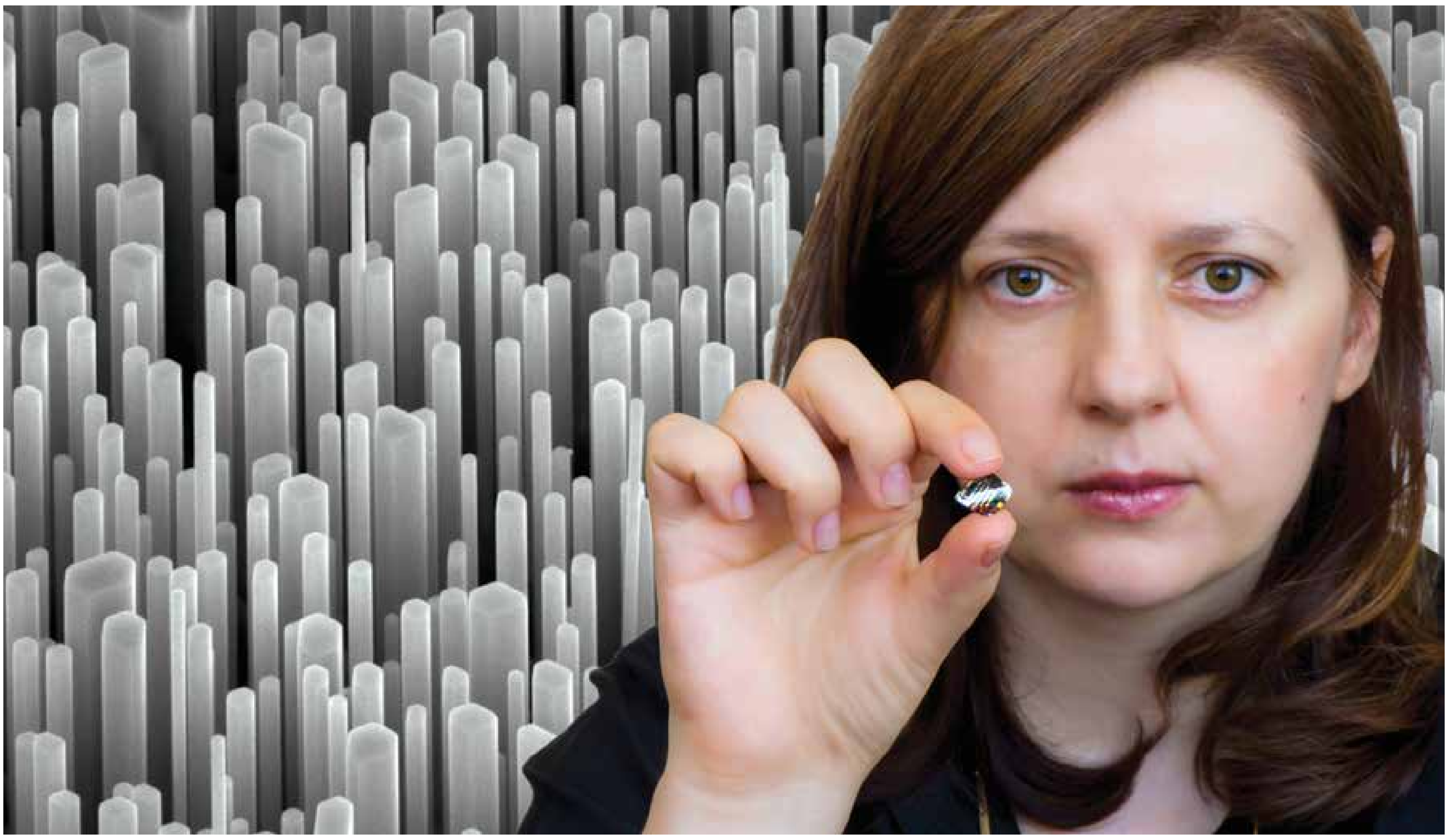
One signature application to emerge from this nanowire research is a new and different kind of light-emitting diode (LED). Gradečak's device more closely approximates sunlight's red and green wavelengths than current LED technologies. In addition, instead of utilizing expensive materials such as sapphire as a growth medium, as is the typical practice of current manufacturers, Gradečak's nanowire-based LEDs can be grown on abundant, inexpensive substrates, including flexible plastics. Her invention may prove much more economical for home and industry consumers.

Another key development from Gradečak's lab is a solar cell made from zinc oxide nanowires embedded with tiny quantum dots — nanocrystals made from a semiconductor material that are so small they essentially have no dimension. While the device does not yet convert solar energy to electricity as efficiently as today's silicon-based solar cells, Gradečak notes, "Our devices are transparent and flexible, and in just a few years, we've improved efficiency of our cell by two orders of magnitude; this is an amazing accomplishment."

— LEDA ZIMMERMAN

SEE MORE:
Welcome to the nano age
spectrvm.mit.edu/webextras

Silvija Gradečak's nanoscale work creates big-scale results that could transform energy production, storage, and lighting. Photo illustration: Len Rubenstein



A REVOLUTION IN HIGHER EDUCATION

"Michelangelo didn't attend a semester of lectures," says Sanjay Sarma, "he learned in the studio with a master looking over his shoulder." And the future of higher education, Sarma says, will carry us right back to the past.

"As the volume of knowledge has increased, frankly we have slipped into lecture mode, which is very passive. And that's taken us away from a participatory learning approach," says Sarma, director of MIT's Office of Digital Learning. "Now there's a rethinking of pedagogy where the 'doing' is making a comeback."

MIT is helping lead the way to this kind of educational future with initiatives like edX, the platform developed by MIT and Harvard to host more than 30 schools' massive open online courses, or MOOCs, including MITx. The edX platform has been customized and deployed on campus so that professors can give students instant feedback and, in some cases, "flip" the classroom from an environment focused on rote learning to active participation.

It's a natural progression for MIT. More than 150 years ago the Institute pioneered the hands-on approach to teaching science and engineering. "And we've never forgotten our roots. MIT's retained that deep interest in learning by doing," says Sarma, the Fred Fort Flowers and Daniel Fort Flowers Professor of Mechanical Engineering. Examples of Institute innovations applying that approach over the years include the Experimental Studies Group, the Technology-Enabled Active Learning (TEAL) project, and the 2.007 robotics course and competition.

Sanjay Sarma is leading an educational revolution now underway in higher education. Photo illustration: Len Rubenstein

What will a college education look like in 10 years?

When future students come to campus, Sarma says, they might take a few foundational courses with many online elements — perhaps even video games — coupled with instant online assessments that give them real-time feedback on their understanding of a subject. That feedback would also be available to the professors, who can then focus classroom work on concepts students struggle with rather than explaining material already understood. As a result, more class time can be spent on activities like building circuits or robots to explore concepts learned online.

"MOOCs and other digital technologies will not replace professors or the residential college. Rather, they'll enrich them."

