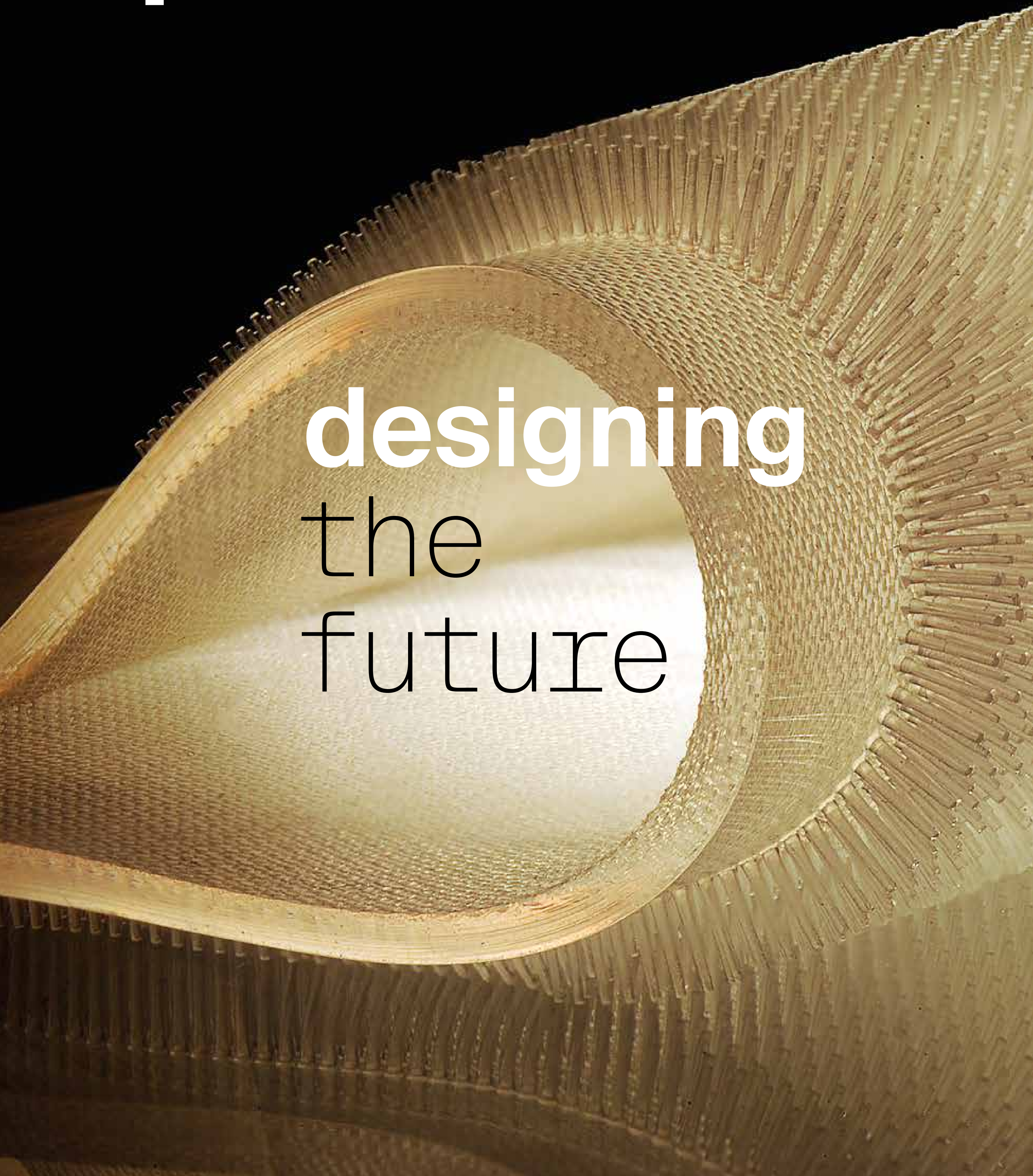
Spectrum

Massachusetts Institute of Technology
Winter 2017



designing
the
future

The MIT Media Lab's Tangible Media group created TRANSFORM, shown here at the 2014 Lexus Design Amazing exhibit in Milan, "to challenge the conventional notion of static furniture design." More than 1,000 tabletop pins respond to human movement captured by sensors. The project was led by Tangible Media head Hiroshi Ishii, the Jerome B. Wiesner Professor of Media Arts and Sciences; among the contributors were Daniel Leithinger PhD '15, Sean Follmer PhD '15, Philipp Schoessler SM '15, Basheer Tome SM '15, Felix Heibeck SM '15, and Amit Zoran PhD '13. The group has continued to explore the use of such pin-based displays for remote interaction and the physical manipulation of digital data.

PHOTO: © LEXUS DESIGN AMAZING 2014 MILAN

Wide Angle

Subjects

SPECIAL SECTION

Designing the Future

Breakthroughs

Inside the MIT Campaign for a Better World

FRONT COVER
Mechanical engineering and mathematics faculty Anette (Peko) Hosoi of the MIT Sports Technology Research Group collaborated with grad student Alice Nasto SM '13 to design an innovative, lightweight material for wetsuits. Their research focused on beavers and sea otters, whose pelts trap insulating air pockets around their bodies when they dive. Nasto constructed a series of molds, using a laser cutter. The team ran experiments on her swatches to arrive at a mathematical model predicting how much air will be trapped based on the hairs' length, spacing, and arrangement.

PHOTO: © FELICE FRANKEL

BACK COVER
In the lab of Moungi Bawendi, the Lester Wolfe Professor of Chemistry, nanocrystals of cadmium selenide fluoresce under ultraviolet light.

PHOTO: © FELICE FRANKEL

Design at MIT: Inventing Excellent Answers

To outsiders, MIT can appear to be a place where people are good at "getting the right answers." But I believe a more revealing distinction is that the people of MIT have a gift for *asking the right questions*—and one of the ways we frame those intriguing questions, experiment with the possibilities, and arrive at compelling answers is through the process called design.

