

Massachusetts Institute of Technology
Fall 2017

Spectrum

QUESTIONS



Technical staff at the Kavli Institute for Astrophysics and Space Research (from left, Daniel Riley and Stephen Thomson) load a flight camera into a vacuum chamber for testing. The camera will be part of a NASA mission led by MIT launching next year in search of exoplanets that may harbor life (see page 27).

PHOTO: SAM LIANG

Wide Angle

- 2 Tega, the fuzzy robot who tells stories with kids

Subjects

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- 5 A new Environment and Sustainability Minor

FRONT COVER

A detail of pink cockscomb (*Celosia cristata*). By examining everything closely—nature, society, assumptions—MIT's researchers arrive at new perspectives and fresh answers.

PHOTO: SUE BISHOP / PHOTOLIBRARY

BACK COVER

Ebenezer Nkwate '17, photographed during his 2016–17 SuperUROP project as a MIT EECS Undergraduate Research and Innovation Scholar: "Synthetic Gene Circuits for Cardiomyocyte Proliferation and Heart Disease Treatment," advised by professor of electrical engineering and biological engineering Timothy Lu '03, MNG '03, PhD '08. Nkwate is now applying to medical schools and working on an invention to prevent medicine overdose in children.

PHOTO: GRETCHEN ERTL

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Questions and Answers

In February 2016, scientists from MIT, Caltech, and the National Science Foundation did something not easy to top: They confirmed a prediction Albert Einstein made a century ago.

Through an effort known as the Laser Interferometer Gravitational-Wave Observatory (LIGO), the research team directly observed gravitational waves caused by the collision of black holes. Einstein had anticipated the behavior, but he lacked the technology and the tools necessary to observe the waves' rippling and imperceptibly faint messages.

The LIGO news was, of course, groundbreaking in its own right. But it also demonstrated, on a grand scale, why and how human beings pursue deep scientific questions—and why it matters.

The world knows MIT as a place that leverages innovation to solve complex problems, in service to humanity. But without basic science—without a deep passion for answering fundamental questions like the one the LIGO team set out to address—you don't get innovation. It's that simple.

The challenge of conveying the value of basic science is that its payoff takes time, four decades in LIGO's case. But its impact can be catalytic. In addition to revealing thrilling new insights into the cosmos, LIGO has given the world gifts of immediate practical value, like a crucial training ground for thousands of top young scientists and engineers, and tools that are already being used in commercial manufacturing. And if history is any guide, we will feel its full impact far down the road—just as 1940s experiments with nuclear magnetic resonance led to the MRI scanner, a 1950s effort to create clocks to measure how gravity warps time made GPS possible, and research in the 1960s and 1970s gave the world the Internet.

To me, basic science is the engine that produces so much of what matters to us all: security, prosperity, competitiveness, health, jobs. But an engine doesn't build itself. To uncover fundamental truths about the world around us tomorrow, we must act today—with a commitment of time, funding, and patience.

These efforts may be painstaking, but their value to the nation and the world is clear. That much is without question.

L. RAFAEL REIF



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betterworld.mit.edu



DIMENSIONS 7.5" (L) × 7.5" (W) × 13.6" (H)

WEIGHT 10.1 pounds

FUR

Tega's furry coat is easily removable, and designed to withstand repeated hugs, tickles, and exploratory pats. In fact, thanks to capacitive touch sensors on the head and the belly of the coat, Tega can recognize physical interactions and react accordingly.

The New Robot in School

Meet Tega—one of the newest creations from the Personal Robots Group (PRG), led at the MIT Media Lab by associate professor of media arts and sciences Cynthia Breazeal SM '93, ScD '00.

PRG is working toward a future in which, simply put, we “live better with robots.” Its award-winning creations Nexi and Leonardo, for example, are designed to fit engagingly into peer-to-peer teamwork and family life. “Over the past few years,” Breazeal says, “our research has focused on advancing the artificial intelligence, user experience design, and application of social robots in the real world where they help people achieve long-term goals and can build personalized and positive relationships.” Educational goals are

of particular interest: “There is huge need to help children enter school ready to learn, and social robots can offer something truly unique as an intervention both in schools and homes.”



WATCH TEGA IN ACTION
spectrum.mit.edu/tega



SPEECH

Kids respond to expressive speech, especially during storytelling, and it can help them learn and retain more words and information. Computer-generated speech is often too monotonous, so PRG tapped a youthful-sounding teammate to record a library of scripted dialogue. Tega's animated mouth is virtually articulated and can produce lip-sync that corresponds with its speech.

FACE

As Tega listens to a child speak, it exhibits backchanneling, aka active listening, with utterances or by gazing, smiling, nodding, or leaning forward.

Enter Tega, the product of extensive research on child-robot interaction and educational best practices. The development of Tega was led by former graduate student Jin Joo Lee SM '11, PhD '17, along with numerous contributors who designed and assembled early prototypes. Research scientist Hae Won Park has spearheaded the interaction intelligence and deployment of Tega out in the field—most recently on a three-month literacy study in Massachusetts kindergartens, meeting weekly with children from 12 different classrooms. Tega is equipped to tell stories to kids, then to conduct autonomous conversations about those stories, testing comprehension and vocabulary and making emotional or inferential prompts (“how did the frog feel?” or “what will happen next?”)—all while tailoring its hints and reactions to the child's verbal and physical responses. Eventually, Tega invites the child to retell the story. “By analyzing the story and speech sample, Tega can gauge that child's language ability and which parts of a

CAMERA

Tega's ability to collect visual data is extended with an external high-resolution, wide field-of-view camera.

MECHANICAL CHASSIS

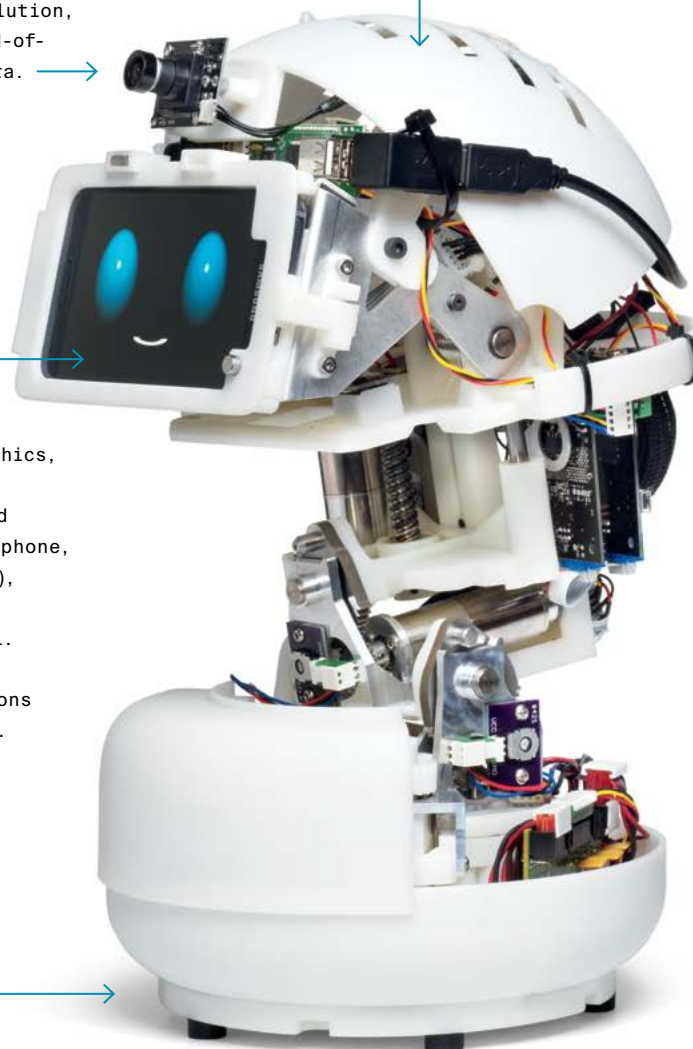
When kids first meet Tega, Park says most are excited, while some are nervous: "It's as if they're seeing a puppy for the first time. Some kids actually ask if it's going to bite!" The scientists remove Tega's fur and show students the machinery underneath. "Regardless, they treat Tega as something alive—as their friend."

SMARTPHONE

Tega utilizes an Android smartphone as an embedded device for displaying graphics, playing speech and sounds, networking, collecting and sending sensor data (microphone, camera, and accelerometer), as well as computation for behavior and motor control. Heavier computations for making interaction decisions are conducted in the cloud.

BATTERY

Tega's efficient battery-powered system can run for up to six hours without being recharged.

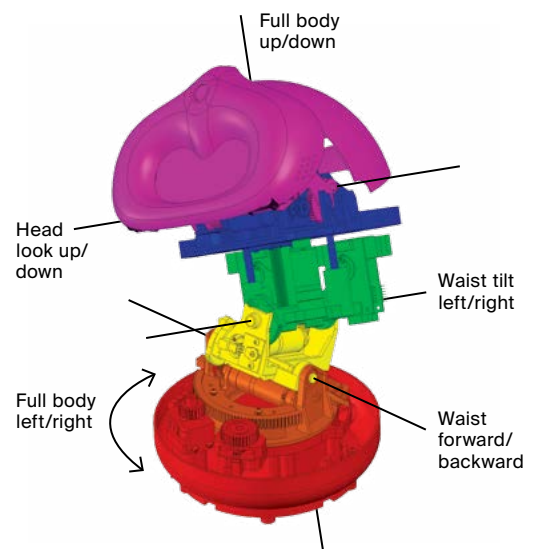


MOTOR CONTROLLER STACK

The motor controllers on Tega know the current position of each joint by reading encoder values. They communicate with the smartphone to receive next-position commands and send signals to the motors to reach the goal positions using feedback control.

DEGREES OF FREEDOM

Guided by conceptual character animations, the team gave Tega five basic degrees of freedom, with "squash-and-stretch" capability. Tega combines these movements to express a range of emotions on a matrix of valence (positivity/negativity) and arousal (level/intensity)—such as nodding to agree, leaning in to show engagement, tilting its head in thought, or straightening up in excitement.



story the child is particularly interested in," says Park. Relationship-building moments—such as conversations in which both child and robot share what they like about school—are key to nurturing richer, more personalized repeat interactions.

Tega's bubbly, childlike demeanor makes it a unique research tool as well as educational platform. "As human beings, we are wired to learn from others," Breazeal observes. And because it is designed to interact with kids as a peer rather than a tutor and to model productive mindsets, Tega offers a powerful, flexible social learning dynamic that PRG is doing rigorous experiments to better understand. Findings so far have reinforced the idea that "we learn not just knowledge and skills from others, but also important attitudes about learning—such as to be open and curious, to persevere through challenge, and to see mistakes as an opportunity to learn and grow."

Robot Design, Assembly, and Development

Version 1: Jin Joo Lee SM '11, PhD '17, Luke Plummer '14, Kristopher dos Santos '10, SM '12, Sigurður örn Aðalgeirsson, Cooper Perkins Inc., IFRobots Inc., Stacey Dyer, Fardad Faridi. Version 2: Hae Won Park, Meng Xi, Randi Williams, Cooper Perkins Inc.

Advisors on Classroom Interactions and Data Analysis

David DeSteno, Northeastern University; Paul Harris, Harvard University; Stephanie Gottwald, Curious Learning; Maryanne Wolf, Stanford University



Subjects

Left: Students in a 2015 sustainability class at MIT Sloan were led by Sterman through the World Climate role-playing exercise that will be used in this new course.

PHOTO: DHEERA VENKATRAMAN

Actions and Outcomes

Behind the syllabus of a deep dive into science and policy

“My experience working on mercury emissions and policy has showed me that managing this challenge requires not only understanding mercury cycling in the environment, but also the domestic and international governance mechanisms that create incentives and regulate human activities.”

“Science, public policy, the engagement of citizens and industry, and technology formed fascinating elixirs that sometimes succeeded in managing past environmental issues. What’s the magic that made these gel, and does understanding the magic help us on climate change?”

“Science and technology are essential in solving the pressing environmental challenges we face. But that’s not enough: research shows that showing people research doesn’t work. In this course we use simulations and interactive experiences to enable students to learn for themselves about the science and technology of sustainability—and the human and social dynamics we must understand to create a world in which all can thrive.”

TITLE

12.387/15.874/IDS.063

People and the Planet: Environmental Governance and Science

INSTRUCTORS

Noelle Selin, Associate Professor, Institute for Data, Systems, and Society and Department of Earth, Atmospheric and Planetary Sciences

Susan Solomon, Lee and Geraldine Martin Professor of Environmental Studies, Department of Earth, Atmospheric and Planetary Sciences

John Sterman PhD '82, Jay W. Forrester Professor of Management, MIT Sloan School of Management

FIRST OFFERING

Fall 2017

Games include: role-playing scenarios cocreated by Sterman and Selin, respectively: World Climate, which simulates the process and outcomes of international negotiations on emissions reduction, and the Mercury Game, which helps participants explore the consequences of representing scientific uncertainty in various ways in the context of making an environmental treaty.

Topics include: biogeochemical cycling and scientific processes, regulatory challenges, and environmental justice.

Topics include: greenhouse gases (GHGs) and the physical mechanisms of global warming and climate change; the carbon cycle and other biogeochemical cycles; scientific, technical, economic, social, psychological, and political issues relevant to reducing GHG emissions and limiting the damage from climate change.

FROM THE CATALOG

Introduces governance and science aspects of complex environmental problems and approaches to solutions. Introduces quantitative analyses and methodological tools to analyze environmental issues that have human and natural components. Concepts are introduced through three in-depth case studies of environmental governance and science problems. Students develop writing, quantitative modeling, and analytical skills in assessing environmental systems problems and developing solutions. Through hands-on activities including **modeling and policy exercises**, students engage with the challenges and possibilities of governance in complex, interacting systems including biogeophysical processes and societal and stakeholder interactions.

UNITS

- **Introduction: Achieving a Sustainable Ecological Footprint**
- **Case study: Ozone depletion**
- **Case study: Mercury pollution**
- **Case study: Climate change**

Topics include: I=PAT (impact=population*affluence*technology); stocks and flows; system dynamics.

Topics include: Ozone science; the development of US environmental policy in the 1960s and 1970s; the international Montreal Protocol addressing ozone-depleting substances.

LEARNING OBJECTIVES

- Through the case studies, students completing the course will:
- Understand the importance of relationships among population growth, economic growth, natural resources, technology, and environmental challenges, including the drivers and impacts of environmental damages;
 - Identify and understand the scientific principles and interactions that influence environmental systems in the cases presented;
 - Identify and assess individual, collective, public, and private strategies to deal with environmental challenges, and their advantages and disadvantages;
 - Use quantitative modeling tools to simulate environmental systems, including the impact of human activities;
 - Compare different analytical lenses through which differing environmental problems can be viewed and assessed, including risk, economics, ethics, ecology, and policy analysis;
 - Design potential solutions to address complex environmental challenges, incorporating both technical and policy constraints.

A New Environment and Sustainability Minor

Environmental Governance and Science (opposite) is one of two “People and the Planet” core subjects—the other is Environmental Histories and Engineering—required for an Environment and Sustainability Minor launching this fall. In a 2016 survey, more than 40% of roughly 900 undergraduate respondents expressed interest in such a minor, with more than half considering a career related to environment and sustainability. To complete the minor, students will choose three electives from a list of more than 70, in addition to the two core courses, within four content pillars: Earth Systems and Climate Science; Environmental Governance; Environmental Histories and Cultures; and Engineering for Sustainability.

Spectrum interviewed John Fernández '85, professor of building technology in the Department of Architecture and director of MIT's Environmental Solutions Initiative, which hosts the minor.

Why do MIT faculty and students want this minor?

JF: I study cities, and the numbers—demographic, carbon emissions, urban energy, water scarcity—tell me that the coming few decades will bring ever-greater stresses to providing a humane and sustainable world for the more than half of the world's population living in cities. I've had many conversations with colleagues who expect that fast-moving issues such as environmental pollution, resource scarcity, and the consequences of climate change offer important opportunities for teaching with an eye toward creating solutions. Conversations with students almost always include a reminder to us to focus on applications—that is, learning about the environment is important, no question about that, but understanding is not enough. Students are interested in doing something about it.

What is illuminated by juxtaposing the government and science pillars in one core course, and history/engineering in the other?

JF: Professors Selin, Solomon, and Sterman [opposite] have all been deeply engaged with the policy-making world. Through their work, and that of many others at MIT and beyond, there is a very powerful message that science and engineering need to make a sustained effort to motivate international actions to address large-scale environmental challenges. The intent behind the coupling of engineering with history and cultural studies is equally powerful. A good engineer can be even more effective through an understanding of the unintended consequences of technology, in the past as well as in the imagined future. Both of these partnerships of perspectives are meant to bring the complexity of the natural and human world into the classroom.

What kinds of opportunities will the minor help open for students?

JF: Students in the minor will share an enhanced ability to act in an effective, productive, and competitive way, whatever their major and future career choice. The choices are many: Google X's Moonshot Factory is keenly interested in technology solutions for specific consequences of climate change. Northrop Grumman and General Electric and many other large companies are in great need of creative people with a science-based and practical view toward the environment. And the opportunities for startups are endless.

COURSE REQUIREMENTS

This course involves extensive participation by students. Designated “student experts” for a particular day will raise questions about the readings and lead small-group discussions. For each class topic, students will complete an assignment such as an essay arguing an original viewpoint or a quantitative problem set. Students will also complete a **final project** that will draw lessons from across the course topic areas to provide insights about environmental problems and their solutions.

Suggested topics include: deforestation, fracking, bees and pesticides, genetically modified food, ocean acidification, Deepwater Horizon oil spill, Stockholm Convention on Persistent Organic Pollutants.

SAMPLE READINGS

- *Michigan v. EPA, Supreme Court opinion, 2015.*
- Rockström J., et al. “A safe operating space for humanity.” *Nature* 461: 472–475, 2009.
- Selin, N. “Global change and mercury cycling: challenges for implementing a global mercury treaty.” *Environmental Toxicology and Chemistry* 33(6): 1202–1210, 2014.
- Sterman, J. “Communicating climate change risks in a skeptical world.” *Climatic Change* 108: 811–826, 2011.
- Ungar, S. “Knowledge, ignorance, and the popular culture: climate change versus the ozone hole.” *Public Understanding of Science*, 9: 297–312, 2000.