"We want to enable more time for our students to build things and interact more with their professors and peers," says Sarma, co-chair of the Institute-Wide Task Force on the Future of MIT Education with Prof. Karen Willcox and Executive Vice President and Treasurer Israel Ruiz. The group released a report on its findings in August.

Students could also opt to spend a semester abroad, doing field work on a project that ultimately becomes a bachelor's thesis. And all along they could continue to take online courses, interacting with peers and professors at MIT. "The whole college experience will become much more participatory, more like an apprenticeship," Sarma says.

Another important outcome of the digital era is that MOOCs and tools like automatic grading can be easily shared, bringing quality education to the world. Other institutions, for example, could also use these materials to flip the classroom. Independent learners would also benefit.

Sarma emphasizes that MOOCs and other digital technologies will not replace professors or the residential college. Rather, they'll enrich them. "Technology isn't here to somehow displace; it will sweeten the experience."

— ELIZABETH THOMSON

LEARN MORE:
How to make a MOOC
spectrvm.mit.edu/webextras

Yuriy Román knew that to change the future of catalysis he'd have to cross the boundary between chemical engineering and materials science. Photo: Len Rubenstein

CATALYZING GREENER PRODUCTS

As a boy growing up in Mexico City, Yuriy Román was curious about how things worked. He'd go to his backyard and mix chemicals in the detergents his mother used to wash clothes to try to understand why some combinations worked and others didn't. His academic trajectory, driven in part by an interest in sustainability, led him to graduate studies at Prof. James Dumesic's laboratory at the University of Wisconsin—Madison. Dumesic is one of the world's leading researchers in the field of biofuels and biomass chemistry.

Today, Román leads a research group in MIT's Department of Chemical Engineering. The core of his research is the catalytic conversion of the inedible parts of plant matter, such as cellulose and lignin, into chemicals useful for making fuels and substances like plastics, adhesives, lubricants, detergents, fertilizer, and pharmaceuticals. Catalysts are materials that induce or accelerate chemical reactions, and they're often the key to making chemical processes industrially viable. For decades, research and development in catalysts has focused on making them faster and cheaper. The more active the catalytic material, the faster the chemical reactions. And the cheaper the catalytic material, the lower the cost of the end product of those reactions.

But with a changing climate and shifting fossil fuel economics, there's a burning need to change the way the world makes and uses catalysts. Instead of just speed and cost, the field of catalysis needs to add versatility and efficiency, says Román. The drive to use plants rather than fossil fuels as feedstock means the catalytic materials used to process petrochemicals need to be adapted — or entirely new ones developed — to work with biomass. And the processes need to be as efficient as possible to minimize waste, Román says. "When we typically use the catalysts that we had developed for petrochemicals we can perform some of these transformations, but they are never as effective, they are never as efficient, and the materials are never as stable."

One of the Román group's recent advances remade a process that had traditionally taken multiple steps and used precious metals and high-pressure hydrogen gas to turn plant matter into g-valerolactone, a chemical used to make fuels and polymers. The new process happens in a single step and forgoes the use of precious metals and hydrogen gas. The key was fitting infinitesimal amounts of an acid into the microscopic pores of a highly porous material. The action of the acid removed the need for hydrogen gas.

The challenge to finding effective catalysts for biomass processing is that these processes always involve water, and water, in this case, ruins the acid. Using their materials engineering skills, Román's team tuned the pores of the material to be water repellent. "You can start doing some of this chemistry — this Lewis acid-based chemistry — in the presence of water," says Román. "We use that to process different types of biomass-derived feeds to make new types of chemicals."

Román knew that if he wanted to change the future of catalysis he'd have to cross some boundaries, particularly the boundary between chemical engineering and materials science. Before coming to MIT, Román joined Caltech Prof. Mark Davis's laboratory, where he did cutting-edge research on producing and analyzing microporous and mesoporous materials, which are types of materials commonly used as catalysts.

Developing catalysts used to mean doing kinetics and reactivity studies — the stuff of traditional chemical engineering. Now, cutting-edge catalysis research requires tools and skills from a range of disciplines, including spectroscopy, materials design, and computational modeling. "Boundaries between the different fields are really fading, and I think this is something that's really important to embrace," says Román. "This is something that I feel is very specific to MIT, in that the barriers to interact with people from different departments are low," he says. "As we start working at the interfaces of fields, we should begin to see new game-changing discoveries." — ERIC SMALLEY

SOPHISTICATED MEDICINE

"I'm mostly driven by how to fix things," states Sangeeta Bhatia. "I'm always thinking about how to solve problems by repurposing tools."

Although not a mechanic, Bhatia, the John J. and Dorothy Wilson Professor of Health Sciences and Technology (HST), Electrical Engineering and Computer Science (EECS), and Institute for Medical Engineering and Science (IMES), does run a repair shop of sorts. As director of the Laboratory for Multiscale Regenerative Technologies, she tackles some of medicine's most intractable problems, developing sophisticated devices and methods for diagnosing and treating human disease.

Bhatia's research defies traditional academic categories, drawing simultaneously on biological and medical sciences, and multiple engineering disciplines. She has generated dozens of patents, several business spinouts, and earned a host of major scientific honors, including the 2014 Lemelson-MIT Prize, a $500,000 award recognizing an outstanding American mid-career inventor, and the David and Lucile Packard Fellowship, given to the nation's most promising young professors in science and engineering.

Her unorthodox career got an early start, thanks in part to Bhatia's self-described passion for "tinkering." As a child, she could fix the family's broken answering machine, and was handy with hot glue guns "in a Martha Stewart way." Her father, recognizing her potential as an engineer, brought her to the lab of an MIT acquaintance who was using focused ultrasound to heat up tumors. Her encounter with technology used against deadly disease proved formative.

Bhatia determined to become a biomedical engineer, earning an undergraduate degree in the field. She came to view the human body "as a fascinating machine" whose failures she might address by designing interventions. But it was while she was simultaneously pursuing her doctorate in medical engineering at MIT and her MD at Harvard Medical School that Bhatia's core research concerns began to crystallize.

Investigating a potential artificial organ to process the blood of patients suffering liver failure, Bhatia improvised a novel approach. Borrowing microfabrication technology from the semiconductor industry, she arrayed liver cells on a synthetic surface, and to her delight, this hybrid tissue remained alive in the lab for weeks. Scientists had long sought a way to sustain liver cells ex vivo, and Bhatia had delivered a biomedical first.

With her innovative adaptation of engineering tools for medically useful applications, Bhatia conjured a unique research methodology. And she also found her primary research subject: "I had an 'aha' moment, and realized I loved studying the liver."

Diseases of the liver, unlike those of other organs, don't have ready treatments. Severe alcohol abuse, hepatitis, and a host of other liver diseases sicken and kill millions each year. In addition, many aspects of the liver remain a mystery, including its unique tissue architecture and ability to regenerate. "It seemed like an incredible opportunity; anything you provided might have an impact," says Bhatia.