Given its deep roots in engineering and architecture, design thinking has been part of MIT from the start, and it has gained growing relevance across the Institute. Today, you will find the people of MIT "designing" across a huge range of scales, contexts, and levels of abstraction, from a molecule to a machine to a metropolis, from a new material to a nanotextured surface to a system of production.

In the last few years, we have taken steps to promote design thinking across the Institute through the lens of problem *setting*: a multidisciplinary strategy for asking the right questions by thinking expansively about new possibilities, examining their implications, and continuously refining them to generate new approaches.

As you will see throughout this issue of *Spectrum*, design has particular power in addressing questions that have no single correct answer. As Hashim Sarkis, dean of our School of Architecture and Planning, explains, by teaching students to think as designers, we deepen their capacity for judgment. Design thinking gives students a strong but flexible process for exploring, testing, and refining solutions, and for making continual judgments, often centered on the most unmanageable variable of all: human beings.

By imparting the tools, human values, and habits of mind central to the design tradition, we teach a dynamic way of inventing excellent answers. Expanding the strategies we can employ to make progress has never been more important, as we seek—together—to make a better world.

L. RAFAEL REIF

(↗)
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Growing Knowledge

Using cancer cells to study neural development

In cellular society, neurons are the overachievers. When hundreds of billions of them are born in a developing fetus, their work has just begun: they must grow fibers, called axons, that will create the connections of the body's nervous system. Not only do axons travel remarkable distances from their nuclei (the longest in the human body, belonging to the sciatic nerve, can extend up to a meter long), they must wend their way to the designated spot where these highly specialized cells can close specific circuits dictated by their DNA.