“We hold that EPA interpreted §7412(n)(1)(A) unreasonably when it deemed cost irrelevant to the decision to regulate power plants.”



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QUESTIONS

Because someone asked. That's why we know the magnitude of two black holes merging more than a billion light-years away, and the sequence of the billions of genetic letters that merge to make us. Because so many someones asked, and keep on asking, our picture of the planet sharpens in detail every day, and insights into our selves and societies are emerging from oceans of data. Every idea or invention born at MIT that improves lives and paves the way to a better future was developed through the collaborative efforts of considerable talents. And each one began the same way as MIT's mission statement: with the imperative to advance knowledge.

Why do you ask?

The power of wanting to know

On a spring evening in 2016, a wind howled across the plaza in front of MIT's Wiesner Building and through a 30-foot-high art piece titled *Memory Matrix*. The storm ripped tiny green Plexiglas elements from their scaffolding, scattering them across the pavement. For the installation's creator, Azra Akšamija PhD '11, the unexpected wind animated the message of the piece, delivering an answer, of sorts, to a question that greatly interests her.

In fact, Akšamija, an associate professor in MIT's Art, Culture and Technology (ACT) program, had built *Memory Matrix* upon several questions.

What are the core values of architecture? How do we preserve cultural heritage? Why do certain images of destruction inspire more empathy than others? How can we raise awareness about the destruction of cultural heritage in

the Middle East and North Africa region without broadcasting images manufactured by the destroyers? These questions bubbled up from Akšamija's own background as a native Bosnian who experienced the devastation of war, as well as from the occasion for which the installation was created, the centennial of MIT's Cambridge campus. The piece she conceived to explore these questions—collectively funded by more than 20 MIT departments and programs—was an ephemeral monument, an arrangement of 20,000 hanging "pixels." When viewed from a certain spot, the pixels resolved into the silhouette of Palmyra's third-century Arch of Triumph, one of Syria's best-preserved historic treasures until it was blown up in 2015 by the militant group ISIL. Each pixel was laser-cut with the contours of other vanished or threatened cultural artifacts.

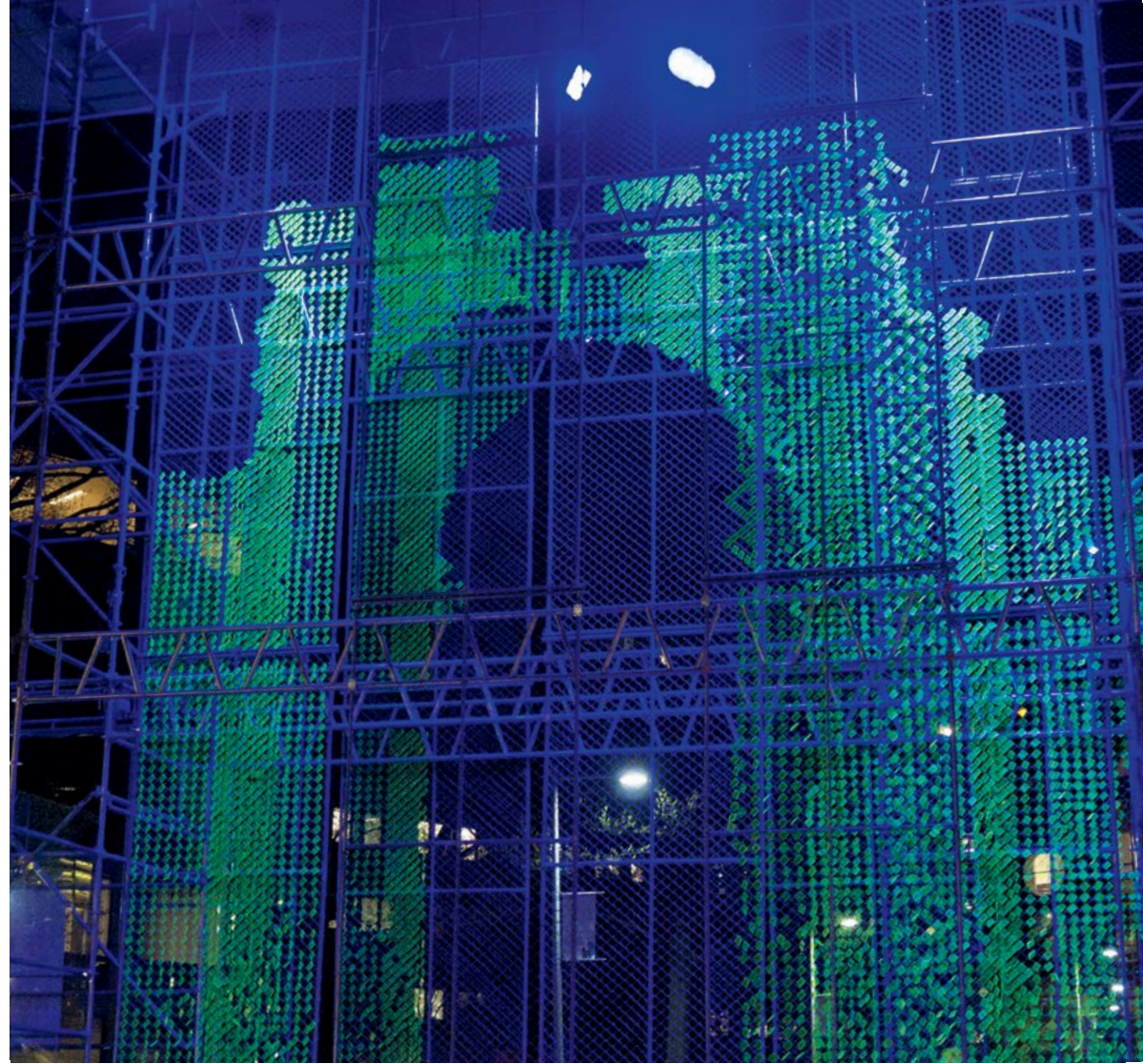
When that wind rattled *Memory Matrix*, Akšamija wasn't surprised that pixels detached. They'd been designed with open hooks—not only to ease installation but to endow the piece with symbolic fragility. The idea that monuments need caretakers was one of the premises under investigation. When pixels fell to the ground, she'd wondered, how would bystanders react? Until the storm, the public generally contributed to communal upkeep of the work, reattaching fallen pieces and thus changing the pattern of the pixels. After the extensive weather damage, however, she was intrigued to note that reactions changed: "Passersby participated in the destruction and theft of the elements."

Insights like this are achieved in art, and in disciplines across MIT, by daring to ask big, intriguing, sometimes disconcerting questions about every part of our world—and being open to answers from unexpected quarters.

Interrogating the problem

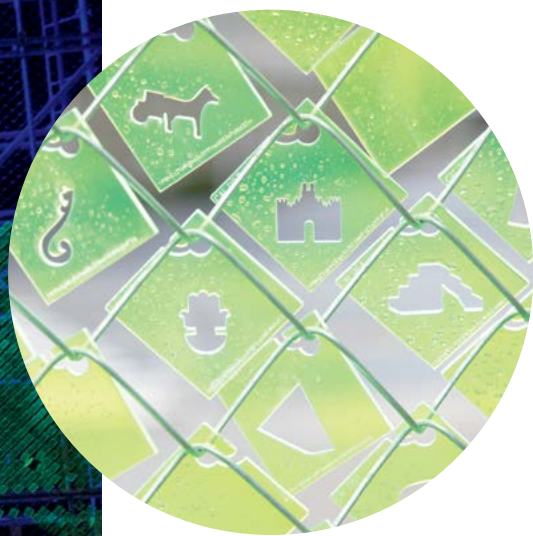
"Science is driven by challenges and challenging questions. Technology is fueled by science and driven by the need for solutions." That's how John Lienhard, Abdul Latif Jameel Professor of Water and Food, and the director of the Abdul Latif Jameel World Water and Food Security Lab (J-WAFS), put it in a speech to the EAT Stockholm Food Forum 2017. At J-WAFS, high-level questions might be posed in such terms as "How will agricultural productivity in different regions be affected by climate change?" or "How can we enhance crop yields without harming the environment?" Researchers define sub-questions and build solutions on the answers.

Likewise, question asking and solution building are inextricably linked at the Institute for Data, Systems, and Society (IDSS). IDSS's mission is to pool the strengths of engineering and social sciences, enabled by new floods of data, to solve problems in areas such as urban systems, energy,



Azra Akšamija's 2016 *Memory Matrix* installation at MIT conjured the ghostlike apparition of a recently destroyed Syrian landmark, formed by 20,000 pixels (inset) bearing the outlines of other vanished artifacts.

PHOTOS, FROM LEFT: AZRA AKŠAMIJA, EDWARD RICE



transportation, politics, and health care. But problem solving within such complex systems cannot occur without incisive questioning about the ways the elements of these systems come together. If the problem is updating a city's power grid for a sustainable energy future, clearly you must ask: How are renewable energy sources generated and transmitted? But also: Why do people do laundry at certain times of day? How is carbon consumption priced? According to Ali Jadbabaie, JR East Professor of Engineering in the Department of Civil and Environmental Engineering and IDSS associate director, "We educate a new breed

of students who not only understand the technical side, but how human behavior comes into the picture and what are the effects of markets and regulators."

In a sea of big data, framing questions properly is more important than ever. Social scientists, Jadbabaie says, are particularly adept at this. He cites his collaborations with MIT political scientists Fotini Christia and Rich Nielsen on two separate projects that ask, respectively, how mobile communication patterns shift in the Middle East during social unrest, and what drives the popularity of jihadist writings. He also notes that while IDSS emphasizes problem-focused inquiry, it also advances basic research on theoretical questions—such as what the fundamental limits of machine learning might be—whose applications we've only just begun to glimpse.

The magnetism of the right question

What happened during the earliest moments of the universe? If that's the kind of thought that keeps you awake at night, you've got something in common with David Kaiser, a professor of physics and the Germeshausen Professor of the History of Science in MIT's Program in Science, Technology, and Society. "I find myself drawn to questions that have a fundamental character, that force me to think about deep conceptual roots at the heart of our most successful theories of nature, like general relativity or quantum theory," Kaiser says. "I find it a great challenge for myself, and really fun, to try to find examples of questions within those frameworks that seem counterintuitive, maybe a little surprising." That's how he came to embark most recently on an international

experiment with fellow MIT physicists Alan Guth '68, SM '69, PhD '72 and Andrew Friedman to investigate the baffling case of quantum entanglement—in which, according to quantum theory, the states of two seemingly separate, far-flung particles are linked.

The history of science repeatedly proves there are unforeseen benefits to chipping away at the great unknown. "Back in the 1920s and 1930s, when physicists first began thinking about anti-matter, no one was thinking about medical imaging," Kaiser points out—yet today's PET scans harness that knowledge. "Likewise, GPS would be unworkable if scientists and engineers hadn't figured out some very subtle effects that gravitation has on the rate that clocks tick." Even those bizarrely entangled particles have a direct bearing on the race to transform information science through quantum computing. "It's not that we strike gold every time, but I'm willing to be patient, because time and time again these questions have borne fruit in unexpected ways," Kaiser says.

Meanwhile, the insatiable human need to explain our world can be a payoff in itself. It starts when we're kids, always ready with the next "why?" to stretch any answer we're given. If we're lucky, we carry this motivating curiosity into adulthood. But how many of us pause on the meta-question of what an answer truly is? Or, as Rockefeller Professor of Philosophy Brad Skow puts it, "What does it take for 'A because B' to be true?" His latest book, *Reasons Why*, outlines a theory distinguishing between an answer to a why-question (which describes a cause or ground of the event), and the reasons why that answer is an answer (natural laws and mathematical models can provide such reasons).

As a philosopher of science and omnivorous reader, Skow often stumbles upon the why-questions he decides to explore in depth. A procrastinatory detour into special relativity while he was a PhD

"I'm willing to be patient," says Kaiser, "because time and time again these questions have borne fruit in unexpected ways."

student inspired another of his books, *Objective Becoming*, in which he asked why we experience time "passing" when physics suggests it does not. For Skow, the impulse to articulate flaws in existing theories, or glimpsing a pathway to a workable new one, can put him in the grip of a new question and compel him to pursue it.

At the MIT Leadership Center, executive director Hal Gregersen teaches a different metric: in business, you know you are asking the right questions if those questions make you uncomfortable. In a recent *Harvard Business Review* article, "Bursting the CEO Bubble," Gregersen reveals that the toughest challenge for executives, especially senior ones, is figuring out "what they don't know they don't know—before it's too late." A senior lecturer at the MIT Sloan School of Management, Gregersen has seen large businesses sink when "senior leaders failed to explore the crucial blind spots that came back to destroy their companies." Conversely, when he arrived at the Leadership Center, Gregersen extrapolated from the exceptional entrepreneurial track record of MIT alumni that they "must have been asking different, better questions.... I believe that this is one of the core capabilities that leaders gain from an MIT experience."

In MIT's Executive MBA and Sloan Fellows programs, Gregersen has taught a technique he calls "catalytic questioning." A rapid-fire four minutes are spent collectively brainstorming questions about a seemingly intractable professional challenge. Eighty percent of the time, he says, queries are raised that reframe the challenge, suggest fresh solutions, and energize people to action.

Asking, together

It is often the process of opening up one's questioning to others that lets the light in. All told, Akšamija's *Memory Matrix* involved some 500 participants, from attendees at the Cairo Maker Faire who sketched examples of cultural heritage, to the students who project-managed and





designed and manufactured the pixels, to the volunteers who showed up to hang them. And then there were all those passersby who added to the dialogue either with their interest or their indifference. Such external engagement propels her work. “These projects are not about: you have a question, you address it, an artwork comes out if it. It doesn’t end there for me.” In this case, the next question—now what?—led her to found the Future Heritage Lab in a Syrian refugee camp in Jordan. With support from ACT, CAST (Center for Art, Science and Technology),

and the MISTI (MIT International Science and Technology Initiatives) MIT-Arab World Program, she has already brought MIT students to the camp for the *Lightweaver* project, in which refugees can alter the austerity of the camp through the beauty of their cultural heritage by punching textile-inspired patterns into wind-powered lanterns.

For Kaiser, outlets for his thinking on quantum entanglement have included collaboration on an educational video by YouTube’s “Physics Girl,” Dianna Cowern ’11, as well as on this year’s “Cosmic Bell” exhibit at the MIT Museum and an accompanying play by Patrick Gabridge ’88 titled *Both/And*. Whether developing analogies for general audiences or lecturing to his Course 8 students on campus, he finds that the effort to convey his thought process to others “can really force a rethinking from top to bottom.” And, Kaiser adds, “talk about being open to surprise—being in a room full of MIT students is guaranteed to generate some really interesting and unexpected questions.” —Nicole Estvanik Taylor

What questions drive MIT grad students?



Gifts to MIT supporting graduate fellowships—such as those listed here—make it possible for exceptional students to come to MIT in search of answers.

How can we make digital education platforms artificially intelligent?

Michael Beeler, PhD candidate, Operations Research

“Digital learning technologies have the potential to fundamentally transform the way we operate our education systems for the better. I am hopeful that students will one day engage in personalized lessons that maximize their rate of progress and engagement, given their interests, abilities, and prior knowledge, as if they had a high-caliber private tutor, and that this technology will be affordable and ubiquitous.”

- Advisors: Cynthia Barnhart SM ’85, PhD ’88, chancellor and Ford Professor of Engineering; David Simchi-Levi, professor of engineering systems
- Fellowships include: Mastercard Foundation Fellowship within the Legatum Center, MIT Tata Center for Technology and Design Fellowship

What is a “good seed”?

Ashawari Chaudhuri, PhD candidate, HASTS (History/Anthropology/Science, Technology, and Society)

“Communities of practice understand and work differently with genetically modified seeds,

specifically Bt cotton, in India. For farming communities, a good seed is a *process* that comes to life through the entire phase of cultivation. For seed companies and government regulatory bodies, a good seed is a bounded *object* with objectives of better germination, higher yield, and resistance to pests. My research aims to coalesce these systems of meanings and values to create a road map for agriculture in India.”

- Advisor: Michael M.J. Fischer, Andrew W. Mellon Professor of Humanities
- Fellowships include: Edward Austin Fellowship, Walter A. Rosenblith Presidential Fellowship

How do neutrinos behave?

Gabriel Collin, PhD candidate, Physics

“The neutrino is the least understood of the fundamental particles; from scales of femtometers to billions of light-years, it holds the keys to the secrets of our universe. My focus is on developing new computational and statistical methods to address our field’s most difficult questions.”

- Advisor: Janet Conrad, professor of physics
- Fellowships include: Lourie Foundation Fellowship

How are the design and development of urban regions shaped by ideological conflict and political agency?

Yonah Freemark MCP ’13, SM ’13, PhD candidate, Urban Studies and Planning

“Cities have widely varying approaches to problems like the inadequate provision of affordable housing or poorly performing transportation networks. I am motivated to understand the divergence between metropolitan areas where planning solutions reduce inequality and increase social inclusion, and places where such remedies are hard to come by.”

- Advisors: Lawrence Vale SM ’88, Ford Professor of Urban Design and Planning; Jinhua Zhao MCP ’04, SM ’04, PhD ’09, Edward H. and Joyce Linde Associate Professor of City and Transportation Planning
- Fellowships include: Edward H. Linde (1962) Presidential Fellowship

What new tools could enable mapping the nanoscale architecture of the brain?

Asmamaw “Oz” Wassie ’13, PhD candidate, Biological Engineering

“The functions of our brain, including our thoughts, emotions, behaviors, all arise from its complex architecture; biological processes ranging from the wiring of neurons to the molecular organization of individual cells define how our brain works.”

- Advisor: Ed Boyden ’99, MNG ’99, professor of biological engineering and brain and cognitive sciences
- Fellowships include: Lemelson Engineering Presidential Fellowship, Viterbi Family Foundation Fellowship

PORTRAITS BY: ELENA SOBRINO (CHAUDHURI); JUSTIN KNIGHT (COLLIN, WASSIE)

How do plants use light?