Motivated by this opportunity, Bhatia began generating a steady stream of liver-focused bioengineering tools. For instance, she transformed her hybrid microfabricated liver tissue into a platform for screening drugs outside the body. In a current study, Bhatia is using an artificial liver as a testing ground for a drug with the potential to destroy the malaria parasite at different stages of its life cycle.

She is also closing in on the "naively audacious" goal of building a replaceable liver for patients in need of a liver transplant. Her team has identified chemical compounds that send regeneration signals to liver cells, and she is now successfully growing human livers in mice.

Bhatia has more recently aimed her biotech arsenal at targets beyond the liver. Exploiting nanoparticles, she is devising an inexpensive urine test for cancer that could prove immensely useful in the developing world. She has also begun attacking two of the deadliest cancers, ovarian and pancreatic, designing nanomaterials that can penetrate tumors with a cargo of RNA to silence spreading cancer genes.

"As an engineer, I have a hammer, and look for the next nail," Bhatia says. "But as a physician, I also want to pick problems with the most clinical impact."

— LEDA ZIMMERMAN

Sangeeta Bhatia's research draws on biological and medical sciences, and engineering. Photo illustration: Len Rubenstein

Jeff Gore's work with baker's yeast helps ecologists respond to trends, like vanishing fisheries and collapsing honeybee colonies. Photo illustration: Len Rubenstein

OF YEAST, ECOLOGY, AND CANCER

A physicist, a mathematician, and an economist walk into a bakery. It sounds like the opening of a witty one-liner, but for Jeff Gore, Latham Family Career Development Assistant Professor of Physics at MIT, it marks the beginning of a career.

Gore—who actually is a physicist, mathematician, and economist (he also studied electrical engineering and computer science at MIT as an undergraduate and studied biophysics as a graduate student at the University of California, Berkeley) — now uses his observations of the behavior of baker's yeast as a way to translate heady theories about evolution and ecology into practical indicators that an ecosystem is headed for a change. His work is already beginning to help field biologists and ecologists detect and respond to troubling environmental trends such as vanishing fisheries and collapsing honeybee colonies.

"There are a lot of really beautiful ideas in theoretical ecology but it's difficult to test those ideas with any sort of experiment," says Gore. "We see an exciting opportunity to take our experimentally tractable microbial communities and do theoretically motivated experiments."

Gore's approach to the study of ecology and evolution is guided by the idea that complex systems, such as populations of living organisms, follow universal patterns of behavior. Those patterns can be expressed mathematically with formulas that exhibit special features, such as stable states and tipping points. A tipping point, a phenomenon popularized by Malcolm Gladwell in his book, *The Tipping Point*, is a critical moment of change, such as the moment when a pot of water accumulates enough heat to boil, or, more alarmingly, the moment the atmosphere accumulates enough heat that climate patterns shift irreversibly.

Tipping points occur in populations of organisms that cooperate to survive. For instance, baker's yeast collectively breaks sucrose into smaller sugars that can be used as fuel. This team effort helps stabilize the population by ensuring there is enough fuel to go around. "But if the population gets too small, it can't break down enough sugar to survive," says Gore. "The population collapses."

Gore's studies of thriving yeast colonies and colonies under duress have uncovered telling signs that a colony is on the verge of tipping into oblivion. In one study, Gore and colleagues found that colonies nearing a tipping point take longer to recover from challenges, such as an influx of salt that substantially slows the growth of the yeast population. "The recovery time grows as you get closer to the tipping point," says Gore. "We can measure this in the lab with yeast."

This recovery slowdown isn't just a phenomenon seen in baker's yeast. Rather, it will occur in other populations with similar cooperative foundations, such as packs of wolves that hunt collectively, schools of fish that travel together, or colonies of bees that work together. Because of this universality, a slow down in recovery could become an early warning that a population is on the verge of collapse. "It may be possible to anticipate that a tipping point is approaching before we cross that threshold, which is important because once a threshold is crossed, it can be very difficult to reverse," says Gore.

Recently, Gore and graduate student Lei Dai have begun applying these findings in collaboration with Christina Grozinger, a honeybee biologist at Pennsylvania State University. Honeybee colonies are collapsing at an alarming rate worldwide and researchers have been looking for new ways to approach understanding and preventing colony collapse disorder. In unpublished work, the researchers found that honeybee colonies need a critical mass of bees to survive. "Smaller colonies all collapse," says Gore.

The work is a first step towards applying the warning signs Gore sees in yeast to natural ecosystems and even complex biological systems, such as cancer. "Depending on the population you're talking about, you either want it to collapse or not," he says. "In the case of a tumor, we do."

In an effort to create laboratory experiments that more closely resemble natural ecosystems, Gore is beginning to work with microbial colonies that involve more than one species. "We want to understand how the dynamics play out when we have more complex communities," he says.

— ELIZABETH DOUGHERTY

FROM FICTION TO SCIENCE

When a salamander loses a tail, it grows a new one. What's the difference, biologist Peter Reddien wondered, between a wound that severs a salamander's tail and one that severs a human spinal cord?

Tweaking a gene or injecting a drug to repair damaged or aging organs, muscles, nerves, or brain tissue is one of the most enticing medical scenarios imaginable — a scenario that Reddien, associate professor of biology and Howard Hughes Medical Institute investigator, hopes will one day make the leap from fiction to science.

Like salamanders, the ordinary flatworm — a small, mud-colored pond-dweller has the seemingly miraculous ability to regrow "every missing part of its body from tiny fragments of nervous systems, skin, — gut everything," Reddien says.

While the creature's regenerative ability — it can replace a decapitated head in less than a week and its entire body from a scrap only one-300th of its original size — has captured scientists' interest for centuries, "there's no good model using existing knowledge that explains how such dramatic regeneration could work," Reddien says.

The Holy Grail of Reddien's scientific career is to elucidate such a model. His fascination with the natural world dates to his childhood, when his home was flanked by the interstate and an unlikely pocket of beauty in North Dallas. His back yard bordered a creek in a wooded ravine where he'd wander barefoot, chasing frogs and snakes and keeping an eye out for raccoons, owls, and possums. He'd talk science with his mathematician father and art with his artist mother, and thought he might go into astrophysics. But after graduating from the University of Texas, buoyed by the new tools available for life scientists, he pursued a PhD at MIT in biology and then chose planaria — then not on many scientists' radar — as a means to investigate regeneration.

Key to a flatworm's regenerative ability is the neoblast, capable of transforming into any cell type in the adult animal. In planaria such as the flatworm, these stem cells have the potential to produce all new tissue — but how do they know what kind of replacements are needed?

Just last year, Reddien's lab made the surprising finding that the genes that "instruct" cells at the wound site whether to start building a new head or a new tail are expressed in the muscle cells of the planarian body wall.

"Let's say you cut off the head," he says. Position control genes (PCGs) become active in the muscle cells at the wound site, providing a system of body coordinates and positional information that drives neoblasts to build a new head.

Reddien believes this "amazing, beautiful system" holds the key to understanding the molecular logic of regeneration.