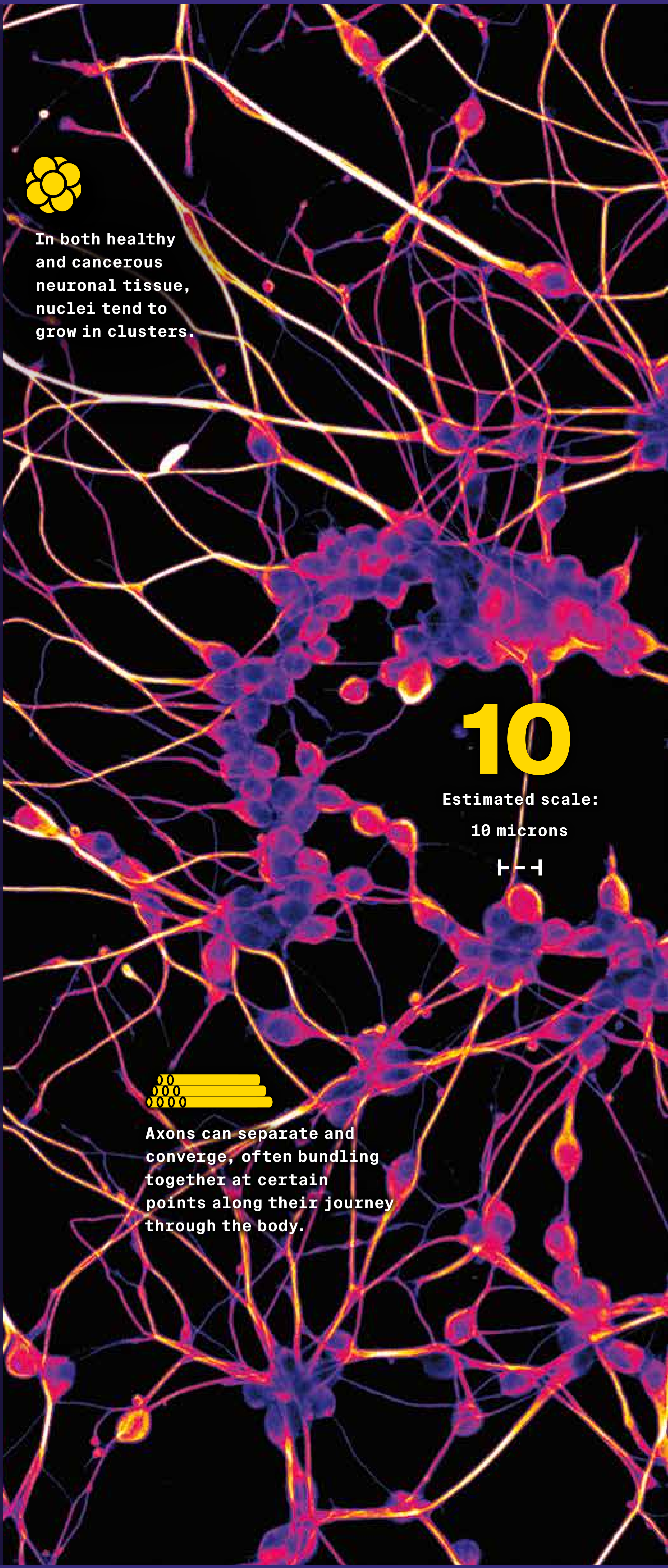
Over the past few decades, scientists' understanding of how axons navigate to exact targets—what types of signals guide them, and how those signals are received—has grown exponentially, according to Frank Gertler, a faculty member of MIT's Department of Biology and the Koch Institute for Integrative Cancer Research. His lab is working to solve some of the remaining mysteries about the process, which he likens to a customized GPS system. "We know some of the basic rules and key players, but we know a lot less about how a growing neuron that's moving through a complex environment coordinates all the information around it and translates that into a precise type of movement," he says.

Primarily, Gertler and his team study actual neurons from developing mouse brains. But samples of the real thing are delicate, and in short supply. So when they want to run large volumes of experiments, test basic ideas, or drastically manipulate cells (expressing or removing certain genes, for example), they sometimes turn to a close approximation: cells from a brain tumor, like those pictured here.