What Gabriela Schlau-Cohen discovers about the proteins responsible for photosynthesis could be critical to agriculture and energy



Savin Hill Park is a small oasis of trees—a splash of green located a few miles south of downtown Boston. It “gets kind of wild very fast,” says Gabriela Schlau-Cohen. And while her neighbors may not appreciate the vegetative overgrowth, Schlau-Cohen basks in it. She marvels at how plants deal with a broad range of light levels, from the searing intensity of high noon in July to the weak, meager rays of a cloudy day. This is one of the knotty questions Schlau-Cohen is working to unravel at her lab at MIT where she’s the Thomas D. and Virginia W. Cabot Career Development Professor in chemistry. And if she figures it out, it could reveal insights that would lead to higher crop yields and boosts in biofuel production.

To get at what the plants are up to, Schlau-Cohen and her students and postdocs are focusing their attention on some of the proteins responsible for photosynthesis, which operate like miniature antenna dishes for light. Schlau-Cohen fires lasers at the proteins and uses special microscopes to understand how they interact with light—how they absorb it, what happens to the light as it moves around inside the proteins, and how some of it gets converted into heat.

For instance, Schlau-Cohen discovered that one of the proteins she’s interested in has two ways of handling light—one that activates quickly in response to fast-moving clouds or shadows, and another that activates slowly during sunrise or sunset. These initial steps in photosynthesis—when sunshine first washes across a leaf—appear to have a large impact on the amount of new plant material that gets made.

“By 2050, as the population increases, it’s predicted that agricultural output won’t meet food demand,” Schlau-Cohen notes. Certain global regions, especially sub-Saharan Africa, will be hit hard by the shortfall. “To bridge that gap,” she says, “we need to figure out ways to make crops more efficient.” In other words, she hopes that knowing the details of how plants use light could allow us to engineer both crops and the algae used for biofuels to create more plant material out of the same amount of sunlight.

Schlau-Cohen also wants to know exactly how a plant moves energy inside its cells from one protein to the next. That energy can be shunted about so easily in an environment that’s “warm, wet, and noisy” is, to her, nothing short of remarkable. She uses instruments that can detect the movement of that energy in a literal flash—one quadrillionth of a second. This work could revolutionize solar power. Imagine a semi-transparent skin layered onto the windows of your home, a skin that could first absorb the sun’s energy and then shuttle it elsewhere to generate electricity.

One reason we know so little about the questions Schlau-Cohen wants to answer is that the proteins she’s after swim in membranes, and pulling a protein out of its membrane often cripples its activity. Only with the advent of the kinds of technologies Schlau-Cohen is using in her lab has it become

possible to examine these proteins in their natural habitat.

One of the great ironies of Schlau-Cohen’s life is that despite her love of outdoor places like Savin Hill Park and her fierce scientific curiosity about flora, she has the opposite of a green thumb. “Every plant I keep in the house, I kill,” she confesses—even the famously hearty philodendron. She just doesn’t know how to keep them alive. And yet, if Schlau-Cohen succeeds in her lab, she’ll understand something far more tantalizing: how plants keep *themselves* alive.

—Ari Daniel PhD '08

These initial steps in photosynthesis—when sunshine first washes across a leaf—appear to have a large impact on the amount of new plant material that gets made.



How can we measure damage?

Quantifying radiation damage in materials is the first step toward safer reactors and better nuclear compliance, says Mike Short

In science as in life, the seeds of good ideas can lie fallow. Michael Short '05, SM '10, PhD '10 found one such seed in the form of a neglected memo from more than 70 years ago that led him to the scientific question that now drives most of his work.

Short, the Norman C. Rasmussen Career Development Professor in the Department of Nuclear Science and Engineering whose lab is part of the MIT International Design Center, is fascinated by the fundamental definition of material damage at the atomic level. “We don’t have a way to measure radiation damage right now,” he says. “That makes it awfully hard to quantify.” Put a piece of metal into a nuclear reactor, he says, and despite any existing tests you might run on the material afterward, “you can’t tell me how much damage is left behind.”

Such damage—invisible, but with major implications for nuclear reactor technologies and a host of other applications—comes from high-energy particles like neutrons or ions knocking atoms out of place from the ordered atomic lattice of a material, a phenomenon that scientists generally describe using the term DPA (displacements per atom). But DPA doesn’t give the complete picture, as Short explains: “It’s a measure of how many times each atom gets knocked around by ionizing radiation, but it’s not a measure of damage,

because most of the atoms pop back into place like nothing ever happened. Very few of them remain as defects.” Another problem is that DPA calculations are approximations rather than precise measurements. “I always ask experts in the field why we use the DPA, and their candid answer is, well, it’s not that good, but it’s the best we’ve got.”

Short decided there had to be a better way. Unexpectedly, he found the inspiration for one in a World War II-era memo. In it, Manhattan Project physicists Eugene Wigner and Leo Szilard were discussing a phenomenon that came to be known as Wigner energy or the Wigner effect, in which certain materials exposed to ionizing radiation might actually store energy in some way.

Short first learned of the memo from his nuclear science and engineering colleague, assistant professor Scott Kemp. Short also spoke with Ronaldo Szilard, a distant relative of Leo Szilard, who is a nuclear engineer at the Idaho National Laboratory. Using stored energy as a way to quantify damage had occurred to Short and his collaborators, but until hearing about Wigner and Szilard’s speculations, he’d found little encouragement to support such an idea. “We thought we were crazy until we realized this Nobel Prize-winning guy [Wigner] and this other couch-surfing theoretical physicist [Szilard] thought about it earlier.” Kemp showed Short a book noting the document’s location deep in the research library of the DuPont Corporation, where Short’s uncle, Cyril Milunsky, happened to work. “I was like, hey Uncle Cyril, go find this memo!”

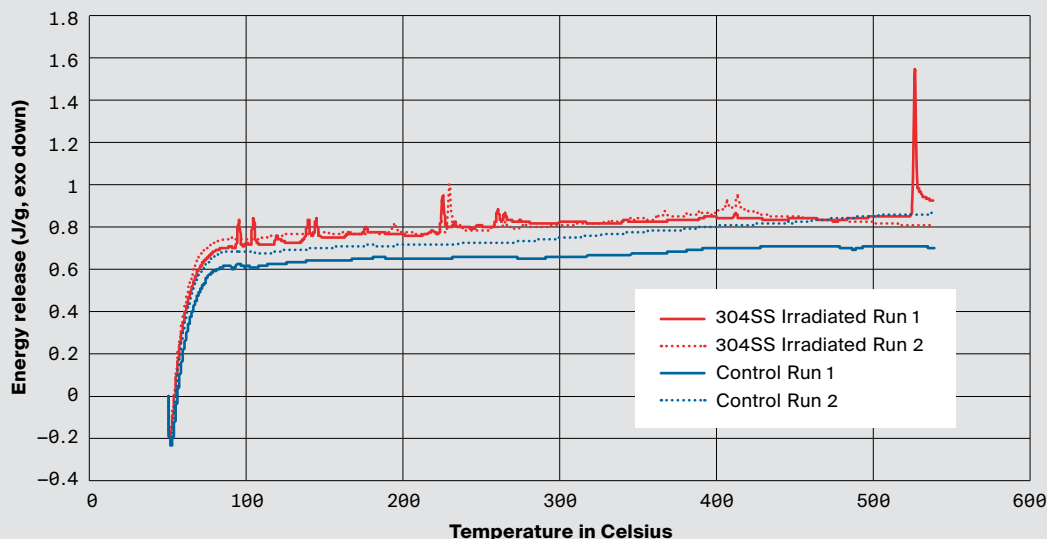
Short realized that the stored energy concept could be expanded to encompass not only radiation damage in metals, but any sort of damage in materials. “Damage is defects, and it takes energy to make those defects,” he says. “Usually when you want to get rid of the defects in a material, you anneal it—you heat it up to a high temperature for a long time. If those defects go away, they should release the energy that it took to make them. That’s the crux of it, really.”

Short’s insight is that the energy is released as heat in a particular pattern—what he calls a “stored energy fingerprint.” Measured with exquisite precision with a nanocalorimeter, this energy fingerprint can provide a sharp picture of the defects in the material and the specific events that created them. This ability, applied to radiation damage and nuclear technology, has startling implications both for civilian and military uses.

“Scott Kemp has called this ‘radiation forensics,’ using radiation in different ways to reconstruct the historical usage of things,” says Short. “He and I are working together on using stored energy to reconstruct historical uranium enrichment. Scott and I think we can take, say, the centrifuges in Iran, and measure the stored energy in the walls of the devices and figure out how many bombs they’ve made.” That would provide a

means of technical verification for international inspectors assessing nuclear deal compliance. For nuclear reactors used to generate energy, Short envisions a “cheek swab test” to check the health of steel reactor vessels, correlating the stored energy fingerprint to embrittlement and other important material parameters, and thus providing the technical reassurance required for extending the life of existing nuclear plants.

An energy fingerprint of irradiated stainless steel



Recent data from Short’s group shows the energy released or absorbed once irradiated stainless steel is heated. Features in heat flow for the irradiated steel (red), compared to an unirradiated piece (blue), support Short’s premise that radiation creates a “stored energy fingerprint” in materials. Two unexpected energy absorption spikes above 400 degrees Celsius helped Short and his collaborators in Kazakhstan identify another, previously undocumented effect that could assist in identifying damage: some materials become magnetic when irradiated.

GRAPH: COURTESY OF THE RESEARCHERS



How does water behave at the nanoscale?

“Inside tiny tubes, water turns solid when it should be boiling,” announced the headline atop the most-viewed MIT News story in November 2016. The story’s popularity underlines that basic research can reveal fascinating surprises about the most familiar phenomena in nature. The tiny vessels described by the headline are carbon nanotubes, whose inner dimensions are not much bigger than a few water molecules—mere billionths of a meter—and which are typically expected to repel rather than take in fluid. Within the tubes, MIT researchers observed the molecules entering a ice-like, stiff phase rather than the liquid or vapor that would be expected at the high temperatures employed. The team, led by Michael Strano, MIT’s Carbon P. Dubbs Professor in Chemical Engineering, used a technique called vibrational spectroscopy to track with unprecedented precision the movement of the water molecules inside the nanotubes. According to MIT News, “The finding might lead to new applications—such as, essentially, ice-filled wires—that take advantage of the unique electrical and thermal properties of ice while

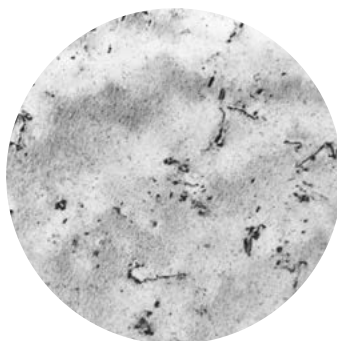
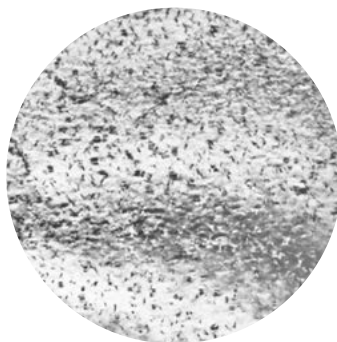
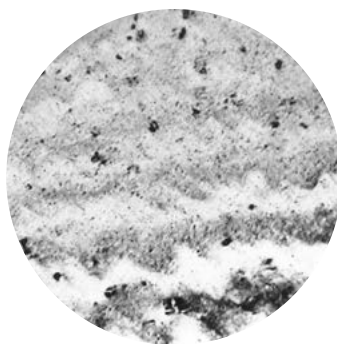
After a year of intense simulations, the project is now moving ahead to the dedicated experimental phase, using MIT’s research reactor and other facilities. For example, with funding from the MIT International Science and Technology Initiatives, Short is working with the research group of Oleg Maksimkin at the Institute for Nuclear Physics in Almaty, Kazakhstan, a collaboration he describes as indispensable, the 14-hour flights between continents notwithstanding. Maksimkin’s group has provided some of the theoretical explanations required to interpret Short’s calorimetric findings, confirming the measurements by their own magnetic techniques.

As a nuclear scientist, Short’s main focus at present is defining a standard unit for radiation damage, but he’s actively exploring other possibilities for the stored energy idea. “Let’s say you have a piece of steel that looks fine, but isn’t on the inside, and you can’t just cut it open and look at it because that would destroy it. Can you scoop out a microgram-sized sample of material and make a stored energy measurement to figure out what’s going on?” If Short’s work is successful, the possible applications range far beyond nuclear science to practically all areas of engineering.

For Short, the project has proven not only that good ideas are planted in unexpected ways and places, but also the value of persistence. “I’ve spent pretty much my whole life until now”—including 17 consecutive years at MIT, as a student and then a researcher—“thinking of things and finding out that somebody else has already thought them through,” he says. “Finally, after four years on the MIT faculty, I have an idea that no one else had already!”

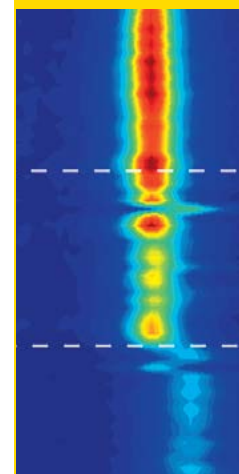
—Mark Wolverton

Wolverton is a 2016–17 MIT Knight Science Journalism Fellow.



Different views of the exact same sample of radiation-damaged material via transmission electron microscopy (from top, using decreasing magnification and regions of increasing thickness) illustrate the variability of assessing damage through imaging.

IMAGES: STEVE ZINKLE, UNIVERSITY OF TENNESSEE-KNOXVILLE



remaining stable at room temperature.” Or, as Strano puts it, “All bets are off when you get really small.”

Bright colors on this image of water in a carbon nanotube indicate changes in vibrational energy associated with phase transition.

IMAGE: COURTESY OF THE RESEARCHERS

How are poverty and geography linked?

Amy Glasmeier's map of the country has a lot to say about economic opportunity

A professor of economic geography and regional planning in MIT's Department of Urban Studies and Planning, Amy Glasmeier has spent decades exploring the root causes of income inequality and of regional disparities in economic opportunity. She is widely known for developing the Living Wage Calculator, which analyzes the minimum income required to pay for basic living expenses. Launched in 2003, the calculator today is widely used by companies and regional governments to set wages that meet the needs of local populations. Glasmeier has also published several books, including *An Atlas of Poverty in America: One Nation, Pulling Apart 1960–2003* (Routledge Press, 2005).

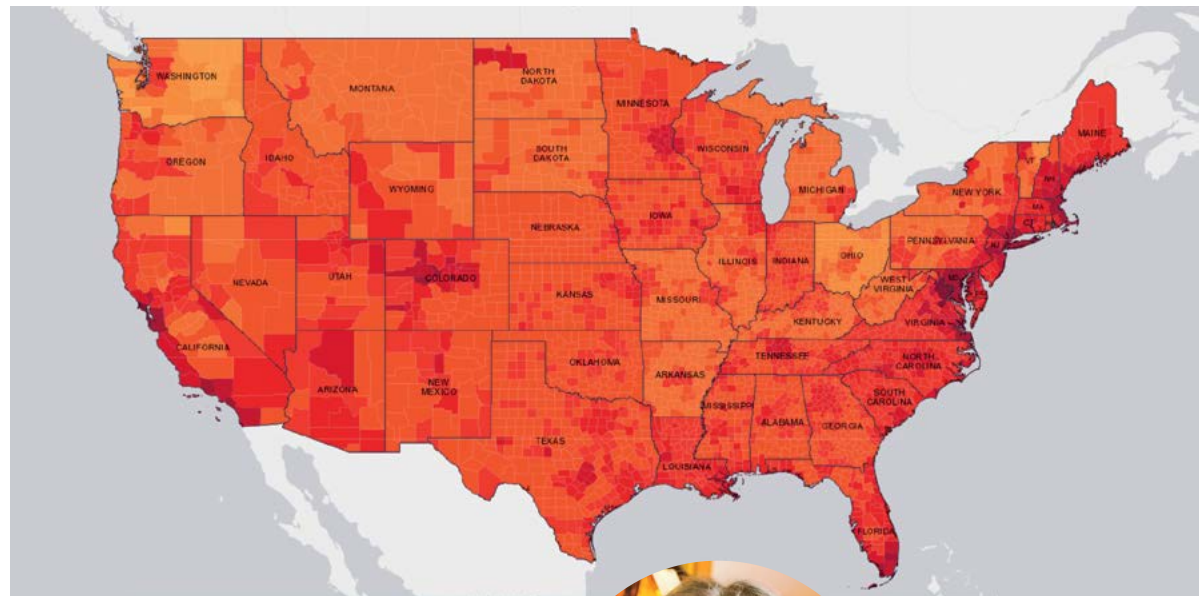
Spectrum asked her to explain how her research is helping us better understand the sources of poverty, and of wealth.

—Kathryn O'Neill

What has your research in economic geography revealed about how where people live affects their chances for economic advancement?

AG: Economic geographers study how economic activities, processes, and outcomes vary by location. My area of expertise is the underlying economic causes of such variation in economic opportunity—for example, how a region rich in natural resources, like central Appalachia, remains among the nation's poorest.

I spent 25 years advising the Appalachian Regional Commission, a governmental economic development agency, and can say the explanation comes down to four core factors: exploitative industries, geographic remoteness, failed institutions, and political corruption. The



A map based on data from Glasmeier's Living Wage Calculator shows regional patterns in the gap between minimum wage and the amount of money needed to meet a minimum standard of living. (The darker the color, the larger the gap.)

IMAGE: ESRI

remoteness of Appalachia meant there was a lack of markets and population centers, which in turn meant few job-generating alternatives to coal. While the single-industry economy produced low pay and poor working conditions, the absence of information about opportunities beyond the region's rugged mountains discouraged people from moving. In addition, the coal industry was in cahoots with Appalachia's political leadership, scaring away other industries that might have created alternative opportunities.

Stories like that of Appalachia still resonate today. Countries in Africa that are rich in resources, including Nigeria, Sierra Leone, and Tanzania, suffer a similar fate.

How have the data and analysis you've gathered from the Living Wage Calculator helped address economic inequality?

AG: The calculator was created when I was working on a Ford Foundation grant revisiting poverty policy. We noticed that from 1990–2000 a number of counties that had crawled out of poverty had fallen back in. It turned out many of these places had lost major sources of employment. We knew that recovery would not come easily, so we built the tool to demonstrate that cost of living adjustments can lag behind job decline. Now we can look at data from areas such as Appalachia and see that this is exactly what happens.