"PCG expression is dynamic in muscle cells after injury, even in the absence of neoblasts, suggesting that muscle is instructive for regeneration," he says. "We concluded that planarian regeneration involves two highly flexible systems: neoblasts that can generate any new cell type and muscle cells that provide positional instructions for the regeneration of any body region."

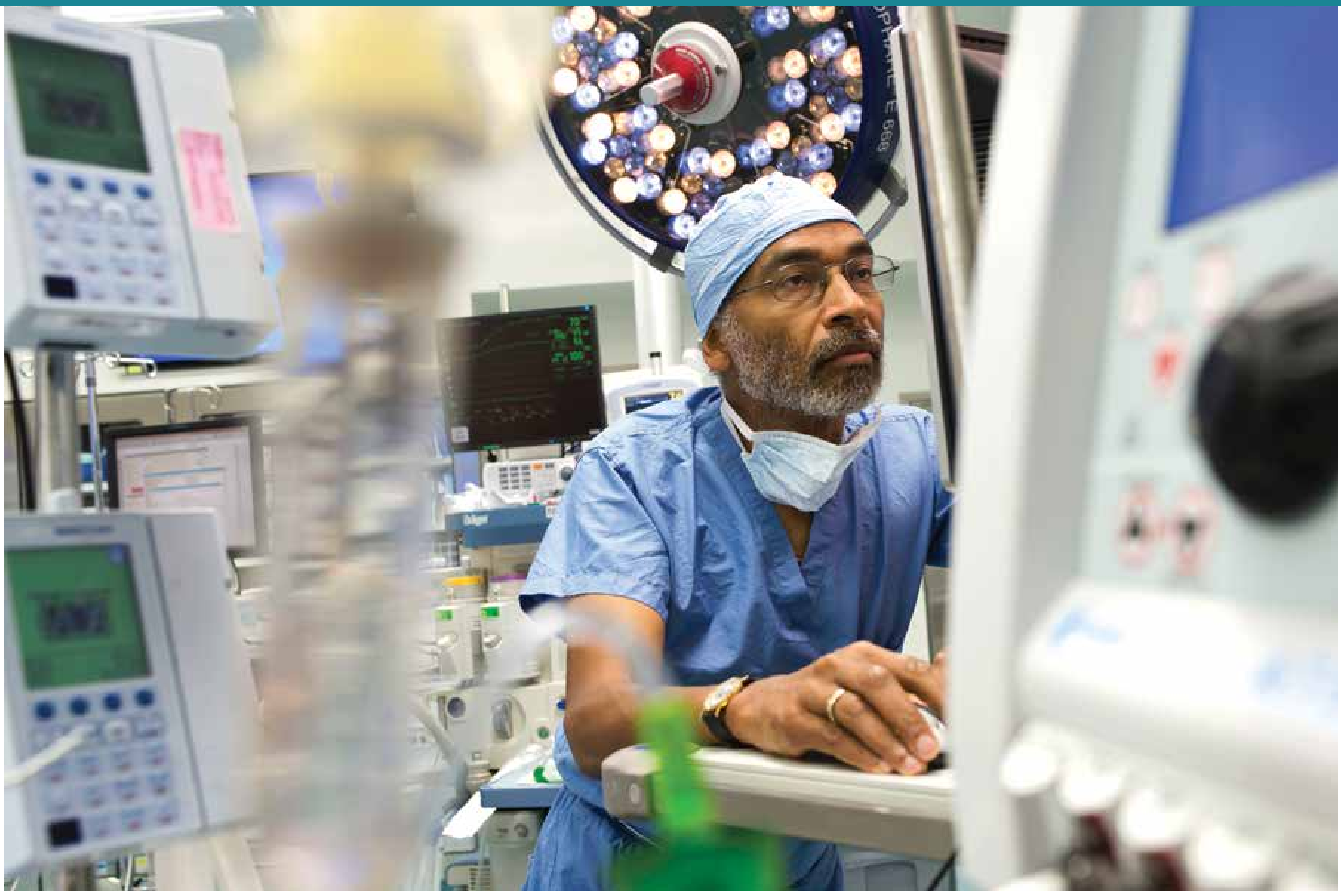
Reddien believes we are in the midst of an explosion of basic biological discovery in which new tools for studying genes shared by the flatworms and humans could boost understanding of stem cells, holding out hope that one day human stem cells could be regulated to replace aged, damaged, and missing tissues.

Even humans "last longer than most machines we can build," he says. "It's amazing how good the body is at repairing its tissues, muscle, skin, blood vessels, peripheral nerves, bones — but there are limits on how much it can do." With a boost from the ordinary flatworm, those limits might one day be redefined.

— DEBORAH HALBER

Peter Reddien believes human stem cells could one day be regulated to replace aged, damaged, and missing tissues.

Photo illustration: Len Rubenstein



Emery Brown: "Now that we understand how it works, how can we devise new strategies for anesthesia?" Photo: Len Rubenstein

NEW STRATEGIES FOR ANESTHESIA

In operating rooms around the world, machines attached to anesthetized patients blip and bleep, reporting second-by-second accounts of vital organs. Blood circulation and respiration are closely monitored, but the one organ that is drugged, the brain, has no readout. Anesthesiologists simply watch for signs of wakening, says Emery Brown, Edward Hood Taplin Professor of Medical Engineering and Computational Neuroscience at MIT.

Brown, who won a 2007 National Institutes of Health Director's Pioneer Award to study how anesthesia drugs work, hopes to change that. Stat.

Anesthesia drugs have been used in the US for more than 160 years without being well understood, so they've taken on an air of mystery. But according to Brown, the way they work is simple. The same way a loud, long tone, like the Emergency Broadcast tone, drowns out all other noise, anesthesia drugs create long, large, and lasting brain waves that make it impossible for new signals to be passed from one brain region to another. "If your brain can't transmit information, you're not going to be conscious," says Brown.

These waves readily appear on an electroencephalogram (EEG), a recording of brain waves. "They are like big tsunami waves," he says. "WAA–WAA–WAA."

Since 1937, it has been possible to monitor an anesthetized brain using EEG. But until recently, no one understood what the readouts meant. Brown's research has brought together the neuroscience underlying anesthesia, revealing the roles of different brain regions and the circuits that connect them in producing these readouts.

Brown, who is also an anesthesiologist at Massachusetts General Hospital (MGH), now understands those EEG readouts so well that he has put them to work in the operating room. He and collaborators have developed computer programs that transform the scribbles on an EEG into a spectrogram, a colorful visual display that provides an at-a-glance picture of the state the brain is in.

Using this display to monitor his patients, Brown has found that, particularly among the elderly, he can cut the dose of anesthetic used by 50 to 75% in some cases. "I'd never have the courage to do that without monitoring because the amount of drug that is needed is so little, I'd be afraid the patient will have awareness," says Brown. "But with the EEG, I can be sure the amount is appropriate."