Tumor cells' weedlike ability to reproduce and thrive, so threatening inside the body, becomes an asset in the lab. Scientists have capitalized on this for decades: the most widespread of such cell lines, HeLa, dates back to a 1951 case of cervical cancer. Gertler says the usefulness of neuronal tumor cells in research is limited by significant differences from their healthy counterparts. Nevertheless, they are a valuable tool in illuminating fundamental neurobiology.

And in vivid images like this one—currently on display in the Koch Institute Public Galleries, on an enormous canvas visible from the street—Gertler sees another benefit: "It makes you say wow, that's gorgeous, what is it?" Hanging alongside other winners of the Koch Institute Image Awards, it's a reminder of the beauty of discovery. "Scientific images contain a lot of information and meaning, but some are also works of art," the biologist says. "They serve a purpose in sparking imagination and curiosity and interest."

IMAGE: RUSSELL MCCONNELL/GERTLER LAB



Blue = DNA
Red = microtubules

In the imaging method used here, fluorescent microscopy, molecules emitting certain colors bind themselves like labels to certain cell components.

As axons extend, “growth cones” at their tips read and interpret the information that causes them to forge ahead, turn, or stop. The growth cones of tumor cells are less developed than those of healthy neurons.

These cells were cultured on glass coverslips—a much stiffer surface than the very compliant environment of the brain, through which axons normally extend during development.

Flight School

A roster of experts steers students through the inner workings of the airline industry

TITLE

1.232/15.054/16.71
The Airline Industry

DEPARTMENTS

Aeronautics and Astronautics (Aero/Astro), Civil and Environmental Engineering (CEE), Management

PRINCIPAL INSTRUCTORS

- **Peter P. Belobaba SM '82, PhD '87,** principal research scientist, Aero/Astro
- **Arnold I. Barnett PhD '73,** George Eastman Professor of Management Science, MIT Sloan
- **Cynthia Barnhart SM '85, PhD '88,** chancellor and Ford Professor of Engineering, CEE
- **R. John Hansman SM '80, PhD '82,** T. Wilson Professor in Aeronautics, Aero/Astro
- **Thomas A. Kochan,** George Maverick Bunker Professor of Management, MIT Sloan
- **William Swelbar,** research engineer, Aero/Astro; executive VP, InterVistas Consulting

FALL 2016 ENROLLMENT

40 graduate students, representing:

- **MIT Sloan School of Management (17)**
- **School of Engineering (18)**
- **School of Architecture and Planning (2)**
- **School of Humanities, Arts, and Social Sciences (1)**
- **Harvard University (2)**

FROM THE CATALOG

Overview of the global airline industry, focusing on recent industry performance, current issues, and challenges for the future. Fundamentals of airline industry structure, airline economics, operations planning, safety, labor relations, airports and air traffic control, marketing, and competitive strategies, with an emphasis on the interrelationships among major industry stakeholders. Recent research findings of the MIT Global Airline Industry Program are showcased, including the impacts of congestion and delays, evolution of information technologies, changing human resource management practices, and competitive effects of new entrant airlines.

ORIGINS

The global airline industry today generates hundreds of billions of dollars in revenue; it comprises more than 2,000 airlines operating more than 23,000 aircraft and providing service to more than 3,700 airports. The Global Airline Industry Program was founded in 2000—under the umbrella of the Sloan Foundation's Industry Studies Program, and supported by the MIT Airline Industry Consortium—to develop a body of knowledge for understanding development, growth, and competitive advantage in this critical industry. The program spun out this graduate-level offering in 2001, aiming to educate future leaders of the airline industry while providing practical solutions to its most pressing problems.

FORMAT

Many different faculty members and guest lecturers—all participants of the Global Airline Industry Program—teach the class. Belobaba coordinates all the lectures and also teaches a wealth of material related to air transportation economics, airline planning, and competitive strategy. Over the course of the term, students hear from about 10 scholars and industry experts. In Fall 2016, for example, MIT Sloan's Barnett, an expert in applying mathematical modeling to problems of health and safety, taught students how to estimate the mortality risk of commercial air travel. Aero/Astro's Hansman, a specialist in aircraft design, flight information systems, and air traffic control, introduced students to airline operations and provided an overview of current surveillance and communications technologies. And Kochan, co-director of the MIT Sloan Institute for Work and Employment Research, taught a class on labor relations.