Interestingly, while we designed the tool for individuals to understand their personal cost



of living, today's users also include groups—ranging from unions to cities to religious organizations—interested in improving employee compensation. Employers like IKEA, for example, use the tool to set entry-level wages. Their motivation is fairness and reward for consistency in employee performance.

The City of Dallas uses the tool to set the wage rates contractors must pay their workers as part of its bid process. This has worked so well, improving both productivity and service, that the city has actually offered full-time jobs to former contract workers.

Can economic geography help us understand what drives wealth as well?

AG: Absolutely. The theories and tools we use are central to understanding the development process in booming areas. Consider what's been happening within the environs of MIT and Kendall Square. Geographic concepts help explain why, given the rising cost of real estate in the area, firms continue to agglomerate here.

The simple answer is there are economic and noneconomic benefits to being close to companies in the same or similar industries. These include being able to access a diverse and highly skilled source of quality workers and something intangible but essential: access to the knowledge people learn on the job.

Why should companies invest in employees?

Zeynep Ton's win-win theory of labor management

Why do some companies retain happy employees, while others find their ranks thinned by burnout and absenteeism? Is it possible for companies to boost their bottom line while also boosting employee satisfaction?

Zeynep Ton, adjunct associate professor of operations management at the MIT Sloan School of Management, answered these questions in her landmark 2014 book: *The Good Jobs Strategy: How the Smartest Companies Invest in Employees to Lower Costs and Boost Profits* (Amazon Publishing/New Harvest). Now, she works with a growing number of companies to implement the Good Jobs Strategy through MIT Sloan and the nonprofit Good Jobs Institute. *Spectrum* asked her to describe the results. —Kara Baskin

What problem has your research solved?

zT: A widespread assumption is that people are just a cost to be minimized and that companies should work to minimize that cost. But I've found that underinvestment in people leads to operational and customer service problems, which leads to lower sales, which leads to shrinking budgets. This vicious cycle is costly for investors. It hurts customers. It is downright brutal on workers, from their wages to their schedules to their treatment and dignity. Everyone loses. There has to be a better way.

What sector could benefit the most from your work?

zT: My research has been in retail, but the framework is applicable to other settings. Quest Diagnostics recently applied it in its call centers. If you want to fix income inequality and increase median wages, we need to transform low-wage service jobs first: retail sales, cashiers, food workers. Their median wages are poverty level, the schedules are unpredictable, and employees often lack meaning or purpose.

How do we fix the issue?

zT: When I examined successful companies, like Mercadona or Costco, I found that they created an entirely different, human-centered operating system to make their employees productive.

There are four components to my strategy. First, offer less. A typical store offers, say, so many kinds of toothpaste. How long does it take someone to shelve them and be knowledgeable about each type? Offering less can reduce costs and increase customer and employee satisfaction. Second, standardize and empower, instead of adopting a culture where rules come from the top down. More people will follow company standards if they feel like they're involved in creating them and empowered to improve them. And how many times have you heard, "Sorry, we can't help you, this is against our policy"? A smart company knows to empower employees to provide customer service at their discretion. Third, cross-train.

Many retailers manage variability in customer traffic and needs by changing the number of employees, which creates unpredictable work schedules. Instead of changing quantity, change what employees can do. Take Mercadona: If you're standing in line with nobody to help you, you don't hear, "Sorry, that's not my department." Chances are, any employee you see can leave the soup aisle to come help. Finally, operate with slack. Many retailers cut corners by understaffing. Model retailers overstaff, building in slack—instead of being so busy coping with issues caused by understaffing, employees can spend time looking for ways to improve and innovate. The combination of these choices with investment in people and strong values is what simultaneously produces great outcomes for workers, customers, and investors.

Why is your approach different from others?

zT: It appeals to people's heads but also their hearts. I recently asked the co-CEO of a retail chain based in Washington state, "This requires a huge transformation. Why take it on?" He said, "I wanted to create an organization that would stay around, but there's also a moral argument: Why on Earth *not* do this?"

It's been so nice to work with organizations. It's inspiring to see how excited people are, because the way that they change not only will result in their company being more successful, but it will also affect the lives of people—vulnerable people. My mission is to improve the lives of low-wage workers in a way that benefits customers and companies. It has to benefit companies, or it's not going to be sustainable.

The Good Jobs Strategy

- 1 Offer less.
- 2 Standardize and empower.
- 3 Cross-train.
- 4 Operate with slack.



How can computers apply what they've learned to new situations?



Barzilay



Tenenbaum

Developing this capability in machine learning could better equip it for human interaction and a host of medical applications

The hottest ticket on the MIT campus this fall isn't a seminar on virtual reality, a talent-scouting hackathon, or a robotics demonstration. It's an undergraduate class in the Department of Electrical Engineering and Computer Science (EECS) whose humble course catalog label, 6.036, belies its exponentially growing popularity. The subject, Introduction to Machine Learning, was first offered in 2013 and now attracts hundreds more students than can fit into a 500-seat lecture hall. In addition to enrolling droves of EECS students, 6.036 brings in registrants from nearly every discipline MIT offers, from architecture to management. The

irresistible draw? A chance to get a jump on the most powerful driver of technology innovation since Moore's Law.

If artificial intelligence is the rocket ship to which tech giants like Google, Apple, and Facebook have strapped their fortunes, machine learning (ML) is the rocket fuel, and boundaries between the two are increasingly blurred. While machine-learning techniques are intricate

Tommi Jaakkola addresses a packed auditorium during the popular course he co-teaches with three other faculty members, 6.036 Introduction to Machine Learning.

PHOTO: LILLIE PAQUETTE

and various, the discipline differs from traditional computer programming in one foundational way: instead of writing out in advance all the rules that govern a piece of software's behavior, machine learning attempts to equip computers with a means of inferring those rules automatically from the various inputs and outputs they encounter. Consider email spam filters (one of the earliest ML applications): it would be impossible to predict every possible instance of what counts as spam. So instead, spam filters learn directly from the data (and from the labels on those data that users provide), making the application more flexible, more automated, and more effective over time.

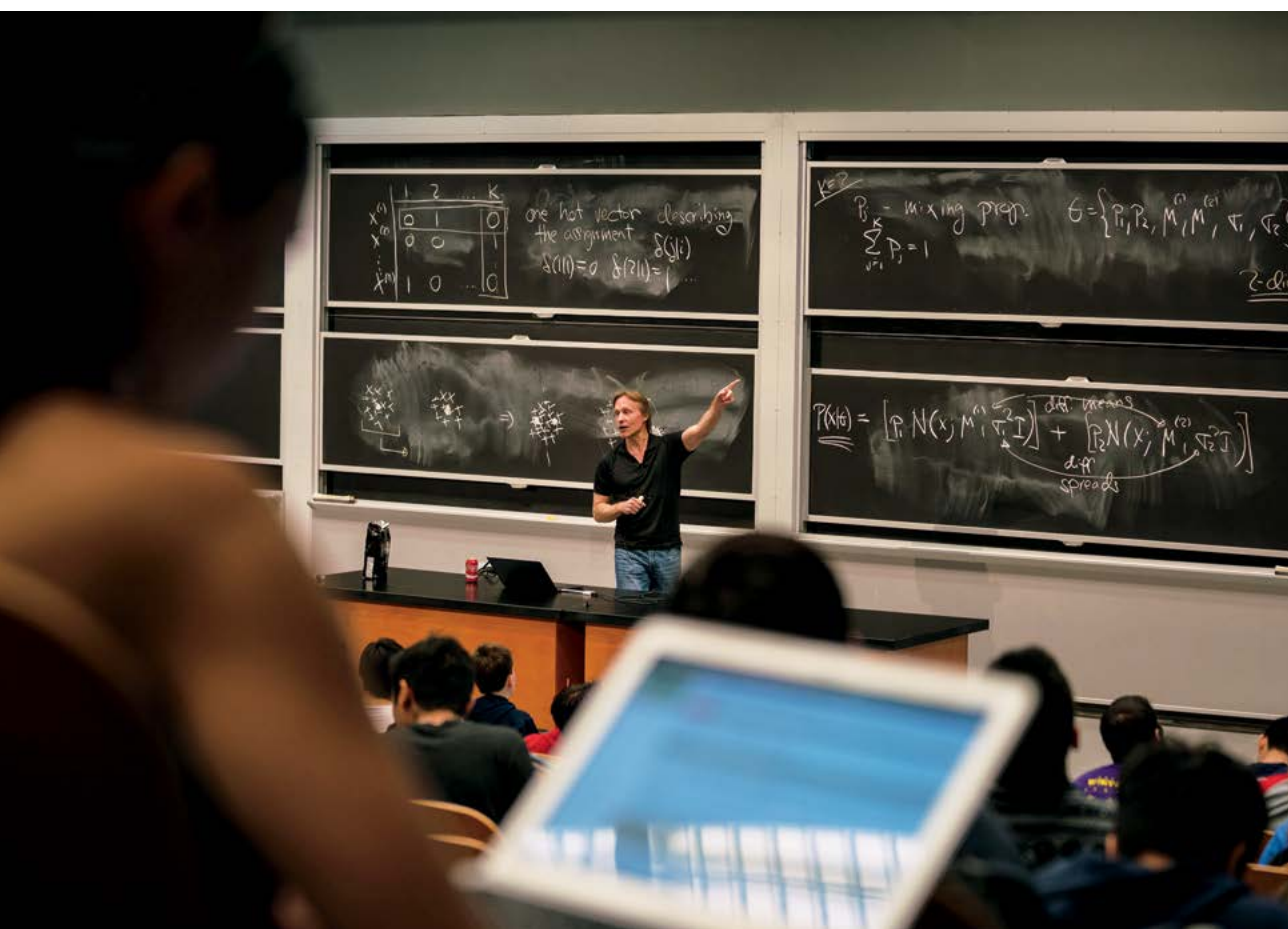
Building on strong underpinnings in computer science, optimization, and mathematics with a recent wave of new faculty hires, MIT has amassed "very good expertise in the foundations, theory, algorithms, and some applications of machine learning," says Stefanie Jegelka, the X-Window Consortium Career Development Assistant Professor in EECS—herself one of those hires (she joined MIT in 2015). She adds that "the research activity here, and in the Boston area as a whole, fosters the kind of interdisciplinary research that increases the impact of machine learning" on applications like robotics, computer vision, and health care. But because machine learning has recently experienced an explosion in effectiveness, distilling reality from hype can be difficult.

"Paradoxically, the public tends to both underestimate and overestimate machine learning capabilities today," says Tommi Jaakkola PhD '97, Thomas M. Siebel Professor of Electrical Engineering and Computer Science. "In the

context of narrowly defined tasks such as image analysis and game playing, the potential of machine learning already exceeds public perception. But in open-ended tasks requiring flexible common-sense reasoning, or pulling together and combining disparate sources of information in a novel way, the imagined capabilities may reach somewhat beyond where we actually are." The Introduction to Machine Learning course—which Jaakkola teaches alongside three other instructors—appeals to students as a means of accessing the ground truth of the field as a whole.

Machine learning and medicine
One of those 6.036 co-teachers is Regina Barzilay, the Delta Electronics Professor of Electrical

PORTRAITS, FROM TOP: JASON GROW, JUSTIN KNIGHT

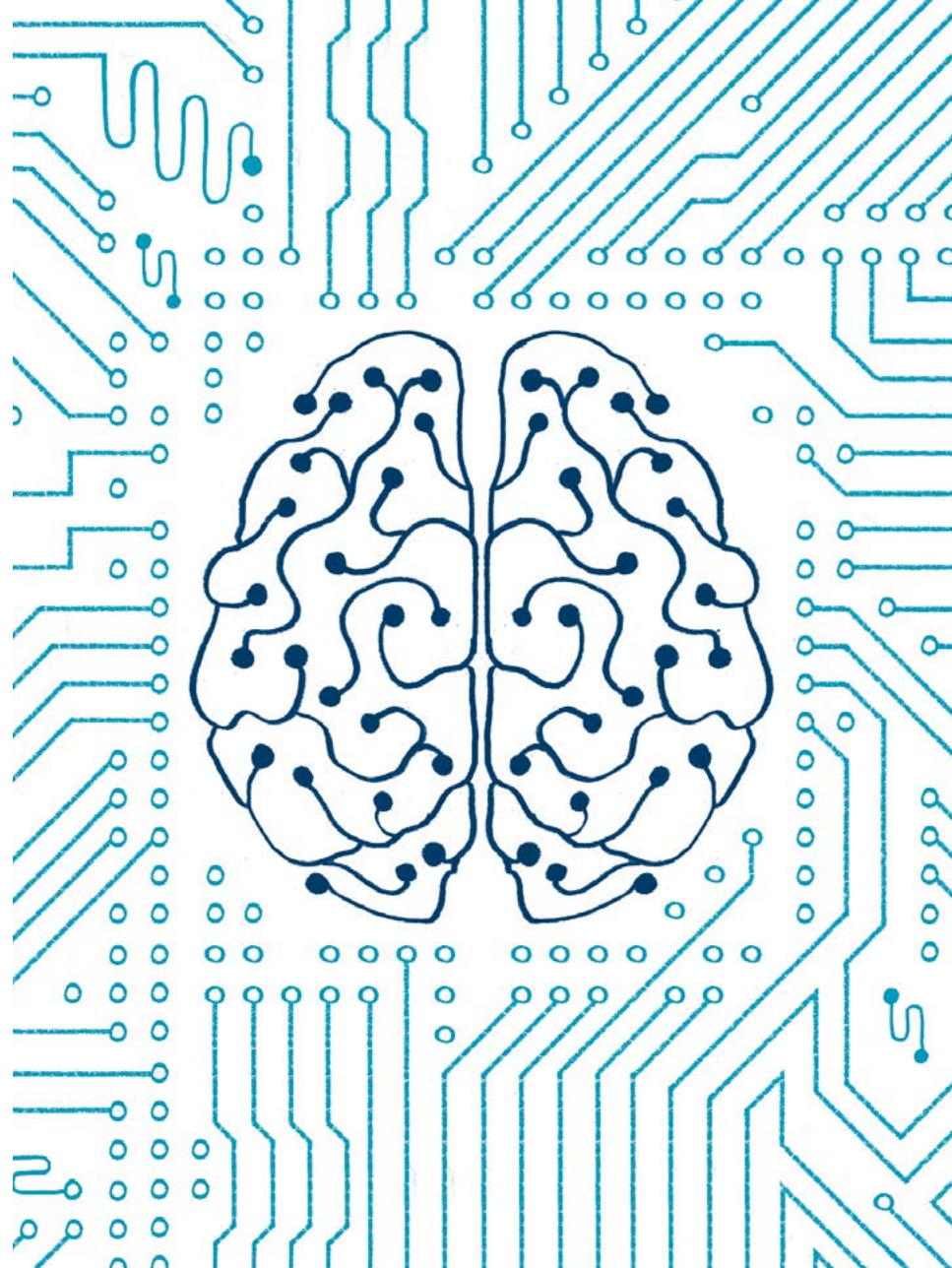


Engineering and Computer Science, who has an acutely personal interest in figuring out the big questions in machine learning. In 2014, she was diagnosed with breast cancer, and a portion of her current work is focused on making ML more relevant to medicine, where it might someday unlock advances in cancer diagnosis and personalized treatment. Since so much of medical data is stored in the form of written records and other text-based data, Barzilay's background in natural-language processing (NLP)—a computer-science discipline that focuses on engineering software that can interpret written and spoken language—provided a toehold for applying machine-learning techniques to medical problems. It also drives Barzilay's concern about the “interpretability” of ML models when used in medical diagnoses. “Today the majority of the machine learning field focuses on making accurate predictions,” Barzilay explains. “But for medical predictions, accuracy isn't enough—you really need to understand *why* the software is making a recommendation, and you need to make that process transparent. That means generating rationales that humans can inspect and understand.”

The rise of big data has been instrumental in driving advances in machine learning, because the software models—especially ones relying on a technique called deep learning—“are very data-hungry,” Barzilay says. For companies like Google or Facebook that serve more than a billion users, this appetite is easily sated. In the medical field, a similar surfeit of data exists. But because medical records are not standardized, ML models—which must be “trained” to recognize relevant features in data by feeding them thousands of hand-labeled examples—run into problems that social network recommendation engines and email spam filters don't.

“Let's say you are working with diabetes, and you labeled text-based diagnosis data for one hospital in great detail,” Barzilay explains. “Now, you go to another hospital and you still want to be able to predict the disease. Most likely, the performance of the machine-learning model will be degraded because they put the same kinds of data in a different format.” That means re-training the model again and again—an expensive and impractical prospect, especially for life-or-death medical matters. The key question, says Barzilay, is how to develop models that can transfer their initial learning to new data sets with much less “supervision,” as it's technically termed, while retaining their predictive powers.

A new research paper by Barzilay, Jaakkola, and Barzilay's PhD student, Yuan Zhang, offers the beginnings of an answer. They use a machine-learning technique called adversarial training, in which two systems learn about the same data by pursuing competing goals. In Barzilay and her collaborators' work, one ML system learns how to classify data according to labeled examples—for example, patient pathology reports noting evidence of cancer. Meanwhile, another ML system learns how to *discriminate* between the cancer labels and another kind of evidence that may also be present in the reports, albeit less extensively labeled—say, evidence of lymphatic disease. By working in concert, the two ML systems teach each other how to correctly classify evidence of cancer *and* lymphatic disease, despite the dearth of



Barzilay wants to make machine learning more applicable to medicine, where it might someday unlock advances in cancer diagnosis and personalized treatment.

you think of big data,” he says, “but when we talk about learning in school, it's really *generalization* that we prize. How can you figure out how to take something you've learned from one instance and generalize it to situations that aren't quite like the ones you've been in before?”

Tenenbaum's Computational Cognitive Science group uses computational models of learning to investigate how the human mind pulls off this feat. “We're reverse-engineering intelligence—which means doing science using the tools of engineering,” he says. “We feel that if we've understood something important about how the mind

training data for the latter. Since individual medical records almost always encode many different aspects of a patient's health, such a model could offer a powerful way of automating disease detection.