Real-time monitoring also makes automatic control of anesthesia possible. The biggest need for automated control of anesthesia is among patients who are in medically induced comas to aid recovery from brain trauma or intractable seizures. During the days, or in some cases, months, that these patients are anesthetized, their comas are managed sporadically by nurses in intensive care units. "There's no way you can keep their brains precisely controlled with intermittent changes," says Brown. "It's a very compelling need."

While Brown is working towards meeting that need — he has submitted patent applications on his devices and is seeking US Food and Drug Administration approval through MGH — he is also looking ahead. Brown's monitoring technology has made it clear that the most common anesthesia drugs used today act in different ways on different brain regions to control pain and consciousness. This insight opens the door for these drugs to be used in a more informed way.

It also provides Brown the foundation he needs to begin reinventing anesthesia. In 2012, he received a National Institutes of Health Director's Transformative Research Award to begin the redesign. "We're taking a step back and saying, now that we understand how it works, how can we devise new strategies for anesthesia?" he says.

Brown envisions — and is working to design — new approaches that target the right parts of the brain for the right amount of time, if possible, without the side effects of existing drugs, such as confusion or clouded thinking after surgery. This work will most certainly lead to new strategies for managing other troubling brain states, such as chronic pain, depression and insomnia, he says. "Once you start paying attention to what happens to people under anesthesia, the insights you get are amazing."

— ELIZABETH DOUGHERTY

LEARN MORE:

MIT medical pioneering dates back to the x-ray

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Miho Mazereeuw designs a plan to guard against floods, earthquakes, tsunamis, and typhoons. Photo Illustration: Len Rubenstein

PREEMPTIVE DESIGN SAVING CITIES

Miho Mazereeuw is the founder of the Urban Risk Lab. She designs buildings and cities in anticipation of disasters. "Working in a field that has traditionally been the domain of emergency managers and engineers, we bring preemptive design and community engagement into the risk reduction equation," she says.

An architect, landscape architect, and Assistant Professor of Architecture and Urbanism, Mazereeuw's lab has a rapidly growing list of projects across the globe. Current projects take her to Haiti, India, Peru, and Japan — all sites vulnerable to earthquakes and floods. In Haiti, she and her research partners developed a framework for hurricane evacuation, working with the Department of Civil Protection and the World Bank. Considering the vast differences in terrain and levels of urbanization, the team developed nine strategies, with prototypes for coastal, valley, and mountainous areas.

In India, she is embarking on a two-year project in Odisha, a state on the east coast that is hit frequently by cyclones and floods. Working with a team that includes material science systems engineers and logistics experts, Mazereeuw is helping plan a large industrial corridor and the housing needs that will come with large-scale development, preemptively building disaster planning into the process.

Her work recently brought her to the White House for a discussion on Disaster Response and Recovery, which focused on the most effective uses of technology to better prepare communities for a disaster.

Half Japanese and half Dutch, Mazereeuw has roots in two countries that have dealt with floods, earthquakes, and typhoons. "Ever since I was back in Kobe, Japan, volunteering in the aftermath of the earthquake in 1995, I've been researching how the city can be designed better to prepare for such events. Urban developers focus on livability and economic vitality, but risk factors rarely come into that dialogue."

Initiating a community dialogue, in fact, is the center of Mazereeuw's approach. In San Francisco, a US city most associated with earthquakes and anticipation of "the big one," Mazereeuw works with the Neighborhood Empowerment Network, tapping into one community at a time to engage people in disaster planning. It's a six-step process, and by the end, she says, the community has its own plan to make its social and physical environment more resilient and is prepared for earthquakes, floods, and heat waves. This model goes beyond an individualistic approach to disaster planning — from "I've got my water, my food, and my batteries" — to community-based awareness, concern, and planning.

And that awareness can be used to recognize existing community assets. A park with a spray pool may not look like part of a disaster plan, until you consider the water tank beneath it. That water may become vital to putting out a fire when other systems are impaired. We need to look at our schools, churches, parks, and everyday public places though that lens. "It is important to recognize the dual purpose of many community features, and better yet, when planning an urban environment, build in dual purposes preemptively," she says.

"We define risk as the hazard times the vulnerability divided by the coping capacity. The hazard is about the probability, location, frequency, and magnitude of an earthquake happening." How vulnerable, she asks, are the people? "How can the community's resilience change the outcome? We have little control over the hazard, but we have great control over the living part — where we live, how we plan, and how we build and structure our cities."

— LAURIE EVERETT

CONTROLLING THE BRAIN WITH LIGHT

Ed Boyden has come a long way since 2004, when he co-developed the barrier-smashing neuroscience technology, optogenetics, as a side project while in graduate school at Stanford. At the time, researchers were daunted by the challenge that truly understanding the brain would require precisely controlling discrete sets of neurons to learn what they do. Optogenetics does just that, by exploiting light-sensitive proteins, called opsins, found in algae and similar organisms. Late one night with borrowed equipment, Boyden showed that a pulse of blue light nearly instantaneously activated neurons he had engineered to express one of these opsins. Later he and others found opsins that silence neurons with yellow light.

Neuroscientists quickly recognized that optogenetics solved a huge problem. Every brain region has intermingled, heterogeneous neurons that respond to different stimuli, produce different signals, and connect to assorted neurons in different brain regions. With optogenetics, researchers can selectively control just one type of neuron to dissect elusive neural pathways and learn how neurons initiate or sustain behaviors, or malfunction in brain disorders. Typically, researchers implant miniscule optic fibers that deliver light to an animal's brain region with the modified neurons. Optogenetics' first human application may be to treat some forms of blindness, by endowing retinal neurons with opsins. Eventually, optogenetics may improve brain stimulation techniques for treating epilepsy, Parkinson's disease, and other disorders.

Boyden, who joined the MIT Media Lab in 2006 and the McGovern Institute for Brain Research at MIT in 2010, and is associate professor in the Departments of Brain and Cognitive Sciences and Biological Engineering, is continuing to develop and enhance optogenetic techniques — most recently a noninvasive means of control and a "multiplexed" control method for the study of more complex patterns of neural activity.