Sanchez: "It helps to have a large number of students from different backgrounds. The engineering students and the management students often approach the same problems from different perspectives."

Caitlin Bradbury, MBA candidate: "I'm interested in working in the airline industry after Sloan, so I thought this class would be helpful in preparing me."

Benjamin Sanchez, CEE graduate student: "I worked in the airline industry for three years before coming to MIT. Whenever you work for a company for a significant period of time, you tend to look at the industry through the perspective of that company. I wanted to take this class to get a broader understanding of what is happening in the industry from a global perspective."

Belobaba: "It's a very unusual course in which you are getting world experts in each of the different areas. No single faculty member could possibly provide that level of expertise."

GUEST SPEAKERS

In addition to tapping MIT experts, The Airline Industry typically features one or two lectures by an industry leader. This year, the former CEO of Spirit Airlines, Ben Baldanza, discussed the impact of competition on the evolution of the airline industry. Previous speakers include:

- Montie Brewer, former president and CEO, Air Canada
- Scott Nason SM '77, former CIO, American Airlines
- Bill Brunger, retired senior vice president for network planning, Continental Airlines

Bradbury: "This class has been extremely useful in introducing me to aspects of the industry that I was not as familiar with, like operations and the regulatory environment."

SAMPLING OF LECTURE TOPICS

- Airline Pricing Theory and Practice
- Fleet Planning and Aircraft Acquisition
- Airline Operations
- Human Resource Management in Airlines
- Overview of Air Traffic Control
- Environmental Impacts of Air Transportation
- Aviation Safety and Security

Belobaba: "You can use mathematical models to optimize networks and schedules, but none of that is operationally possible without people. Labor relations and human resources can make or break all optimization."

Belobaba: "The textbook is based on the lectures developed for this course."

FROM THE TEXTBOOK

Belobaba, P., Odoni, A., and Barnhart, C. (eds.), *The Global Airline Industry*, 2nd Edition, John Wiley & Sons Publishers, 2015.

> *At the time of this book's publication, the airline industry is about to enter yet another phase in its continuing transformation, with the development of global networks served by new airlines from emerging regions and by new alliances of existing carriers. Mature (North America) and maturing (Europe and parts of Asia) markets will test the extent to which new capacity can continue to be added. Energy costs will play a large role in the development of markets and service, as inevitable increases in ticket prices will begin to test the elasticity of air travel demand as never before in many regions of the world. As the industry evolves, the airline planning process will not undergo dramatic change, aircraft fleet decisions will remain long term, route planning decisions will remain medium term, and short-term decisions will continue to be driven by unpredictable events. What will change is how the global airline market develops, as many new route opportunities will emerge. Global alliances, and possibly even global mergers, will present different decision-making challenges for airline management.*
> —Chapter 16, "Critical Issues and Prospects for the Global Airline Industry"