Reverse-engineering intelligence

Addressing the “transfer” problem in machine learning from another angle is Josh Tenenbaum PhD '99, an MIT professor of brain and cognitive sciences affiliated with the multi-institutional Center for Brains, Minds, and Machines (CBMM). “When you think of machine learning these days,





and the brain work in engineering terms, then we should be able to put that into a machine and have it exhibit more human-like intelligence.”

An area of machine learning called Bayesian program learning (BPL) has captured the major interest of Tenenbaum and his collaborators as a means for implementing this more human-like learning capability in computers. Based on Bayesian statistics—a branch of mathematics dedicated to making precise inferences based on limited evidence—BPL has been shown to enable a computer to learn how to write unfamiliar letterforms (such as “A,” or a Chinese logogram) more accurately than a human can after just one training example. The research, done by Tenenbaum in collaboration with his former student Brenden Lake PhD ’14 as part of Lake’s MIT dissertation, made headlines in the popular press last year.

Computers capable of this kind of one-shot learning—using models that more closely correspond to how our own minds work—would create a powerful complement to the capabilities already exhibited by deep-learning software, whose artificial reasoning can be inscrutable to human users. Tenenbaum’s collaborations with MIT neuroscientist and CBMM investigator Rebecca Saxe PhD ’03 focus on illuminating how social intelligence manifests in human beings, with the aim of implementing it in computers—relying on some of the same Bayesian mathematical frameworks that power one-shot machine learning. “We want to build machines that humans can interact with the way we interact with other people, machines that support ‘the 3 T’s,’” Tenenbaum says. “We can talk to them, teach them, and trust them.”

Long before machine learning reaches that apex, the discipline must coalesce from its current state—a cluster of multidisciplinary ad-hoc investigations and successes within narrow domains—into “a really systematic understanding of how to take these advances and put them in the hands of less sophisticated companies who don’t have armies of PhDs at their beck and call,” says EECS professor Sam Madden ’99, MNG ’99. As co-director (with Jaakkola) of the Systems That Learn initiative at the MIT Computer Science and Artificial Intelligence Laboratory, Madden hopes to achieve that very end—turning machine learning into a broadly understood computing infrastructure that anyone can leverage.

“I like to make an analogy with computer programming,” Madden says. “Today, using machine learning is like writing code in assembly language—very technical and low level. What I want is for it to be more like using Microsoft Excel. You don’t need a computer science degree to be able to use Excel effectively to do data analysis. It would be really cool if we could package up machine learning in a similar way.” Until then, MIT course 6.036 will likely continue on its current enrollment trend: standing room only. —John Pavlus

How will the MIT Libraries help to answer tomorrow’s big questions?

In 2016, a task force on the Future of Libraries consisting of 30 representatives from MIT’s faculty, student body, and staff released its preliminary report. *Spectrum* asked MIT Libraries director Chris Bourg, who led the effort, what the report reveals about the Institute’s plans to advance the creation, dissemination, and preservation of knowledge.

—Nicole Estvanik Taylor

Is the role of MIT’s research libraries changing in the 21st century, or just their tools and platforms?

cb: I think the fundamental role of research libraries will always be to provide enduring, abundant, equitable, and meaningful access to knowledge. Certainly, the tools and platforms for doing that will continue to evolve. In today’s environment, for example, providing access to knowledge includes having a licensed drone pilot on the MIT Libraries staff who accompanies an EAPS [Earth, Atmospheric and Planetary Sciences] class on a research trip to Death Valley. Another change is that modern research libraries must ensure that our collections are accessible to text- and data-mining applications, algorithms, and machine-learning tools. And at the MIT Libraries, we are responsive to our community’s desire to interact with our content in more participatory ways—through annotation, mashups, and other creative uses and reuses.

The report recommends an ambitious increase in the digitizing of analog collections. What are some of the priorities?

cb: We are looking to prioritize collections that are distinct to MIT. Because we have high-quality digital versions of MIT theses only from 2008 forward, the MIT Theses Collection is exactly such an example. But with over 109,000 theses published by MIT graduates from 1868 to 2007, we will have to prioritize within this collection as well. We also have a sizable collection of MIT-generated technical reports that are not available online. Both of these collections represent some of MIT’s unique contributions to scholarship, and digitizing them is the best way to increase their accessibility and impact.

What trends are you seeing in terms of how researchers on campus—as well as off-campus and non-MIT-affiliated researchers—are engaging with the MIT Libraries?

cb: While we have seen an expansion of the ways in which researchers engage with the libraries in online environments, the role the libraries play in providing space for quiet contemplative work, and for scholarly events, has remained very important to our community. So while the MIT Libraries are working hard to make our collections and services broadly available online, we also have to continually update our physical spaces. Researchers also are increasingly coming to the libraries to learn about and use new kinds of tools and techniques



READ THE FULL INTERVIEW
spectrum.mit.edu/futurelibraries

for engaging in digital scholarship. We are seeing a shift from the library as a place for consuming knowledge to a place to both consume and to create new knowledge.

LAST YEAR AT THE MIT LIBRARIES

6,000,000 e-books circulated

85,000 print books circulated

533,000 physical visitors

196 loans of maker kits to students

350 workshops and events

How do governments shape the course of innovation?

Economist Daron Acemoglu examines how inclusive political structures embrace disruptive change

In the late 16th century, William Lee, a humble parish priest in Calverton, England, invented a machine to relieve his mother and sister from the drudgery of knitting. His revolutionary “stocking frame” vastly reduced the time to knit textiles. Why, then, was it not widely adopted until two centuries later?

Daron Acemoglu, MIT’s Elizabeth and James Killian Professor of Economics, credits the winds of political change. One of the 10 most-cited economists in the world, Acemoglu says the ability to empower revolutionary innovation “goes back to the institutional fabric of society.” A prolific contributor to his field, Acemoglu has written on topics ranging from the persistent wage gap between higher-skill and lower-skill workers to the cascading effects of economic shocks within particular industrial sectors. His area of deepest exploration has been the relationship between political systems and economic growth—including the ways governments shape the course of innovation.

In his recent, influential book *Why Nations Fail: The Origins of Power, Prosperity, and Poverty* (co-authored with James Robinson), Acemoglu uses Reverend Lee as a case in point. With the help of his local representative to Parliament, Lee got an audience with Queen Elizabeth to ask for a patent. She refused. He got the same reaction from her successor, James I, and from the king of France. Acemoglu says their reasons were the same: fear that all the people knitting clothing by hand would be put out of work, would rebel, and would destabilize the political system. Beholden to the small wealthy class that controlled banking and industry, the rulers opted to uphold the status quo.

Sweeping innovation requires an “inclusive” government, says Acemoglu—one that considers everyone’s needs and abilities, not just society’s elite. “If we only enable a small fabric of society to become leaders or scientists, it’s like having our limbs tied to our bodies,” he says.

Lee died penniless. But his invention survived, was refined by others, and helped spur one of the main industries of England’s Industrial Revolution some 200 years later. Political upheaval began in England in 1688, when both houses of Parliament united against James II, forcing him to abdicate the throne. The English Bill of Rights then gave more power to Parliament, especially to the House of Commons. By the late 1700s, commoners were allowed to take out patents, borrow money, and start companies, and the Industrial Revolution began.

Of course, Queen Elizabeth was also right. The Industrial Revolution did create instability. It destroyed many existing institutions and created horrible working conditions for factory workers. It sparked the rebellion of Luddites as well as demands for better working conditions.

As Acemoglu and Robinson write in *Why Nations Fail*:

Economic growth and technological change are accompanied by what the great economist Joseph Schumpeter called creative destruction. They replace the old with the new. New sectors attract resources from old ones. New firms take business away from established ones. New technologies make existing skills and machines obsolete....



Fear of creative destruction is often at the root of the opposition to inclusive economic and political institutions.

For innovation to flourish, says Acemoglu, political leadership must deal with, rather than prevent, such destruction. Inclusive governments and economic systems help people through the destructive years and empower them to participate in the new economy. “It can only work in a democracy, where there’s participation by the public,” he adds. “Most of the important decisions are in our hands.”

Acemoglu notes that countries governed by dictatorships or elected leaders who cater primarily to an elite ruling class tend to be “extractive,” not inclusive. They may increase economic growth in the short term by extracting resources, such as oil or cheap labor, and moving most of the wealth to the elite. But that can last only as long as the resources are available—or willing.

Furthermore, he cautions that even within democracies, voters must stay vigilant to ensure their societies remain inclusive, and therefore hospitable to innovation. Political candidates may succumb to wealthy interests that fund elections, while government propaganda and biased news organizations may conceal political agendas. “There’s not any guarantee,” Acemoglu says, “that democracy is self-correcting.”

—Richard L. Brandt

Brandt is a 1991–92 MIT Knight Science Journalism Fellow.



How can we transform 21st-century education?

The new Abdul Latif Jameel World Education Lab will develop and scale up solutions for all learners

“Education and learning are fundamental to a strong society and economy... Enabling individuals to do their very best and reach their full potential, whatever their background, is a key priority for Community Jameel and the world. That is exactly why we are establishing the Abdul Latif Jameel World Education Lab with MIT.”

—Fady Mohammed Jameel, president of Community Jameel International

“Through J-WEL, we will forge new and long-lasting collaborations as we learn, share, and train together, using the assets developed at MIT as well as by leveraging the community convened by J-WEL.”

—Sanjay Sarma, MIT Vice President for Open Learning

The Abdul Latif Jameel World Education Lab (J-WEL), co-founded in May 2017 with Community Jameel, has the grand goal of sparking a renaissance in education. Here’s how:

Transforming 21st-century education is a goal MIT is already working on...

Steered by executive director M.S. Vijay Kumar, MIT’s associate dean of digital learning, J-WEL is an anchor entity within MIT’s open education and learning initiatives. These include the MIT Integrated Learning Initiative (MITili), devoted to the science of learning; pK–12 efforts to improve STEM education in primary and secondary education; and digitally focused endeavors—such as MITx, OpenCourseWare, and the Digital Learning Lab—overseen by the William A.M. Burden Professor of Physics and recently appointed dean for digital learning Krishna Rajagopal. MIT is engaged in several collaborative initiatives that seek to improve teaching by providing flexible instructional tools and professional development opportunities for educators, including the Tata-MIT Connected Learning Initiative (CLIX), which advances educational quality and access through technology in underserved Indian schools; the Woodrow Wilson Academy, an MIT collaboration out of the Teaching Systems Lab; Fly-By-Wire, led by AeroAstro professor Karen Willcox; and MIT-Educator, which focuses on curriculum design and pedagogy for higher educators. Also among the Institute’s global education bonafides are the popular, kid-friendly coding platforms Scratch and App Inventor. MIT has a long history of collaborative formation of new universities, such as Singapore University of Technology and Design and Brazil’s Instituto Tecnológico de Aeronáutica. And on the policy front, the School Effectiveness and Inequality Initiative, with its rigorous economics research, has contributed to educational reforms.

...but it’s not a goal MIT aims to reach alone.

J-WEL will create a locus of ongoing engagement for universities, foundations, corporations, and schools from the US and around the world to define and address their own specific goals for their regions’ needs. Members of J-WEL will work with MIT resources through J-WEL Weeks, signature events held twice a year on campus, as well as J-WEL Exchanges providing deeper dives into specific aspects of education. Continued interaction with MIT faculty and staff, as well as online modules, webinars, and research briefs, will build a community of global colleagues. Kumar also notes that beyond its philanthropic support, “Community Jameel is making important contributions to J-WEL by identifying target needs, and in identifying other initiatives and agencies engaging in this space with whom we might collaborate and cooperate.” Kumar emphasizes that J-WEL will address opportunities for improving education in both developing and developed countries, including in the US: “These kinds of needs are everywhere.”

Learning is a lifelong process.

The lab will concentrate on three levels of education: pK–12, higher education, and workplace learning. On the pK–12 track, Angela Belcher (James Mason Crafts Professor of Biological Engineering and Materials Science) and Eric Klopfer (director of the Scheller Teacher Education Program and the Education Arcade) serve as faculty directors; Hazel Sive, professor of biology and member of the Whitehead Institute for Biomedical Research, is J-WEL’s director of higher education; and George Westerman, of the MIT Sloan Initiative on the Digital Economy, serves as the workplace learning lead. Among the many challenges facing these sectors, Klopfer and Belcher are eager to address a “global epidemic in science education”

Improving global access to education is one of the issues J-WEL members will address together.

250M

More than 250 million children worldwide are not enrolled in school.

25M

An estimated 25 million of these children (15 million girls and 10 million boys) will never start school.

Only 50% of children in displaced populations have access to primary education.



SOURCES:
UNESCO AND
UN REFUGEE
AGENCY, 2016

PHOTO:
FRANCISCO
KIT REYES





that favors shallow memorization, while Sive is interested in engaging on problem-solving cultures and curricula relevant to students' lives and careers. Westerman shares additional concerns about rapid shifts in the employment landscapes of both emerging economies and developed nations. "As automation reshapes the corporate workforce, the challenge goes beyond training," he points out. "Companies, and people, need to understand what the worker of the future will be doing." Meanwhile, for learners at all stages of life, in many parts of the world, basic access to education is a critical issue (see graphic). Empowering underserved populations—such as displaced populations, and girls and women worldwide—is a guiding focus of J-WEL.

There's more than one avenue for transforming education.

J-WEL members may choose to concentrate on new teaching methods, digital tools, curriculum design, institution formation, capacity building (including teacher training), or even on nationwide educational reforms. On the higher education track, Sive envisions members coming to MIT to "explore, redesign, and reform" their educational systems. She offers the example of MIT-Educator, now in its test phase, in which visiting participants from Tunisia have designed new courses from the ground up, informed by case studies presented by MIT faculty. In the pK–12 arena, improving tools for assessment is one way to help shift the conversation around learning. Klopfer points to research by MITili director and neuroscientist John Gabrieli PhD '87, the Grover Hermann Professor in Health Sciences and Technology, on how to measure executive function, an important set of mental skills for young learners to develop. "Until the assessment regimen shows the value in such things," Klopfer says, "schools are going to be reluctant to put much emphasis on them."

J-lab rigor will be in full force.

J-WEL's founding is consistent with a focus by Community Jameel and its chairman Mohammed Jameel '78 on collaborating with MIT to create a better future. Abdul Latif Jameel Poverty Action Lab (J-PAL), established in 2003, seeks answers to poverty in a changing world. Abdul Latif Jameel World Water and Food Security Lab (J-WAFS), established in 2014,

addresses water and food scarcity issues. Both emphasize rigorous research and measurable, systemic change over time, and J-WEL will take a similar approach to education. The randomized evaluations in which J-PAL specializes are of particular interest to Kumar: "The initiatives we launch can't just be based on an idea; they have to be founded on research and early, meaningful, quantitative and qualitative evidence."

"Quality at scale" must be a consistent theme.

"Through connecting with MIT, J-WEL members will articulate their goals of engagement. Figuring out what resources we can bring to address those goals in a scalable way will be very important for J-WEL," Kumar says. Belcher suggests: "Think of J-WEL as a hub whose ideas and curriculum and technologies can be distributed to all parts of the world." Yet, as Klopfer observes, "Some of the same issues may ultimately affect kids in Detroit and in Mumbai, but they manifest themselves in different ways." For J-WEL to maximize its impact, Klopfer suggests making connections between underlying causes "to help disparate geographic entities to simultaneously think about solutions, so we are not solving one-off problems, but rather dealing with a network of related issues."

Education at MIT will be clarified and strengthened as a result.

"The mind-stretching way we empower our students with problem-solving skills at MIT is not how I was educated [in South Africa]," says Sive, "and not how many students in universities in the world are educated." J-WEL will offer a chance for MIT faculty not only to articulate and celebrate their most successful educational practices, but to apply for funding to scale those up for global application in collaboration with colleagues around the world. MIT students will also have the opportunity to become J-WEL ambassadors, highlighting their own learning experiences. J-WEL is a way for MIT to share what it does best, and to analyze what it can do even better in service of global education.

—Nicole Estvanik Taylor

Above: MIT students work on the production of online courses.

PHOTO: MITX

How can we defeat the growing threat of antibiotic resistance?

For MIT researchers working to hold the line against infection, step one is to know your enemy

Unexpected outbreaks of viruses like Zika and Ebola may seize headlines, but there is a less exotic and even more formidable threat on the horizon. “A post-antibiotic era,” says the World Health Organization, “in which common infections and minor injuries can kill—far from being an apocalyptic fantasy—is instead a very real possibility for the 21st century.”

Microbial pathogens, including the kinds of bacteria and fungi we come in contact with every day, are designed by evolution to play cat and mouse with a host’s immune system. Driven by the excessive and often unnecessary use of antibiotics—whether in animal feedstocks or to treat human infection—these nimble organisms are mutating at an accelerating pace, some capable of foiling even last-resort medications.

“We are really excited about the possibility of immunizing against bacterial infections,” says Nolan.

“It’s very scary,” says Elizabeth Nolan PhD ’06, an associate professor in the Department of Chemistry, whose research on infectious disease is aimed at the problem of antibiotic resistance. “There are more and more drug-resistant strains of bacteria being found, strains that can travel around the world wherever humans go.”

In the US alone, antibiotic-resistant superbugs currently cause 2 million cases of illness and 23,000 deaths a year, according to the Centers for Disease Control. A recent British government assessment projects an astonishing 10 million annual deaths globally from superbugs by the year 2050.

Given these stakes, says Nolan, “We really need people to think outside the box.” And that is precisely what she and a contingent of fellow MIT scientists have set out to do. Deploying the latest technologies and working within and across diverse fields in science and engineering, these researchers are developing new tactics in the battle against superbugs.

Starve them out

Nolan’s chosen strategy uses metals essential to an organism’s survival. “Humans have three to five grams of iron inside our bodies, which is critically important for our health,” she says. “Many kinds of bacteria also need this iron, but it’s hard for them to find it.” During infection, microbes and hosts compete for iron and other metals, and this contest has provided Nolan with ideas for new therapies.

In a series of studies, she has investigated the metal-acquisition systems in such pathogenic bacteria as *Escherichia coli* and *Salmonella*. Inside the infected host, these bacteria fabricate molecules called siderophores, which are set loose in the environment outside of cells. “Siderophores scavenge iron from the host, and deliver it to the bacterial cell,” says Nolan. The human immune system fights back through a metal-withholding response, which includes

unleashing proteins that can capture certain iron-bearing siderophores.