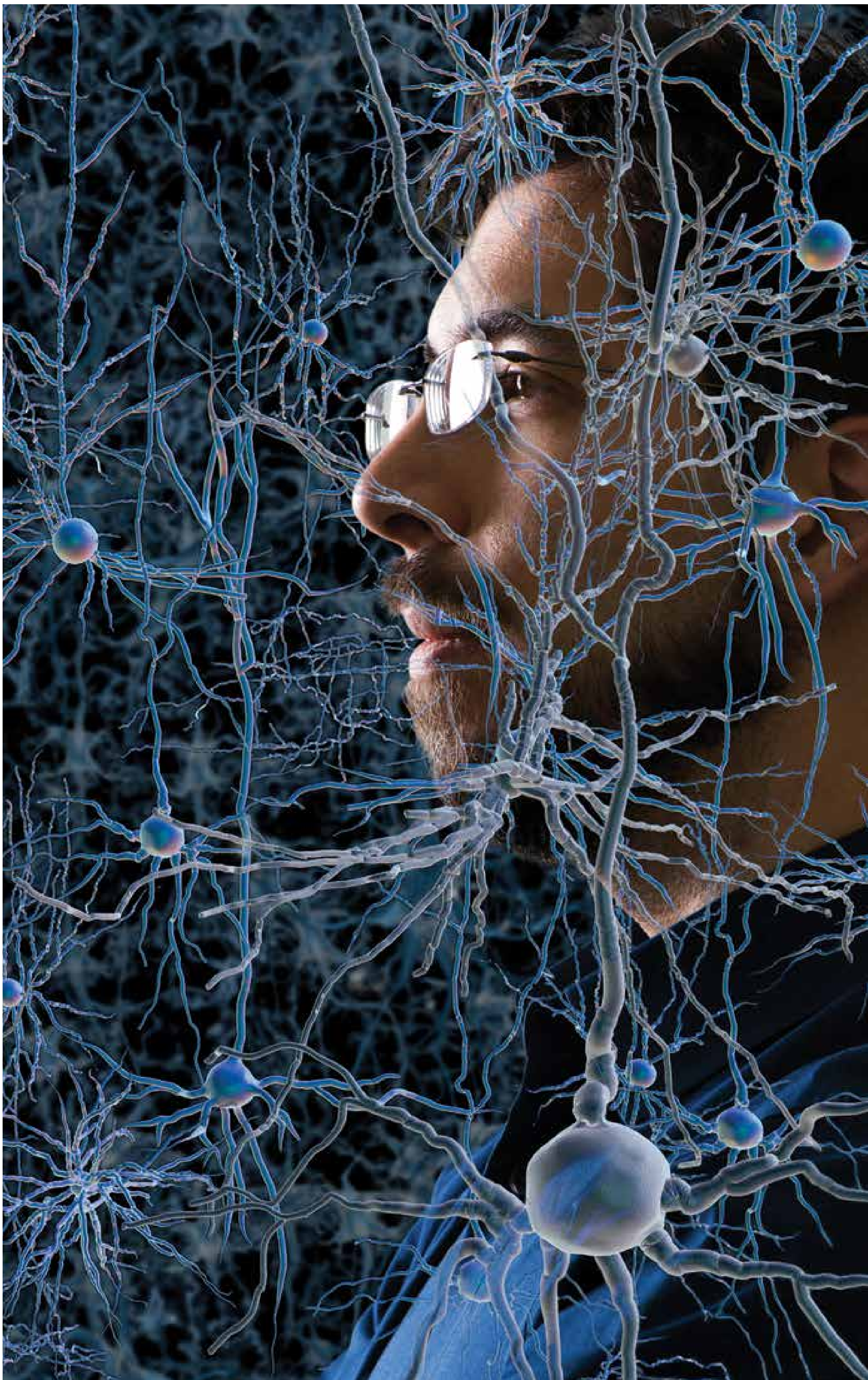
"My bigger goal, though, is to build tools that help solve the brain," says Boyden. Reflecting his MIT undergraduate training in physics, computer science, and electrical engineering, Boyden thinks of the brain as a 3-D structure, with a parts list, a wiring diagram, and integrated components. "I want to map the brain to understand how it works as a network of neurons, and how neurons work as networks of molecules. When we stimulate a neuron, how does it alter the rest of the neural circuit? What is that circuit's wiring diagram? How does a neural circuit generate a thought or feeling, and can we simulate it and learn how to fix brain disorders?" To that end, his lab is developing many more tools besides optogenetics.

One such tool is whole-brain imaging of all the neural activity in an organism as it responds to a stimulus or initiates a behavior. For a test, Boyden and his collaborators modified all the 302 neurons in the worm *Caenorhabditis elegans* to express fluorescent proteins that glow when neurons fire. But even the worm's tiny nervous system is a three-dimensional structure. A scanning microscope can gather 3-D images, but too slowly to capture individual neurons firing. So Boyden and his collaborators adapted a light-field microscope with multiple lenses, which mimics a human visual trick: Just as each eye gathers light rays from different angles that are then integrated into three-dimensional images, these microscopes gather rays from different angles as the firing neurons fluoresce. The resulting 3-D video shows what upstream and downstream neurons are doing as the worm goes about its business. Boyden's lab is also developing a novel microscope to map the connectivity of the neurons — and a genetic tool to discover the protein "recipe" for individual neurons.

Eventually, Boyden wants to build a brain from scratch (i.e., from stem cells). "We could see how brains naturally develop their wiring. We could create replacement parts for diseased brains, and we could create a personalized diagnostic platform to test how a patient's 'mini brain' responds to a potential treatment." Such a construct would also satisfy the engineering maxim that Boyden embraces: "What I cannot build, I cannot understand."

— CATHRYN DELUDE

Ed Boyden aims to build tools to help solve the mystery of the brain. Photo illustration: Len Rubenstein



INNOVATIVE ENTREPRENEURSHIP

Why do MIT graduates start so many companies? Maybe it has to do with the Institute's culture of hacking. "For many people outside MIT, the notion of hacking is a bad thing," says Professor Fiona Murray. "Here, hacking is something we celebrate because it means trying something out, experimenting, understanding its strengths and weaknesses, going back and adapting it. That's very much an entrepreneurial act."

The marketplace shows hard evidence of MIT's entrepreneurial spirit. The MIT Digital Shingle Project tracks hundreds of companies created annually by MIT alumni, and more than 100 start-ups are founded by current MIT students each year. MIT faculty frequently launch companies, too, based on their research (more than 300 patents were issued for MIT technologies last year alone). Just because this is ingrained in MIT's culture doesn't mean it goes unscrutinized. On the contrary, the Institute has made itself a lab for studying innovation-driven entrepreneurship.

"MIT has been a pioneer in that research domain for the last 25 years, and in bringing that new knowledge into the classroom," says Murray, the William Porter Professor of Entrepreneurship and Associate Dean for Innovation. She says a creative tension powers entrepreneurship at MIT: mind and hand, theory and practice. In a course called Innovation Teams, which she teaches with School of Engineering researcher Luis Perez-Breva PhD '07 and entrepreneur/investor Noubar Afeyan PhD '87, students discuss seasoned founders' experiences alongside data on effective practices, then design commercial applications for technologies fresh from MIT labs.

Along with Vladimir Bulović, the Fariborz Maseeh Professor of Emerging Technology, Murray will co-direct MIT's soon-to-launch Innovation Initiative. Folded into that initiative will be ways to guide students through the sprawling ecosystem MIT has developed for bringing innovations to market, either by engaging existing companies or starting their own.

For those who choose the latter route, several resources — including a roster of entrepreneurs in residence, and the Global Founders' Skills Accelerator, which helps students launch start-ups — are housed in the Martin Trust Center for Entrepreneurship, where Murray partners as faculty director with managing director Bill Aulet SM '94. There's also a menu of popular courses on the topic offered through MIT Sloan School of Management, the School of Engineering, and the Media Lab; support for new endeavors from the Deshpande Center for Technological Innovation and Legatum Center for Development and Entrepreneurship; and advice and networking through the Technology Licensing Office, Venture Mentoring Service, and 25-chapter MIT Enterprise Forum. A host of prizes, hackathons, workshops, and clubs provide hands-on experience and a safe environment for mistakes. As Aulet says, "There is no such thing as innovation-driven entrepreneurship without failure. The more you do it, the better you get. MIT wants to time-compress that learning curve."