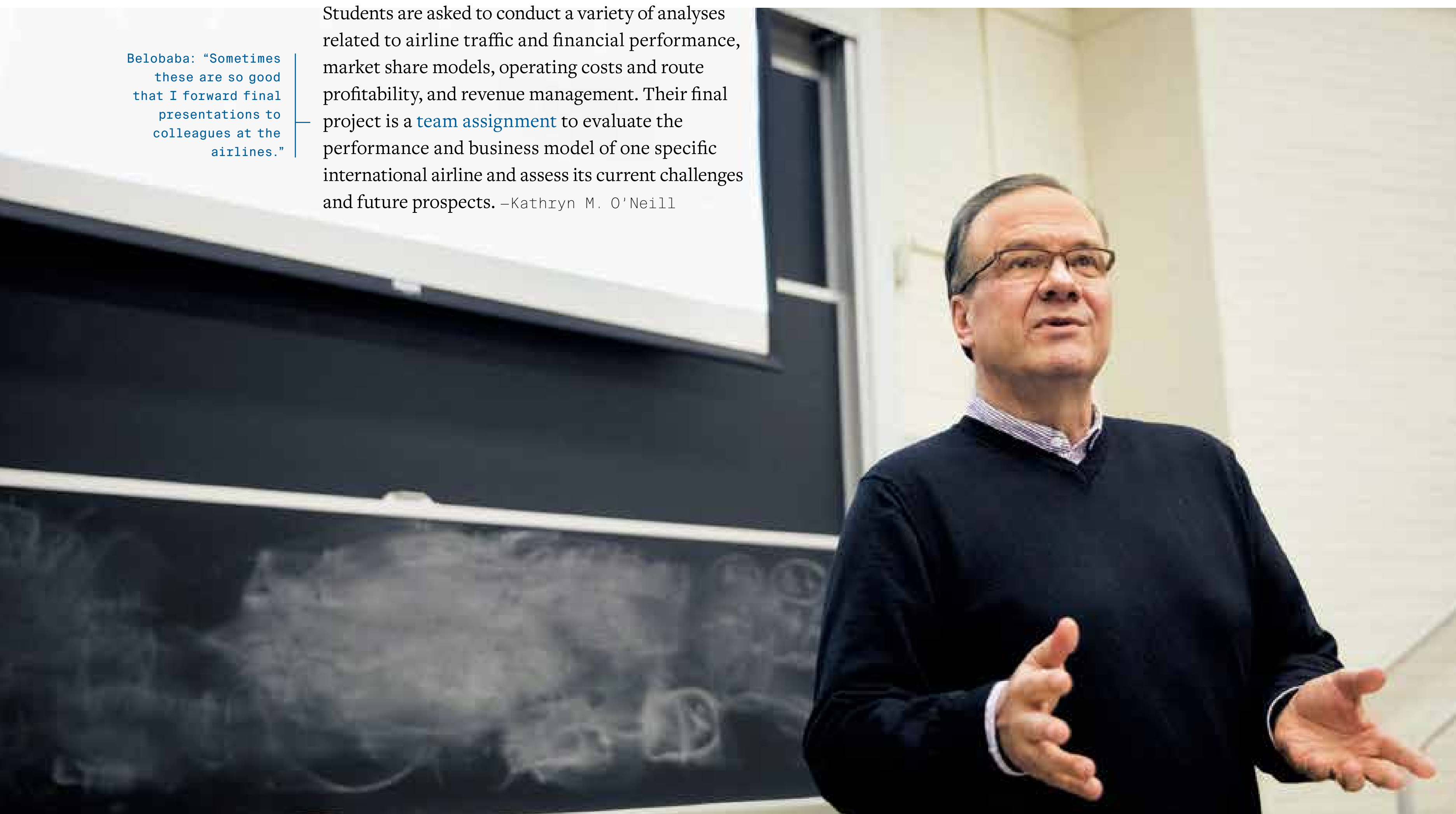
The subject's Fall 2016 lecturers included associate professor of aeronautics and astronautics Hamsa Balakrishnan, opposite, whose work includes a collaboration with the Federal Aviation Administration and major US airports to upgrade air traffic control tools; and Peter Belobaba, below, program manager of the Global Airline Industry Program.

PHOTOS: BRYCE VICKMARK

ASSIGNMENTS

Students are asked to conduct a variety of analyses related to airline traffic and financial performance, market share models, operating costs and route profitability, and revenue management. Their final project is a team assignment to evaluate the performance and business model of one specific international airline and assess its current challenges and future prospects. —Kathryn M. O'Neill

Belobaba: "Sometimes these are so good that I forward final presentations to colleagues at the airlines."



designing the future

What is design *for*? The answer to that question has accumulated layer upon layer throughout modern history. As mass production became the norm, manufacturers looked to design to humanize the output of machines. As industrialized society trended toward specialization, design brought coherence to everyday environments. And in today's era of smartphones and big data, we rely on design more than ever to mediate complexity and to interpret the noise around us.