In short, as Nolan puts it, “There’s a total battle for nutrient metals going on. The question is whether the host outcompetes the microbe, or vice

Elizabeth Nolan is investigating how certain bacteria, including *E. coli* (above) and *Salmonella* (opposite), clash with the human immune system.

IMAGES: GETTY (ABOVE), CENTERS FOR DISEASE CONTROL AND PREVENTION (OPPOSITE)



PORTRAITS BY:
M. SCOTT BRAUER (COLLINS),
BRYCE VICKMARK (NOLAN, RIBBECK),
KATHLEEN DOOHER/WHITEHEAD
INSTITUTE (FINK)

\$20B

The total economic cost of antibiotic resistance to the US economy has been estimated as high as \$20 billion in excess direct health care costs.

SOURCE: CENTERS FOR DISEASE CONTROL AND PREVENTION, 2013

versa.” To give an edge to the host, Nolan has been exploring several strategies. One involves tethering antibacterial cargo to siderophores and unleashing them against specific pathogens. Another, in partnership with researchers at the University of California, Irvine, is designed to boost the immune system’s metal-withholding response by generating siderophore-capturing antibodies in the host. In early laboratory tests of this method, Nolan and her partners successfully inhibited the growth of *Salmonella*. “We are really excited about the possibility of immunizing against bacterial infections,” she says.

Nolan sees great potential in fundamental research aimed at revealing the structural and functional properties

of the human immune system’s metal responses. In one recent study, for instance, she discovered that calprotectin, an abundant, metal-sequestering human protein that is present at sites of infection, has uniquely versatile properties that allow it to seize whatever metal an infectious microbe requires for its survival. This is the kind of discovery that might someday generate a new antibiotic therapy. It is another reason why Nolan is confident, she says, that “deciphering the pathways used by organisms and hosts for sequestering nutrient metals will lead to new insights for preventing and treating disease.”

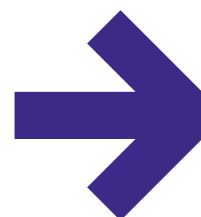
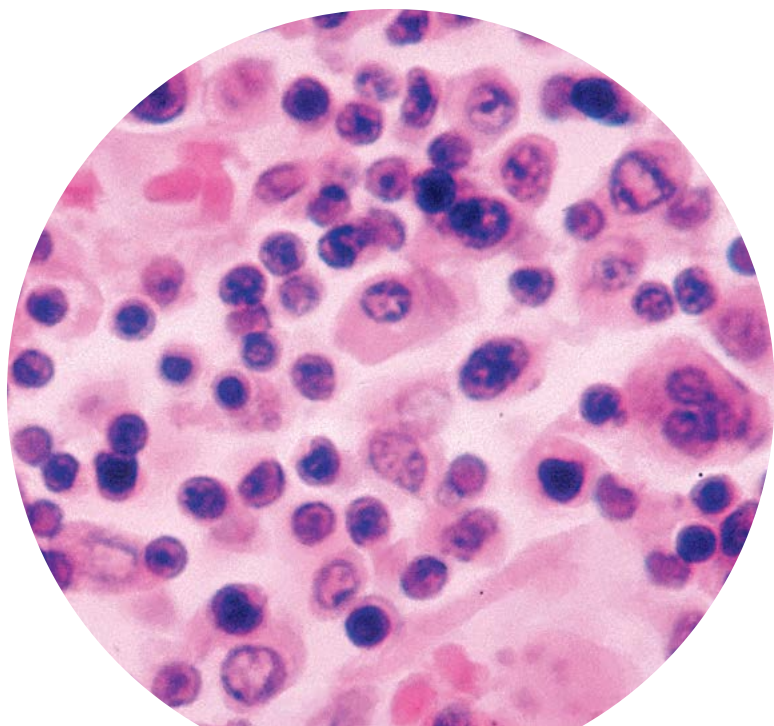
Chart their defenses

With the help of the latest technologies, it is now possible to map microbial behavior in the finest detail.

“We couldn’t easily explore drug resistance before, but CRISPR technology makes it much easier for us to manipulate the genome,” says Gerald Fink, another researcher working in this area, who is the Margaret and Herman Sokol Professor in Biomedical Research at the Whitehead Institute, and American Cancer Society Professor of Genetics at MIT. Fink is using the popular DNA-editing technology CRISPR-Cas9 to unravel antifungal resistance in the human pathogen *Candida albicans*.

Why study fungi? Unlike bacteria, whose toxins damage host cells, they often do harm simply by growing in the wrong places—so while *C. albicans* “normally lives in our gut happily and harmlessly,” says Fink, it can prove deadly if it moves elsewhere (by way of catheter or prosthesis, for example). Fungi, like bacteria, can also develop resistance to antibiotics. Masters of disguise, they evolve mechanisms to evade detection by altering the composition of their cell membranes. Fink notes that there is huge natural variation in resistance among fungi. “Bacteria and fungi have been here for hundreds of millions of years, and there’s no game they haven’t played,” he adds. “We’re just trying to keep one step ahead.”

Fink previously created a working model of harmless baker’s yeast to serve, in his words, as “a paradigm for





Up to 50% of all the antibiotics prescribed in the US are not needed or are not optimally effective as prescribed.

SOURCE: CENTERS FOR DISEASE CONTROL AND PREVENTION, 2013

all higher cells.” Now he is working to create a comparable paradigm with *C. albicans*, a fungal pathogen whose invasive behavior can range from superficial skin infections to life-threatening systemic infections. Using CRISPR, Fink’s lab is systematically snipping out genes to determine which ones help *C. albicans* live outside of the gut and also survive immune system defenses. Fink’s lab has already found a number of genes promoting *C. albicans*’s drug resistance, and hopes that as the entire genome is decoded, “we can know what the enemy looks like and think about designing new antibiotics.”

CRISPR-based tools have also begun to revolutionize the detection of infection. A new method that uses a modified genome editing enzyme, Cas13a, comes from James Collins, MIT’s Termeer Professor of Medical Engineering and Science and a member of the Broad Institute at MIT and Harvard. Collins has collaborated with Broad colleague Feng Zhang, James and Patricia Poitras Professor in Neuroscience, and others to develop a highly sensitive diagnostic platform they named SHERLOCK (for “specific high sensitivity enzymatic reporter unlocking”). Using chemicals and biomolecules freeze-dried on a piece of paper, SHERLOCK not only identifies a bacterial pathogen quickly from just a few strands of DNA, but also determines whether that microbe is resistant to certain antibiotics and susceptible to others. At a cost of 61 cents per test, SHERLOCK—which can also detect cancer mutations and viruses such as Zika—is cheap and durable enough for any clinical setting, including those in developing countries. “It’s a platform with transformative power,” Collins says.

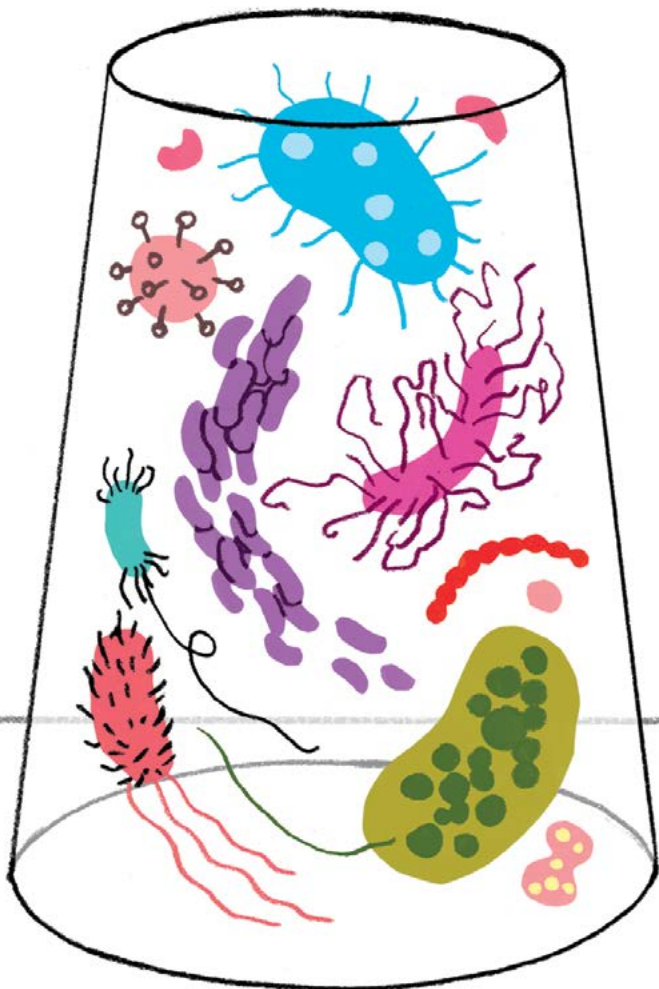
Send in your best agents

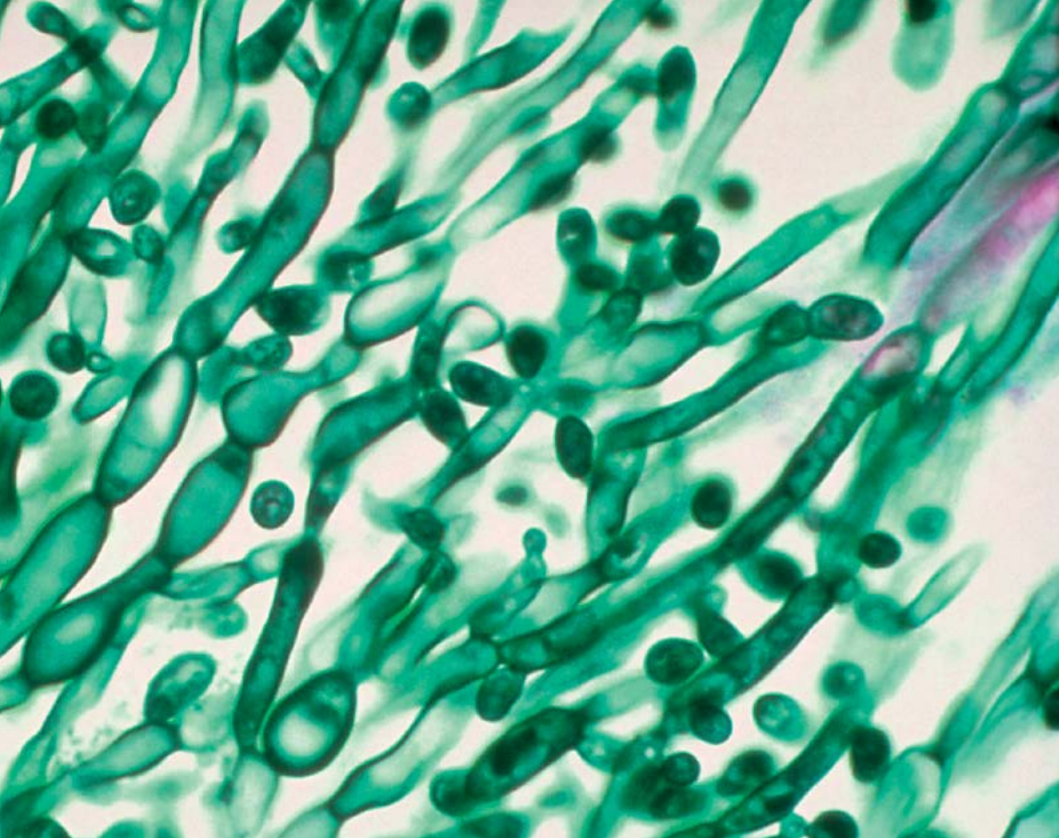
In addition to his work in diagnostics, Collins is taking direct aim at bacterial defenses, fabricating what he calls “next-generation antimicrobial agents” that could overcome antibiotic resistance.

A founder of the new field of synthetic biology, Collins has spent much of the past decade developing intricate biomolecular models of bacterial cells that shed light on their metabolic state—how they produce and consume energy, and what conditions promote or stymie growth. He has taken a special interest in “persisters,” strains of bacteria that deviously go dormant in the presence of antibiotics, leading to the kind of chronic infections plaguing tuberculosis and cystic fibrosis patients.

Recently, Collins and colleague Graham Walker, American Cancer Society Professor of Biology at MIT, have worked out how bacterial metabolism determines whether an antibiotic “will kill the bug, stop it from growing, or make it more resistant,” says Collins. What’s more, their labs have engineered a way to manipulate bacterial metabolites, substances produced by bacteria to regulate their own development, to make these pathogens vulnerable to antibiotics.

Metabolic tuning could resensitize previously antibiotic-resistant strains. “This has largely been overlooked by the drug discovery community and the clinical community, but we think it’s a gold mine that can be harnessed to boost our existing arsenal of antibiotics,” Collins says.





“Bacteria and fungi have been here for hundreds of millions of years, and there’s no game they haven’t played,” says Fink. “We’re just trying to keep one step ahead.”

Collins’s group is also designing new weapons to attack pathogens. “We’re looking to engineer and enhance bacteriophages, naturally occurring viruses that go after bacteria, to make them more effective.” In one venture, they have endowed bacteriophages with enzymes that break up biofilms, the gooey matrix produced by bacterial pathogens that often kicks off infections in artificial joints, implants, and pacemakers.

These new tools will be arriving not a moment too soon, he says. “Nature is remarkably clever, and the next pandemic is coming, and it could be a bacterial pathogen,” he says. “I hope we will be in a good position to address it.”

Try diplomacy

While she shares this hope, Katharina Ribbeck, associate professor of biological engineering, takes a radically different view of the problem: “We need to step out of the arms race and instead form an alliance with problematic microbes,” says Ribbeck. “But how?”

In a word: mucus. Ribbeck sees myriad opportunities for coping with problematic pathogens by exploiting this primitive product of the immune system. Trillions of microbes,

many benign and performing vital functions, live inside mucus, which lines the intestinal tract, lungs, mouth, nose, and other orifices in humans, coating

some 2,000 square feet of internal surface area.

“Somehow our mucus keeps microbes in check, whether they are beneficial or serious pathogens,” says Ribbeck. “Mucus doesn’t kill them, like antibiotics, but it tames them.”

In recent studies of two types of *Streptococcus* bacteria found in saliva, one associated with cavities and the other with healthy oral conditions, Ribbeck gained insight into how the infrastructure of mucus keeps the two types in balance. “Preventing certain microbes from teaming up and surrounding themselves with a protective biofilm is at the core of mucus function,” she explains. “In this state, they can’t dominate as easily, and are more vulnerable to the immune system.”

Now Ribbeck seeks to leverage “biochemical motifs” of mucus to achieve a new repertoire of responses to microbial pathogens. She’s discovered mucus components that can be used to suppress and dissolve the dangerous biofilms built by pathogenic bacteria, and with natural and engineered polymers, believes she has found a way of dislodging tenacious pathogens, thereby preventing infections and empowering the immune system and antibiotics to perform better.

“We could apply our synthetic dressing on real wounds and on mucosal surface infections such as those in the digestive tract, mouth, or lungs, allowing both antibiotics and the immune system better access to subdue harmful microbes,” she says. “This could solve some of the most vexing problems related to resistance.”

Ribbeck’s strategy depends on strengthening the body’s beneficial microbes, striking a balance with pathogenic strains and encouraging a diverse microbiome. “Microbes don’t necessarily want to harm us; they just want a safe place to eat and divide,” she says. “By harnessing mucus to help us with microbes, we can domesticate them and find better ways to protect ourselves.” —Leda Zimmerman

23,000

Each year in the US, at least 2 million people become infected with bacteria that are resistant to antibiotics and at least 23,000 people die each year as a direct result.

SOURCE: CENTERS FOR DISEASE CONTROL AND PREVENTION, 2013

Gerald Fink is using CRISPR technology to understand antifungal resistance in *Candida albicans* (above).

IMAGE: CENTERS FOR DISEASE CONTROL AND PREVENTION

How does the brain connect smells with behaviors?

For Gloria Choi, olfactory cues are a gateway to some of the brain's greatest mysteries



A whiff of feline will send mice running for cover. That makes sense, given the propensity cats have for eating mice, but, in fact, it's more than sensible: the behavior is built into the mouse genome. “Even a laboratory mouse that has never been exposed to cats will respond to their scent in fear,” says Gloria Choi, the Samuel A. Goldblith Career Development Professor of Brain and Cognitive Sciences, and an investigator at the McGovern Institute for Brain Research at MIT.

Most smells, however, have no intrinsic meaning to an animal. The connection has to be learned. This learning process intrigues Choi and has inspired her to study how mice link particular smells to specific behaviors. In her most recent work, she discovered that oxytocin, known as the “love hormone” because of its role in forming mother-child bonds, also plays a role in binding smells with social behaviors, such as mating or frightening off an intruder.

Early on in her career, Choi decided to study the senses because they act as gateways into the brain and make an ideal starting point for asking questions about how the brain works. Happenstance led her to join an olfaction lab, working with Richard Axel at Columbia University. Using mice, Axel had discovered the receptors in neurons that detect odors. “Smell is the primary sense mice use to interact with the world,” says Choi.

Choi stuck with olfaction because smell has deep meaning for humans. A familiar scent can be transcendent, taking one back in time or to faraway places. “It’s very personal,” says Choi, “and very experiential.”

To unlock the secrets of smell’s power to recall memories and guide action, Choi used optogenetics, a technique that uses laser light to stimulate and activate neurons selectively. Such artificial stimulation allowed her to simulate the sense of smell precisely so that she could study the neural circuits that respond to odor detection. In early experiments she did with Axel, this technique allowed her to zero in on a brain region called the piriform cortex as the seat of learning about a smell.

In more recent work, she and her team trained mice to associate a particular smell with a reproductively receptive female to illustrate a positive social interaction. To illustrate an aversive one, they associated a different smell with an aggressive male intruder. The team used both genetic and pharmacological techniques to manipulate the neurons involved in learning these associations to tease apart the neural circuitry.