Fiona Murray will help guide the next generation of business founders to bring innovations to market. Photo: Len Rubenstein

It's not enough, Aulet adds, to implement these resources on campus. "If MIT's going to have an impact on the world, we need to systematize our entrepreneurial expertise, and then we need to ship it out." Nearly 55,000 people enrolled last spring in an online course taught by Aulet on the edX platform titled Entrepreneurship 101: Who Is Your Customer? and in August, 47 of those students, from 22 countries, visited campus for a 5-day start-up bootcamp. And MIT's two-year Regional Entrepreneurship Acceleration Program (REAP) has attracted the participation of such cities as Veracruz, Hangzhou, London, Rio, and Moscow, all eager to develop their unique entrepreneurial capacities.

As the Institute works to optimize its own entrepreneurial and innovative capacity, it will continue to expand it. Near the top of students' wish list is more physical infrastructure for business ideas based on hardware solutions. "The maker spaces, the lathes and mills and 3-D printers, are increasingly in demand," says Murray. Students have concrete ideas for confronting huge challenges like clean energy and food security, and they're impatient to begin. "Our students no longer want to wait to have a 20-year career in a large corporation before they can demonstrate impact on the world." — NICOLE ESTVANIK TAYLOR

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Students who start companies
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Amy Finkelstein, an MIT economist, is principal investigator of the groundbreaking Oregon Health Insurance Experiment. Photos: Len Rubenstein

MEASURING HEALTH CARE

When Oregon voted in 2008 to use a lottery to determine which low-income adults to add to its Medicaid rolls, Stephen Colbert mocked the effort as "gambling for health insurance."

MIT economist Amy Finkelstein wasn't laughing.

"I heard about it and immediately thought, 'Oh my god, drop everything and get on this!'" says Finkelstein, Ford Professor of Economics at MIT and a principal investigator of the groundbreaking Oregon Health Insurance Experiment. "What they saw as humorous, we saw as an unprecedented opportunity to bring the gold standard in scientific research to one of the most pressing questions of our day."

By using a lottery to assign coverage, Oregon had unintentionally created the perfect conditions for a randomized controlled trial that could reveal the true costs and benefits of health insurance. Since the population that received coverage was statistically equivalent to the group that didn't, economists could simply compare outcomes between groups to gauge the effects of insurance. "Remarkably, this had never been done before in the United States," says Finkelstein, who won the 2012 John Bates Clark Medal from the American Economic Association for most significant contribution to economic thought by an economist under 40.

The results were stunning. Researchers found, for example, that Medicaid increased health care use and reduced rates of depression, despite often-heard claims that Medicaid coverage was worthless. Medicaid also increased visits to the emergency room — notwithstanding many policy-makers' predictions to the contrary. "The beauty and power of randomized evaluations is that they really allow you to be surprised," Finkelstein says.

The study also showed that health insurance successfully provides a financial safety net. "People often think of health insurance as a way of improving health, but to economists, health insurance is a financial instrument. The first idea is not to improve health but to protect you financially against large medical expenses," Finkelstein says. "We found Medicaid basically eliminates the prospect that a person will have a catastrophic financial issue."

The results from the Oregon Health Insurance Experiment made headlines again and again, underscoring for Finkelstein the power that randomized evaluations have to change both public perception and policy debate. "Nobody is arguing about what the results are," Finkelstein says. Instead, they're arguing about what to do with this new information — and that is the way of the future.

To catalyze a wave of similar research across the continent, Finkelstein last year helped launch the North American branch of MIT's Abdul Latif Jameel Poverty Action Lab (J-PAL), which pioneered the use of randomized evaluation to evaluate social programs.

"One of the reasons I cofounded J-PAL North America with Professor Lawrence Katz of Harvard is because we think [randomized evaluation] should be much closer to the norm than the exception in health policy," Finkelstein says.

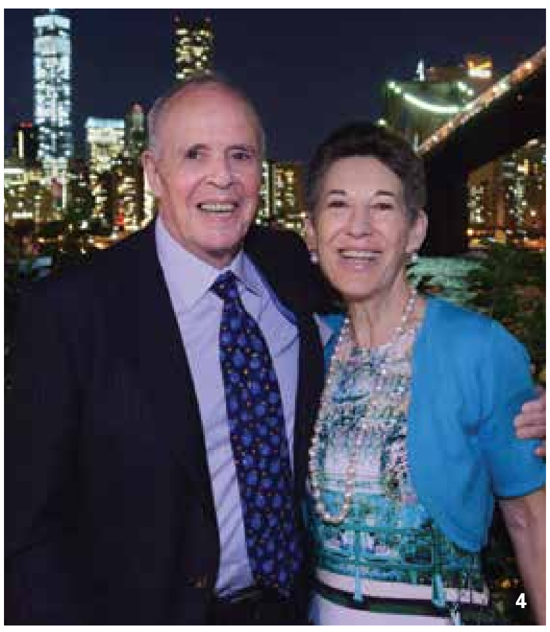
Since most health care programs start small and ramp up, they are ripe for regular testing, Finkelstein notes. Already, J-PAL North America affiliates have completed five health-care studies, and the lab has lined up more than two dozen academics to conduct randomized evaluations of a wide range of social issues, from health care to education, crime, and discrimination.

As for Finkelstein herself, she is currently studying a Camden, NJ, program that provides intense after-care interventions for patients at high risk for repeat hospitalizations. Since the program can't yet accommodate all such patients, Finkelstein and her partners will compare results between those who receive the intervention and those who don't to see whether the program meets its goal of preventing future hospital visits.

"Ideally most policies going forward would have an evaluation component built in so that we can tell the effects of a program," Finkelstein says. "My real hope is that this will become a movement."

— KATHRYN M. O'NEILL

CURRENT EVENTS



BROOKLYN, NY — President L. Rafael Reif and Mrs. Christine Reif recently hosted a celebratory dinner to recognize the philanthropic leadership of members of the MIT Charter Society. The Society honors individuals and families whose philanthropic commitment to MIT has reached or exceeds $1million. Barrie Zesiger organized the event. Prof. Alexander D'Hooghe, director of MIT's Center for Advanced Urbanism, spoke about innovative solutions to protect coastal cities from storms. Recently, his team was among the winners of the *Rebuild by Design* competition for a project focusing on 30 square miles of the NY/NJ metro region. The event was held at the River Café, which was rebuilt after damage by Hurricane Sandy.