At MIT, design meets these needs and many more. Our creators and problem-solvers call on their strengths in design to define the challenges and opportunities at hand, to improve systems and processes, to bridge the familiar and the unexpected, to find new modes of expression. The innovative technologies and scientific breakthroughs so central to MIT's identity continue to push design in new directions—and that, in turn, makes new inventions and discoveries possible.

Opposite: The "Fluid Lattices" project is part of a series of investigations by MIT's Self-Assembly Lab looking at autonomous assembly in complex and uncontrolled environments such as water and air. Housed at MIT's International Design Center, the lab is led by Skylar Tibbits, assistant professor of design research in the Department of Architecture.

PHOTO: JOSÉ MANDOJANA

The Lens of Design

New initiatives from the School of Architecture and Planning sharpen MIT's focus on design-based learning

Scan a list of MIT's departments and you won't find the word "design" anywhere. And yet, there are enclaves of design all over campus. Some are student clubs: from the civic-minded Design for America, to teams that construct rockets and solar cars. Others are research groups whose territories seem to have minimal overlap: synthetic biology, self-assembling materials, smart cities, educational video games, DIY health devices.

"This is typical of MIT. You may think something doesn't exist, and it turns out to exist in a hundred places," remarks the dean of the School of Architecture and Planning, Hashim Sarkis.

Such permeation has been helped along, says Sarkis, by the gradual dissolving of traditional boundaries between "problem solving and solution improvement" that historically framed design as a late-stage step. "In the world of products, it's become very important for design to be an integral part of the making," he says. Not only do managers, engineers, and scientists increasingly want to have a designer in the room from the beginning—often, they want to look through the lens of design themselves. And why not? "Linear thinking and holistic thinking are not separate," Sarkis says. "Scientific method and design method are not separate. They are enmeshed."

Now, a collection of educational initiatives emerging from Sarkis's school are focusing that design lens for students bound for a range of endeavors. Among these are an undergraduate Design Minor, established in Fall 2016 by the Department of Architecture, and DesignX, an entrepreneurial accelerator. Both D-Minor and DESx, as they're known, are open to participants across MIT (DESx teams must include at least one SA+P graduate student).

Above: At MIT, Tiandra Ray '15 specialized in computational design; her thesis focused on the connection between built environments and mental health.

PHOTO: M. SCOTT BRAUER

According to J. Meejin Yoon, head of the Department of Architecture, the minor provides students of all majors "a methodology for processing context—both physical and cultural—and constraints, seeing the opportunities, and realizing those opportunities." Along the way, students master creative and technical skills that are increasingly in demand throughout the job market.

Fruits of this methodology can be seen in the estimated 1,200 startups that have been launched by SA+P alumni. DESx will provide the next generation of MIT entrepreneurs the specialized resources such endeavors require, aided by research led by Andrea Chegut, the director of the MIT Real Estate Innovation Lab. Her team is studying the landscape for companies innovating in the spheres of the built environment, media, and design: "what makes them tick, and what makes them distinct from other types of businesses," Chegut says. "We'll apply this knowledge to DESx, to enable our entrepreneurs to understand the nuts and bolts they need to form successful organizations." Selected DESx teams receive $15,000 in seed funding,

Below: In 4.031 Design Studio: Objects and Interaction, Wei Xun He '18 shows TA Kathleen Hajash his prototype for a wearable motion-capturing device.

PHOTO: M. SCOTT BRAUER

mentorship, and specialized for-credit workshops over the Independent Activities Period and spring semester. After four months of focusing on business models and prototypes, they will be ready to pitch their ventures to funders.