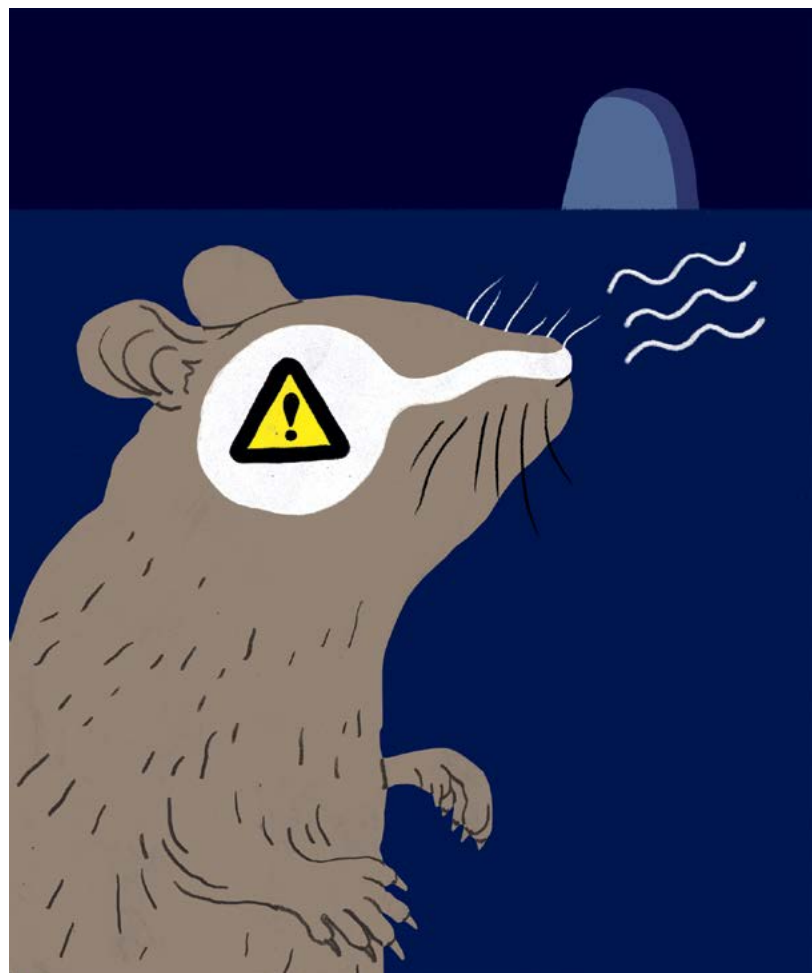
Choi had hypothesized that special signaling molecules would drive learned associations between smell and behavior. When looking at the possible molecular candidates, she decided to zoom in on oxytocin based on previous research suggesting its strong role in directing social behavior.


The research revealed that oxytocin is required for learning social associations, but not for other types of behaviors, such as craving food or feeling stressed. Choi speculates that an array of molecules, oxytocin included, may form a molecular code that governs different types of behavioral responses to smell.

To search for that molecular code, Choi is using single-cell RNA sequencing, a technique that reveals all of the molecules at work inside a cell. This technique will allow her to form a list of candidate molecules and the receptors that detect them to study in relation to learning. “If this mechanism exists, perhaps it exists not only for learning with smell, but also for learning with any other sense,” says Choi.

This work on neural signaling is dovetailing with Choi’s other work on immune signaling in the brain. Immune molecules may also influence behaviors linked to smell. For instance, immune signals present during illness can damp the association between smell and the desire to eat. “We want to understand how the immune system modulates the brain,” says Choi. “This is one of the most exciting emerging fields in neuroscience.”

—Elizabeth Dougherty





TESS is set to monitor more than 500,000 stars, looking for periodic dips in brightness that could be caused by the transit of an orbiting planet.

What planets beyond our solar system may harbor life?

The TESS mission will scan our cosmic neighborhood to identify 50 top candidates

In March 2018, if all goes as planned, a SpaceX Falcon 9 rocket will send an instrument designed and fabricated at MIT, the Transiting Exoplanet Survey Satellite (TESS), into high Earth orbit. From an altitude of about 400,000 kilometers, TESS will conduct an all-sky survey that brings a new perspective to the search for planets beyond our solar system.

On the fourth floor of MIT's Building 37, a dozen computers working in parallel will process data relayed from the orbital satellite, and about 30 MIT scientists and engineers will pore over it for clues about our astronomical neighborhood. "MIT has the overall technical and science responsibility for the mission," says TESS principal investigator George Ricker '66, PhD '71, a senior research scientist at the MIT Kavli Institute for Astrophysics and Space Research. Fellow Kavli scientist Roland Vanderspek PhD '86 serves as deputy PI. Altogether about 300 researchers from more than a dozen universities and other institutes are taking part in this NASA Explorer mission. TESS's unique capabilities should enable it to pick out small, relatively nearby planets (within a few hundred light-years of Earth) that offer at least some of the conditions deemed necessary for life. The ambitious endeavor could give humanity its best shot yet at understanding just how unusual our planet is, or isn't, in the grand scheme of things.

To fulfill its scientific objectives, TESS will rely on the "transit method," looking for periodic dips in a star's brightness that could be caused by an orbiting planet passing in front of it. "If you know the star's size, you can figure out the planet's size from the percentage of light that's being blocked," Ricker explains.

That task falls to the satellite's four CCD cameras—precise photometers fabricated at MIT Lincoln Lab and on campus under the watchful eye of instrument manager Greg Berthiaume '86. Vanderspek, meanwhile, is responsible for achieving the requisite stability and sensitivity of those

cameras, charged with surveying 90% of the southern sky in TESS's first year of operation and a similar portion of the northern sky a year later. Ricker estimates this will turn up approximately 3,000 "transit signals," or

instances of temporary dimming, of which 1,700 might be confirmed as planets by ground observations in the third year.

Leading the TESS science team are Harvard-Smithsonian astronomer David Latham '61 and Sara Seager, MIT's Class of 1941 Professor of Planetary Science and Professor of Physics, as well as an AeroAstro faculty member. Joined by new MIT physics assistant professor Ian Crossfield, they will select 100 candidates for follow-up observations, whittling that down to a list of at least 50 confirmed small planets, roughly Earth-sized, a subset orbiting within the host star's "habitable zone" at a distance where surface water could exist in liquid form. The Hubble Space Telescope and successors like the James Webb Space Telescope would then train their sights on the exoplanetary "Top 50," as would large ground-based telescopes. "We'll definitely want to look at their atmospheres to check for the presence of gases—such as oxygen, water vapor, and methane—that may be associated with life," says Seager.

TESS will complement NASA's Kepler mission, which has already discovered more than 2,000 confirmed exoplanets within a small patch of sky. With its broader sky coverage, TESS can find planets about 10 times closer, circling much brighter stars, making it easier to determine their mass, density, composition, and other properties.

TESS joins other exoplanetary research underway at MIT. Julien de Wit PhD '14, a postdoc in the Department of Earth, Atmospheric and Planetary Sciences who recently accepted an offer to join the MIT faculty, is part of an international team that spotted seven Earth-sized planets orbiting the star TRAPPIST-1. Seager, meanwhile, is the principal investigator of ASTERIA (Arcsecond Space Telescope Enabling Research in Astrophysics), a low-cost mission that's set to launch a cereal box-sized satellite this year in the hopes of finding the best Earth analog yet. Says Seager, "We're following any leads we can to learn more about exoplanets."

At the same time, perhaps, sentient creatures on one of those worlds might be going through a similar exercise, trying to learn about Earth and its curious inhabitants. —Steve Nadis

Nadis is a 1997–98 MIT Knight Science Journalism Fellow.

An artist's rendering of TESS in orbit.

IMAGE: RANDY PERSINGER



Artifacts of the future

Architect
William O'Brien Jr.
opens archetypal
forms to new
interpretations



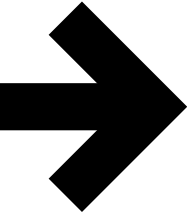
At first glance, WOJR Organization for Architecture looks like any other design office in Cambridge—a single ground-floor room sandwiched between two lopsided storefronts set on a minor city thoroughfare. Inside, three associates toil at workstations at a long table. Renderings, mockups, and a library adorn the walls around them.

But a closer look reveals a practice that is like few others, a teeming space where past, present, and future eddy in silence. At one workstation, a young associate charts the locations of Narragansett Indian burial sites on Rhode Island's Block Island, to avoid building atop the relics. A polished stainless-steel arch—a scale model for a competition—hovers near the edge of the communal table, portal to an unseen but imminent universe.

On the side wall, perched on a bookshelf, an African mask scowls like a stern sentinel, flanked by photographs of the anthropomorphic mask sculptures WOJR prepared for a Spring 2017 exhibition in Switzerland. The masks are abstractions from forms and volumes in WOJR's Mask House, a contemplative home and retreat created for a client in upstate New York.

Like the African masks that inspired it, the Mask House's slatted front façade serves as a physical and spiritual threshold, marking the border to a solemn dimension, and promising refuge to those who enter it.

IMAGE: WOJR



“We believe that the making of architecture is the making of artifacts,” says William O’Brien Jr., eponymous founder and principal of WOJR, and faculty member since 2009 in the MIT Department of Architecture, where, among other duties, he coordinates the first semester studio in the Master

of Architecture program. “They are both objects that are imbued with meaning that the viewer then unpacks. We want to bridge the gap between inception and perception, to imagine how an object or form will be interpreted at the same moment we’re making it.”

With light-colored paneling, vast picture windows, and simple, austere geometries, the Mask House’s central room embodies the home’s primary function as a space for contemplation. Spaces for food preparation, eating, and sleeping—the nook for a bed is pictured here—are secondary.

IMAGE: WOJR

More than an act of will, architecture for O’Brien is an act of cultural expression—an inquiry into the archetypal forms he finds in prehistoric Iceland or baroque Rome, as well as into the meanings present and future viewers will glean from them. J. Meejin Yoon, head of the Department of Architecture at MIT, characterizes O’Brien’s work in terms of “elucidation, refinement, and crystallization.” In her view, “He bridges formal and material concerns of the discipline with representations that test, balance, and literally draw original ways forward with great mastery.”

While his work is firmly rooted in history, O’Brien brings to it a vital digital fluency. He entered the profession at a pivotal time, just as it had begun to fully digest the digital design technologies that had so radically transformed—some might even say hijacked—it. “We’re in a post-digital moment in architecture,” he explains. “For designers of my generation, and even more so in the next generation, we are increasingly facile with

the range of digital methodologies. We’re no longer entertained, in the same way as in the late ’90s and early 2000s, by the formal novelties that can be produced by complex digital processes. Instead, we can go back to thinking conceptually, and use these technologies to support that thinking.”

Studies in perception

Born and raised in Stow, Massachusetts, O’Brien was an undergraduate at Hobart College hovering between career options in music and design before he opted to pursue a master’s in architecture at the Graduate School of Design at Harvard University. In 2010, he was a finalist for the MoMA PS1 Young Architects Program and a winner of the Design Biennial Boston Award. In 2012, he received a Rome Prize Fellowship in architecture at the American Academy in Rome. The following year, *Wallpaper** named him one of the world’s top 20 emerging architects, and *Architectural Record* gave him its Design Vanguard Award.

O’Brien has earned his accolades by seeking out unusual situations





Based on visual elements from the Mask House, the seven masks WOJR displayed this past spring at BALTSprojects in Zurich chart the frontier between architecture and artifact, and between the seen and unseen world. For example, Brush Mask (far left)—a series of slender metal strands concealing a block of wood—recreates the atmosphere of the house's façade.

PHOTO: WOJR

“We’re in what I like to call a post-digital moment in architecture. We can go back to thinking conceptually, and use these technologies to support that thinking.”

and challenges that test and expand his vision. In a house design for a site in Durango, Colorado, he took a very familiar postwar form—the A-frame house—and repeated it in an idiosyncratic, asymmetrical chain. When two brothers asked for twin houses for their land in upstate New York, he drew on a mathematical principle called minimal dissections to create a square house and a hexagonal house made up of the same parts. His modular approach to questions of form—examining, adapting, and assembling old shapes in new ways—could also create new possibilities and processes for builders.

Some of his designs become buildings. Some of them don’t. One of his most ambitious

designs, however—the suggestive and secluded Mask House—is slated for construction by 2018. Set in Ithaca, New York, the 587-square-foot domicile was commissioned by a filmmaker whose younger brother

While its front is designed for privacy, the Mask House features broad windows at the rear that provide unobstructed views of the surrounding countryside.

IMAGE: WOJR

drowned in a nearby lake. It is an almost otherworldly response to the client’s desire for contemplation and sanctuary. One approaches the stilt-supported home on a dark metal gangway. Embedded above a hillside, its façade is concealed behind a broad, slatted wall—a barrier that marks the passage between inside and outside, between man and nature, even between life and the hereafter. The interior is dominated by a large central room with light-colored wooden paneling, broad wall-sized windows, and a conical metal fireplace and chimney—an aesthetic that speaks in potent silences.

A small sleeping nook is sculpted out of the far wall.

In 2015, O’Brien was invited to display his work by BALTSprojects, a gallery in Zurich, Switzerland, that specializes in art and architectural exhibitions. His first impulse was to display drawings and renderings from the Mask House. Instead, he and his colleagues decided to build masks—three-dimensional sculptures in metal, wood, and marble, all inspired by the forms and volumes of the Mask House. The sculptures are studies in perception—a distillation of the experience one might feel approaching, entering, and living in the Mask House. Yet they are also discrete objects that exist and communicate on their own. “I wanted to explore the domain between architecture and art,” says O’Brien. “To create objects that say something about architecture but that aren’t architecture in themselves, conceptual pieces that can get us thinking about architecture in a new way.” The show, which closed this past May, is scheduled for several European venues next year.

While he never pursued music as a profession, music continues to inform his research and practice. Both, for O’Brien, are inquiries into form. “I was fascinated by music theory,” he says. “I loved learning about the different musical

formats, from classical to contemporary, and about how musicians deviated from those formats—while still acknowledging them—to create something new.”

It would not be accurate to call O’Brien a traditionalist or an iconoclast. Architecture for him is an infinite discussion on the continuum between past and future, maker and viewer, idea and matter. And in this discussion, he thinks, the architect can best serve as moderator. “I don’t believe that architects *create* meaning,” he says. “I think we need to envision how our creations will be received. And, whenever possible, to reduce the possibility that these creations will be wildly misinterpreted, whether today or tomorrow. We’re so deeply steeped in history. We don’t have to reinvent the wheel. Our task is to take something that we think we know, and then by subtle alterations and processes of defamiliarization, make something new from the known.”

—Ken Shulman



Prototyping Real-World Problems

An excerpt from Luis Perez-Breva's "doer's manifesto" on innovating

Innovation and entrepreneurship are not one and the same, although aspiring innovators often think of them that way. They are told to get an idea and a team and to build a show-and-tell for potential investors. Luis Perez-Breva PhD '07 describes another approach in *Innovating: A Doer's Manifesto for Starting from a Hunch, Prototyping Problems, Scaling Up, and Learning to Be Productively Wrong* (The MIT Press, 2017).

A serial entrepreneur, Perez-Breva has honed this approach during his decade at MIT as originator and lead instructor of the Innovation Teams Program jointly operated by the School of Engineering and MIT Sloan School of Management. In his book, he shows that to start innovating does not require an earth-shattering idea. All it takes is a hunch, which you then give the structure of a problem. As Perez-Breva writes, "Innovations accrue their novelty as you innovate. They are more easily deemed innovations in hindsight than at their beginnings. In hindsight they can be judged

by how they ultimately empower others—a community—to achieve new things."

In this excerpt from Chapter 2, Perez-Breva discusses how to get started on solving a big problem that initially may feel out of reach.

Luis Perez-Breva discusses his new book, *Innovating*, in Madrid.

PHOTO: FUNDACIÓN RAFAEL DEL PINO

Making the problem tangible

The problem you are proposing to solve very likely lives at a scale far beyond your immediate resources. So, you need to find an easier or more accessible version of your innovation problem to solve. Put another way, you need to scale the problem you want to solve down to a scale at which it corresponds to the resources you have to understand the problem.

For a mathematical problem, a figure would help you turn something otherwise abstract into something tangible that helps your intellect and senses work together. Blueprints or models serve the same purpose for practical and engineering problems. For entrepreneurship and innovation, you might use a slide-deck. But that can help you only so much; a lot remains abstract. If you've brought your problem to a resource-friendly scale, though, there are other things you can do to realize the same value that figures offer in solving mathematical problems. You can physically prototype any aspect of your problem, or, as [Hungarian mathematician George] Pólya puts it, you can build a prototype that "assumes the condition of the problem satisfied in all of its parts." That, of course, might include a gizmo, but it can also include an organization, distribution, marketing, manufacturing, and so on. At that scale, you don't have to limit yourself to prototyping form alone. You should strive to prototype function.

So, you can generalize problem solving to innovating if you work on bringing the problem first to a resource-friendly scale, and work at that scale to make the problem tangible, prototyping all aspects of your eventual

solution—and, in so doing, implicitly outlining all areas in which innovations may be required. After that, your task will be to understand your problem at one scale and work toward scaling up successive demonstrations of the problem.

The final problem you'll solve will likely differ substantially from the problem you thought you were solving at first. That is because your first expression of the problem was, with high probability, ill informed if not outright wrong. That's all right; the purpose of your first hunch was to get you started. You'll discover how wrong as your innovation prototype evolves toward scale.

Scale

The objective of bringing a problem to a different scale is to enable quick and tangible experimentation on the aspects of the problem most critical to move forward. It is also helpful to begin separating the nature of the problem from the magnitude of the impact to which one aspires.

There are many ways to work on the scale of a problem. A common one is to change the size of the community—for instance, “Let's start with five people and then ramp up to twenty.” But there are other, more effective ways to bring a problem to a scale that is more amenable for quick experimentation—for instance, introducing assumptions to extract the most knowledge and impact from the resources at hand.

Let me give you two examples of the interplay between resources and scale.

In class, a group was interested in devising a system to detect infectious diseases quickly. To realize their initial vision, they would have needed a lab with biosafety level 2 or 3. The stage their hunch was at, though, did not justify the investment in resources and skills required to access and use such a facility.