1. Christine Reif, Sara and Doug Bailey '72, SM '74, ME '75

2. Bob Millard '72, Barbara and Ron Cordover '64, SM '65, PhD '67

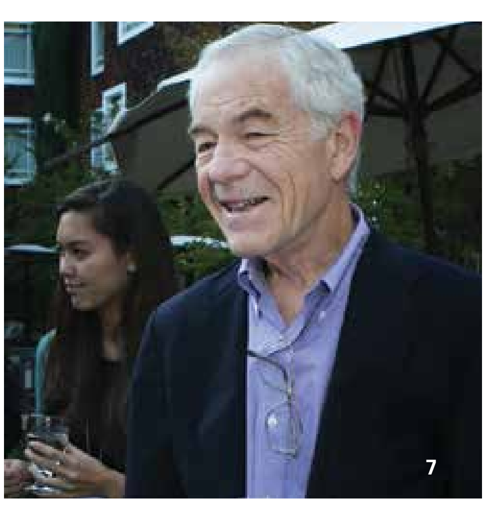
3. Madie Ivy Head and L. Rafael Reif

4. Al '51 and Barrie Zesiger

5. Denis '69 and Terry Bovin

6. Doreen Ma Wang and Ken Wang '71

Photos: Craig Chesek



MENLO PARK, CA — Arthur H. Reidel '73 recently hosted a reception for 50 guests at the Stanford Park Hotel to honor recent graduates of MIT's internship abroad program, the MIT International Science and Technology Initiatives (MISTI). Special guests included Deborah K. Fitzgerald, dean of the School of Humanities, Arts, and Social Sciences, and David Dolev, assistant director of MISTI. MISTI is MIT's largest international student program.

7. Steve Halprin '60

8. Mort Grosser '53, SM '54 and John Sell '91

9. Margaret and Joel Steinberg '68, Robert Bachrach '64, and Arthur Reidel '73

10. Arthur Reidel '73

11. Vivian Dien '13, Ida Wahlquist-Ortiz '04, Kimberly Sparling '12, Kirsten Hessler '12, and Peter Jeziorek '05

12. Dean Deborah Fitzgerald

Photos: Bruce Cook

AN EDUCATION WITHIN REACH

Earl and Suzette Rennison support an undergraduate scholarship at MIT. Marc Longwood

Earl and Suzette Rennison of Atherton, California, made an endowed gift to MIT for undergraduate scholarships. Earl earned a BS in electrical engineering from the University of California, Davis and an SM in media arts and science from MIT in 1995. Suzette graduated from Menlo College and earned an MBA from Golden Gate University, and has worked in telecom and financial services, most recently as vice president of sales for GE Money. Earl, a serial entrepreneur, created and sold two technology companies, Perspecta, sold to Excite@Home, and Trovix, sold to Monster Worldwide.

Earl: "When I was nine years old, I had an egg business, Earl's Eggs. I wanted to collect the eggs of each individual chicken and document the egg production under varying conditions and measure the impact. Later in my career, I built companies focused on data analytics.

"At Trovix, we put together a model sales pipeline and I pushed the team to collect data about each stage and to vary conditions — to run a marketing campaign or make a change in operations — and then see the impact. It was a data-driven business. Now, if you're not running a data-driven business, you're behind the times.

"Ever since I can remember, I wanted to go to MIT. It captured my imagination as the top school in the world for computer technology. But my family didn't think they could afford to pay the MIT tuition. So I went to UC Davis, and after working at IBM and the Stanford Research Institute, I applied to MIT for graduate school.

"Being at MIT was a transformative, even magical experience. It expanded my ability to think about great big complex topics. People at MIT really think about big problems, they don't just theorize about them. They demonstrate what is feasible or what will be feasible in the future. MIT is about doing, showing, demonstrating. Don't just tell me about something or talk about something, but show me.

"With this scholarship gift, we want to help a student who has the desire to go to MIT but whose family is concerned they can't afford it. We want to show that MIT is within reach."

— LAURIE EVERETT

THE COUNTRY'S BEST HOPE

Entrepreneurs Colin and Erika Angle support innovation at MIT. Ken Richardson

Colin and Erika Angle recently established a fund at MIT to support innovation. Colin, who cofounded iRobot in 1990 and is CEO, earned an SB from MIT in 1989 and the SM in 1990. Erika, who earned an SB from MIT in 2004 and a PhD from Boston University School of Medicine, is the founder and executive chairman of Science from Scientists, a nonprofit that brings scientists into classrooms. She is also cofounder and CEO of Counterpoint Health Solutions, a biotech company aimed at preventing chronic diseases.

Colin: "Innovation is the country's best hope to maintain and improve its standard of living, and it is near and dear to our hearts. It has dramatically and positively impacted both our lives. MIT innovates better than any other university in the world. We wanted to give back in a way that facilitates MIT's leading role in birthing new companies. As an MIT undergraduate, the idea that entrepreneurship is for other people is dismissed quickly. You think, 'Gee, if he could do it, why can't I?'"

Erika: "Small business, which grows from innovation, is a unique asset in this country. It's a way for people to start from all sorts of different beginnings to make something of themselves. That is something that should not be lost. There is something about MIT that breeds entrepreneurs. The people here are independent and self-motivated, and want to leave a lasting impact. And it isn't just the faculty, but the student body itself. As an undergraduate I met people my own age who were [starting companies] and succeeding, and who were willing to offer advice and suggestions. I hope that our gift will help the Institute continue to be the kind of place that draws talented people who are interested in entrepreneurship and helps foster the skills needed to become successful."

— ELIZABETH THOMSON

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SAVING LIVES

John Lewandowski saved a life at 16 after performing CPR on an 80-year-old having a heart attack. Then an emergency room intern at the Cleveland Clinic, he now says, "I realized, why save one life when you can save millions?"

Lewandowski — a PhD student in mechanical engineering and CEO of Disease Diagnostic Group, a company he launched in his dorm room — now claims he can save a million lives a year. His company is developing a device to provide accurate malaria diagnosis with one drop of blood in one minute at 100 times the detection level of current tests.

"Eradication of malaria is well within the world's capabilities. It just hasn't been done," he says, adding that the device could entirely wipe out the disease.

About 3.3 billion a year live in areas affected by malaria, half the world's population. Five hundred million are infected, he says, and of those, half go undiagnosed; the other half are diagnosed wrong. The company is now trialing the device in India and Peru.

Lewandowski won top prize in this year's MIT $100K Entrepreneurship Competition, which included 330 entrants. He also won $7,500 in the MIT IDEAS Global Challenge.

His battery-powered machine uses refrigerator magnets and a laser pointer to spot malaria-infected blood. The magnets align the iron-based crystals left behind by malaria parasites and the laser pointer quantifies them. Called Rapid Assessment of Malaria (RAM), the device is portable and easy to use; testers don't need medical training; each test can be done for 25 cents; and it can detect malaria infections in those who yet have no symptoms.

"We could use the same reusable approach in the third world to eradicate tuberculosis, dysentery, and HIV," he says. "In terms of health care, we plan to move mountains."

— LIZ KARAGIANIS

John Lewandowski invents a device that could wipe out malaria.

Photo: Len Rubenstein