They could have stopped at that. Instead, they introduced an assumption of scale: a strawberry is a bacterium. The effect of this particular assumption of scale was (a) because of how easy it is to extract DNA from a strawberry, they could forgo dealing with the complexity of establishing what constitutes a good enough sample of bacterial DNA for their experiments; (b) they didn't need the extra resources of a biosafety lab right away; and (c) getting out of the straitjacket of thinking in terms of the biosafety lab freed them to think about a simple device with which to experiment on the problem. After that, it took only a week to bring together the parts and knowledge they needed and come up with a plan for how to move forward. They were able to articulate their plan by building on conversations with industry experts and a demonstration of a small working device.

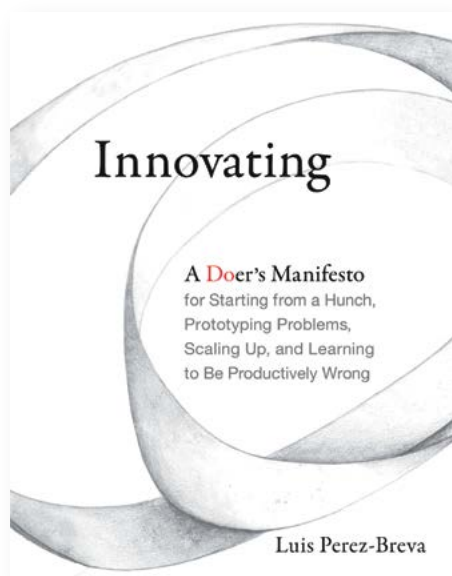
More generally, working on the scale of the problem also introduced a very convenient change to the sequence of proofs of concept. Once their device was ready, the knowledge they would need next would transcend their assumption of scale. At that point, they would need access to the specialized lab only to test for that specific knowledge, and they could either contract out the testing or rent the lab whenever they were ready to move forward.

In a different setting, during a lecture in which I challenged students to think about how to prototype their ideas (form and function) all in one day, a team complained that their idea

could not be prototyped. They were thinking about a pill that would emit a signal when dissolved in the stomach and help measure patient compliance. Their main concerns were miniaturizing the electronics to fit in a pill, any regulatory unknowns that might exist, and what a safe signal strength would be.

On that occasion, the answer to the question of scale was to assume a much bigger human. In other words, miniaturizing electronics and inserting them in a pill were considerations for down the road—considerations that might indeed require significant innovations. At that day's stage of their thinking, though, the team needed to *characterize* the problem. Coating the necessary electronics in cereal, choosing a recipient of the right size to simulate a stomach proportional to the size of the pill, coating the simulated stomach with material that had a density similar to that of a human body, and then developing a number of test scenarios would at least give their questions the next level of specificity they would need to outline all the manufacturing steps, regulatory measurements, and reasoning about the mechanisms by which they could actually measure compliance.

“The final problem you'll solve will likely differ substantially from the problem you thought you were solving at first.”





MIT Better World: The Road Traveled, the Road Ahead

#MITBetterWorld

Following the May 2016 launch of the MIT Campaign for a Better World, alumni and friends gathered to celebrate MIT's community and mission in New York, San Francisco, Hong Kong, London, Tel Aviv, Los Angeles, Mexico City, Washington, DC—and most recently in Boston this September. Now it's time to mark the calendar for the next wave of events, and to look back at the excitement and vision shared by the global MIT community online and face to face over the past year.

@toddsiller

I just made my gift to MIT! Support MIT's Campaign for a Better World: giving.mit.edu/share #MITBetterWorld

JUN 10, 2017



MIT Alumni Association

Tim's getting ready for tonight's Better World (Washington, DC) event by exploring our nation's capital. He stopped by spots connected to MIT like the Lincoln Memorial, designed by one-time MIT student Daniel Chester French and the National Gallery of Art East Building designed by I.M. Pei '40. #MITBetterWorld

APRIL 13, 2017



Newseum, Washington, DC
APRIL 13, 2017

@learntogeth3r

Feeling inspired after attending #MITBetterWorld. Shout out to all the bright peeps out there doing great things and making a difference!

APRIL 13, 2017

@jengustetic

Excited for the program at #MITBetterWorld tonight. Amazing to see so many @MIT alum out in full force to envision a better world.

APRIL 13, 2017

camilomora767

Gran noche con la comunidad #MIT en la #ciudaddemexico #mitbetterworld y lo mejor, el privilegio de conocer al MIT President L. Rafael Reif

MARCH 24, 2017



Four Seasons Hotel Mexico City
MARCH 23, 2017



Universal Studios Hollywood
FEBRUARY 7, 2017

teresapalooza

So excited to see @MIT President L. Rafael Reif speak tonight. Nerd time! #mitpride #MITBetterWorld #universalstudios #universalstudioshollywood

FEBRUARY 7, 2017



"One can be both a scientist and an artist."
—Stephen Allsop PhD '16, MIT Better World (Los Angeles)

@LuzRivas

MIT was part of the discovery of gravitational waves and a woman responsible is here in LA! #womeninSTEM #MITBetterWorld

FEBRUARY 7, 2017

@philbangayan

Listening to CA Sec of State and MIT alum Alex Padilla at #mitbetterworld

FEBRUARY 7, 2017



MIT President L. Rafael Reif with young alumni, Sheraton Tel Aviv Hotel
JANUARY 22, 2017

@MIT_alumni

Amnon Shashua PhD '93 kicks off #MITBetterWorld Tel Aviv. "MIT is where I caught the virus of entrepreneurship; a really special place"

JANUARY 22, 2017

1.19.18

Houston

2.20.18

Seattle

TBD

Miami

(7)

LEARN MORE AND RSVP
betterworld.mit.edu/
events-spectrum

QUESTIONS?
alumnierevents@mit.edu
617.253.8243

A special invitation from MIT Sloan

In addition to partnering to produce the MIT Better World events in Miami and Seattle, MIT Sloan invites its alumni to join Dean David Schmittlein for additional events that will highlight the school's impact in the world.

SINGAPORE 10.17.17

LONDON 12.7.17

(7)

LEARN MORE
mitsloan.mit.edu/campaign/events

@DoriMaradiaga

Thanks @MIT for #MITBetterWorld (London) so inspiring! MIT stands for innovation. There is no challenge big enough! #letsgetstarted

JANUARY 14, 2017

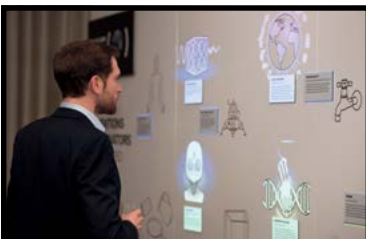
@PaloCabello

Wholehearted thanks to my friends of #MITBetterWorld. An initiative worth attention and commitment. Go, guys!

JANUARY 14, 2017



Photo booth at MIT Better World (London)
JANUARY 13, 2017



The Institution of Engineering and Technology, London
JANUARY 13, 2017



Sky100 Hong Kong
DECEMBER 14, 2016

"The alumni scene in Hong Kong is thriving. We are very excited about the growing MIT presence here. It is re-energizing innovation."
—Julian Lee '97, MIT News

DECEMBER 13, 2016



"At MIT, I was literally living in the future."

—Drew Houston '05, MIT Better World (San Francisco)



San Francisco City Hall
NOVEMBER 2, 2016



"The Aging Brain Initiative is tackling the most urgent topic of the dementias of aging."
—Picower Professor of Neuroscience Li-Huei Tsai, MIT Better World (New York)

@mitclubny

Radar: a 20th c. MIT gift to the world. You can bring the 21st c. gifts <http://giving.mit.edu> #MITBetterWorld

OCTOBER 20, 2016



Cipriani 25 Broadway, New York
OCTOBER 20, 2016

Fully Immersed

Remarks by Julia Sun '15 MIT Better World (London)

When I was six years old, my family moved from China to the village of Shorewood, a small town in Wisconsin. Growing up in the Midwest, I had always imagined MIT as this big institution full of nerds and programmers in every corner. I wasn't sure I could ever fit in. It wasn't until I first came to campus, after staying up until 4 am that last night of Campus Preview Weekend with friends I had just met, that I realized I had truly found paradise.

In the summer of my freshman year, I joined Professor Paula Hammond's lab to create novel dressings to heal chronic wounds. I went to her lab because I had always loved biology, and it was in her lab that I discovered how powerful engineering can be in advancing medicine. So I chose to major in chemical engineering, Course 10, because I wanted to be challenged in ways that I had never been challenged before, and MIT was that perfect place to take risks and really push my intellectual boundaries.

I'm not going to lie: Course 10 is incredibly challenging. We somehow start off with the foundations of engineering, like mass and heat transfer, kinetics, fluid dynamics; and we finish senior year by designing two full manufacturing plants, complete with a gauntlet of reactors, distillation columns, and filtration streams. In my four years in Course 10, I not only gained this incredible wealth of knowledge, but I had discovered that I developed this courage and confidence to seek out ever newer and riskier challenges. Part of what made this transformation possible was that I received financial aid during all my years at MIT. And the generosity of my scholarship donors made it possible so that I could fully immerse myself in my scholarship and follow my dream of creating game-changing innovations in medicine.

My MIT education gave me this sense of momentum, of urgency and desire to give back and help those around me. I worked hard to champion STEM programs for middle school students. I traveled across Asia, through the MISTI program, to introduce MITx courses to students in China, Hong Kong, and Taiwan, so that they, too, can be empowered in the same way that MIT empowers all of us. And that empowerment is why I moved to London to pursue my dream project. At Imperial College London, as a Fulbright Scholar and PhD student, I've been asked to lead an incredibly challenging and ambitious project that could fundamentally change how we understand the brain.

Using bioinspired nanoparticles, I'm working to visualize the communication between neurons in our brain in a way that isn't possible with today's technology. So, on a daily basis, you can find me in the London Center for Nanotechnology, using state-of-the-art equipment to fabricate nanoparticles so small that they're invisible to the naked eye. But outside the lab, these physically minuscule nanoparticles have this enormous potential to help us discover new cures for millions of patients with neurological diseases around the world. MIT has been this critical element in my journey from that small Midwestern town to London's Nanotechnology Center. And just like my nanoparticles, I've

been empowered with this potential for exponential impact. Because of MIT, we all have this enormous potential to create something truly extraordinary for the world.



PHOTO: BEN BULL

PATRICIA DINNEEN

Investing in the Greater Good

Many alums pinpoint their freshman year as the start of their relationship with MIT, but for Patricia Dinneen PhD '80, those roots go deeper. "It's a connection that comes directly from my family," she says, adding that the MIT values of service to others and the pursuit of excellence through education were also values she learned at home. Her father, Gerald Dinneen, was a pioneer in digital computing and satellite communications. In the 1970s, he served as director of MIT's Lincoln Laboratory, where he had

worked since the 1950s. Her uncle, Wilbur "Bill" Davenport SM '43, ScD '50, was a longtime professor and chair of MIT's Department of Electrical Engineering and authored several influential books in the field.

"By the time I graduated from high school," Pat Dinneen says, "I realized I wanted to focus on issues of poverty, global economic systems, and technology. I also wanted to venture beyond Boston." She headed to the University of Pennsylvania and from there to the London School of Economics. She returned to the US to work at the Nixon White House in Energy and Research Development, and as a member of a Presidential Task Force on Energy Self-Sufficiency. These were

challenging roles, she recalls, during the turbulent years of the Arab oil embargo and Watergate. In 1974, Dinneen returned to Massachusetts to earn her third degree in economics—a doctorate from MIT.

"Without question, being a graduate student at MIT was one of the most challenging experiences of my life," she says. "It also gave me credibility, confidence, and access to an incredible professional network." Over the next several decades, Dinneen served in leadership positions at communications and aerospace companies in the US and Britain. In 1997 she joined Cambridge Associates, an investment consulting firm, where she specialized in emerging markets private equity. Preferring investing to consulting, she spent the next 10 years managing a multibillion portfolio of emerging market investments and delved into the field that has become her passion: social impact investing. She defines social impact investing as "investments intended to generate positive, measurable societal and environmental benefits as well as financial returns."

Despite the commonly held assumption that the goals of profit and social good are necessarily at odds, Dinneen points out that "a growing amount of empirical data shows otherwise," and notes there is ample opportunity for MIT alums to add to that success.

"I would love to enlist more of the best and brightest minds from MIT to prove that if you create radically low-cost solutions to global problems, such as health care, education, clean water and sanitation, and alternative energy, and if you can achieve scale, it is possible to outperform traditional investments."

To help new generations of those bright minds get their start at MIT, Dinneen established a scholarship fund in 2014 with her husband, John Mooney. "I have long wanted to promote the core STEM subjects of science, technology, engineering, and mathematics, so the MIT scholarship seemed like a wonderful solution," she says. She is currently exploring links with some of the myriad MIT programs in social entrepreneurship, especially in Africa, working with students, faculty, and other alums who share common goals to create sustainable business solutions for reducing poverty. Now formally retired, but with a full schedule of pro bono work for nonprofits, startups, and other entities in social impact investing, Dinneen says she is "happier than ever," and grateful to have many opportunities for working, learning, and giving back. —Kris Willcox



PHOTO: M. SCOTT BRAUER

A Community of Trust

In June, MIT received a remarkable gift from a donor who wishes to remain anonymous. Certainly, the figure of \$140 million was one of the gift's remarkable features, but something else stands out: the funds were not designated for a specified purpose. Unrestricted gifts like this one signal a strong belief in MIT's mission and in its leadership's ability to use such funds wisely in pursuit of that mission. This donor and thousands of others at all levels of giving embody a community of trust at MIT. The Institute is stronger as a result, able to direct those funds wherever they are needed most.

"Everyone who contributes 'unrestricted' dollars gives MIT flexibility and nimbleness—the ability to seize unexpected opportunities, to solve crucial but unglamorous issues around buildings and grounds, to respond to emergencies, to provide the fundamental support that allows us to attract many of the most creative people in the world. And these supporters give us one thing more: the great gift of their confidence—confidence in the mission, power, and people of MIT to do good for the nation and the world." —MIT President L. Rafael Reif

"In order to take on the world's most pressing problems, we need the very best faculty and the brightest students working in the finest facilities. Unrestricted funds are critical in providing scholarship aid for our undergraduates, startup funds for junior faculty members, and support for campus renewal. The demand for unrestricted dollars to enable MIT to continue to push the boundaries of knowledge is never fulfilled, and we are grateful to donors at all levels who signal their trust and belief in MIT with these kinds of gifts." —Israel Ruiz SM '01, MIT executive vice president and treasurer

WARREN AND TERESA ROSS

A Call to Action

Warren Ross '95 doesn't go easy on himself when he talks about his days as an MIT mechanical engineering (Course 2) student. "I struggled to get through my degree, which was self-inflicted more than anything," he admits. "I believe I missed many opportunities while I was at MIT. I've always regretted that."

Today, "missed opportunities" is not a phrase easily associated with Warren. He is the president and chairman of Ross Group, a development, engineering, and construction company headquartered in Tulsa, and in recent years has played a major role in revitalizing Tulsa's downtown core. But for this alumnus, who also holds an MBA from the University of Tulsa (TU), that memory of the MIT road not taken has been a motivating force in his life. "Long ago I issued a challenge to myself," he says, "to live up to the degree I didn't deserve to get."

With that challenge in mind, Warren and his wife, Teresa—a chemical engineer with a degree from Colorado School of Mines, fellow TU MBA graduate (they met on a class project), and process engineering manager at the Ross Group—are concentrating their philanthropic efforts almost entirely on education.

At MIT, the couple have contributed meaningfully to the Institute's unrestricted fund, which provides crucial resources for student financial aid, among other essential needs, and gives MIT the freedom to invest in high-risk research. "I hope this gift helps MIT leadership to take a swing at opportunities they think may be game changing," Warren says. Warren readily acknowledges that his and Teresa's unrestricted support is an expression of faith in MIT: "I've always had great confidence in the leadership of the Institute, and I'm willing to invest in that," he says.

Warren's enduring confidence in MIT manifests itself, too, inside the laboratory of Alexander Slocum '82, SM '83, PhD '85, the Pappalardo Professor of Mechanical Engineering, whom the couple also support with discretionary funds. As a Course 2 student, Warren worked for Slocum through the Undergraduate Research Opportunities Program, and he refers fondly to his former professor, whose work runs the gamut from smart toothbrushes to large-scale energy storage solutions, as a "mad genius."



PHOTO: JOHN AMATUCCI

"I may not have taken up all the opportunities he gave me, but the time I got to spend with him I really appreciated," Warren says. "He's so passionate about everything. Teresa and I wanted to invest in his lab so he can continue to be the amazing engineer that he is. He has the potential to impact so many people." The Rosses visit Slocum whenever they are in Cambridge, and Teresa comments that the professor "is an incredibly positive and fun person."

For Warren and Teresa, Slocum embodies the MIT values of hard work and persistence that Warren has been striving to live up to since his days as an undergraduate. It's the idea that "no problem should go unsolved," he says. "Sometimes you need a combination of intelligence, research, and persistence, but the answer is out there—you just have to find it. That's what MIT is all about." —Tracey Lazos

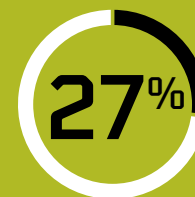
"No one has ever made it through life without someone else's help. As a past recipient of MIT's generous financial aid, I benefited tremendously from the opportunity to pursue my MIT education and am extremely appreciative of all the ways that MIT has shaped me. I am also inspired by MIT's vision in tackling global challenges, and I trust its leadership to take bold steps to make the world a better place." —Anonymous donor of unrestricted gift

"Every time we support MIT, we support a key agent of positive change in the world." —Natalie Lorenz-Anderson '84

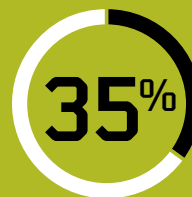
"Forget Peter Pan—MIT was my Neverland! It far exceeded whatever I could have imagined. Giving to MIT is what makes it possible for people from such a wide variety of backgrounds to come together on campus and do the awesome things that we do." —Naren Tallapragada '13



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"The ability of organic systems, especially the human body, to efficiently control so many reactions with vast dependencies has always intrigued me," says Ebenezer Nkwate '17. He spent his senior year working to understand such systems through SuperUROP, an intensive research program that offers undergraduate engineers grad-level training, resources, and guidance. His goal: to build synthetic genetic circuits that could help in heart disease treatment.



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