Over the past decade, MIT's integral role in the creation of the Singapore University of Technology and Design—which led to the establishment of an International Design Center based in both Cambridge and Singapore—has demonstrated the Institute's commitment to formalizing and sharing globally what it knows about teaching and learning design. In that same spirit, SA+P announced this fall that its faculty will help to shape the curriculum of a new Dubai Institute of Design and Innovation (DIDI). Expected to open in 2019, DIDI will offer the Middle East and North Africa region's first undergraduate degree in design, which has become a major driver of economic growth in that part of the world. SA+P is also developing a new MicroMasters in Design, a semester's worth of online courses opening a path for learners worldwide to earn an MITx digital credential for successful completion and, for some high performers, to enroll in a full master's program on MIT's campus.

For undergraduate and graduate students alike, the heart of SA+P's learning model is the studio. The term evokes a small-workshop setting, where peers work elbow to elbow at tables teeming with sketches and materials; it also signifies an iterative, critique-driven learning process. Both meanings of the word were in play this fall in 4.031 Design Studio: Objects and Interaction. The foundational class brought together students majoring in architecture, mechanical engineering, electrical engineering, and computer science, among other fields. The resumes of its instructors, Marcelo Coelho SM '08, PhD '13, and Jessica Rosenkrantz '05, reflect their own multidisciplinary MIT backstories. Coelho, an alumnus of the Media Lab's Fluid Interfaces group,

New Intersections for Design, Science, and Publishing

In early 2016, the MIT Media Lab and the MIT Press launched the online, open-access Journal of Design and Science (JoDS)*. Media Lab Director Joi Ito points to JoDS as "a new model for academic publishing," with a staunchly antidisciplinary outlook. The journal utilizes PubPub, a new platform for open-access publishing, created by PhD candidate Travis Rich SM '13, Thariq Shihipar, and others in the Media Lab's Viral Communications group. In contrast to the rigidity of peer-reviewed, issue-bound academic journals, PubPub enables easy integration of rich media and data, and its extensive annotating and commenting features encourage iteration, interlinking, and participation. Not coincidentally, those are characteristics of the "new kind of design and new kind of science"* JoDS *will explore, as Ito describes in the inaugural essay excerpted here.*

Design has evolved from the design of objects both physical and immaterial, to the design of systems, to the design of complex adaptive-systems. This evolution is shifting the role of designers; they are no longer the central planner, but rather participants within the systems. This is a fundamental shift—one that requires a new set of values. [...] This would be much more of a design whose outcome we cannot fully control—more like giving birth to a child and influencing its development than designing a robot or a car.

An example of this kind of design is the work of Media Lab Professor Kevin Esvelt, who describes himself as an evolutionary sculptor. He is working on ways to edit the genes of populations of organisms such as the rodent that carries Lyme disease and the mosquito that carries malaria to make them resistant to the pathogens. The specific technology—CRISPR gene drives—is a type of gene edit such that when carrier organisms are released into the wild, all of their offspring, and their offspring's offspring, and so on through the generations, will inherit the same alteration, allowing us to essentially eliminate malaria, Lyme, and other vector-borne and parasitic diseases. Crucially, the edit is embedded into the population at large, rather than the individual organism. Therefore, Esvelt's focus is not on the gene editing or the particular organism, but on the whole ecosystem—including our health system, the biosphere, our society and its ability to think about these sorts of interventions. To be clear: part of what's novel here is considering the effects of a design on all of the systems that touch it.

Unlike in the past, where there was a clearer separation between those things that represented the artificial and those that represented the organic, the cultural and the natural, it appears that nature and the artificial are merging. [...] We are finding that we are more and more able to design and deploy directly into the domain of "nature" and in many ways "design" nature. Synthetic biology is obviously about our ability to "edit nature." However, even artificial intelligence, which is in the digital versus natural realm, is developing its relationship to the study of the brain beyond merely a metaphorical one. We find that we must increasingly depend on nature to guide us through the complexity and the unknowability (with our current tools) that is our modern scientific world.

From Joichi Ito's "Design and Science: Can design advance science, and can science advance design?" (*Journal of Design and Science*, MIT Media Lab and the MIT Press, January 30, 2016)

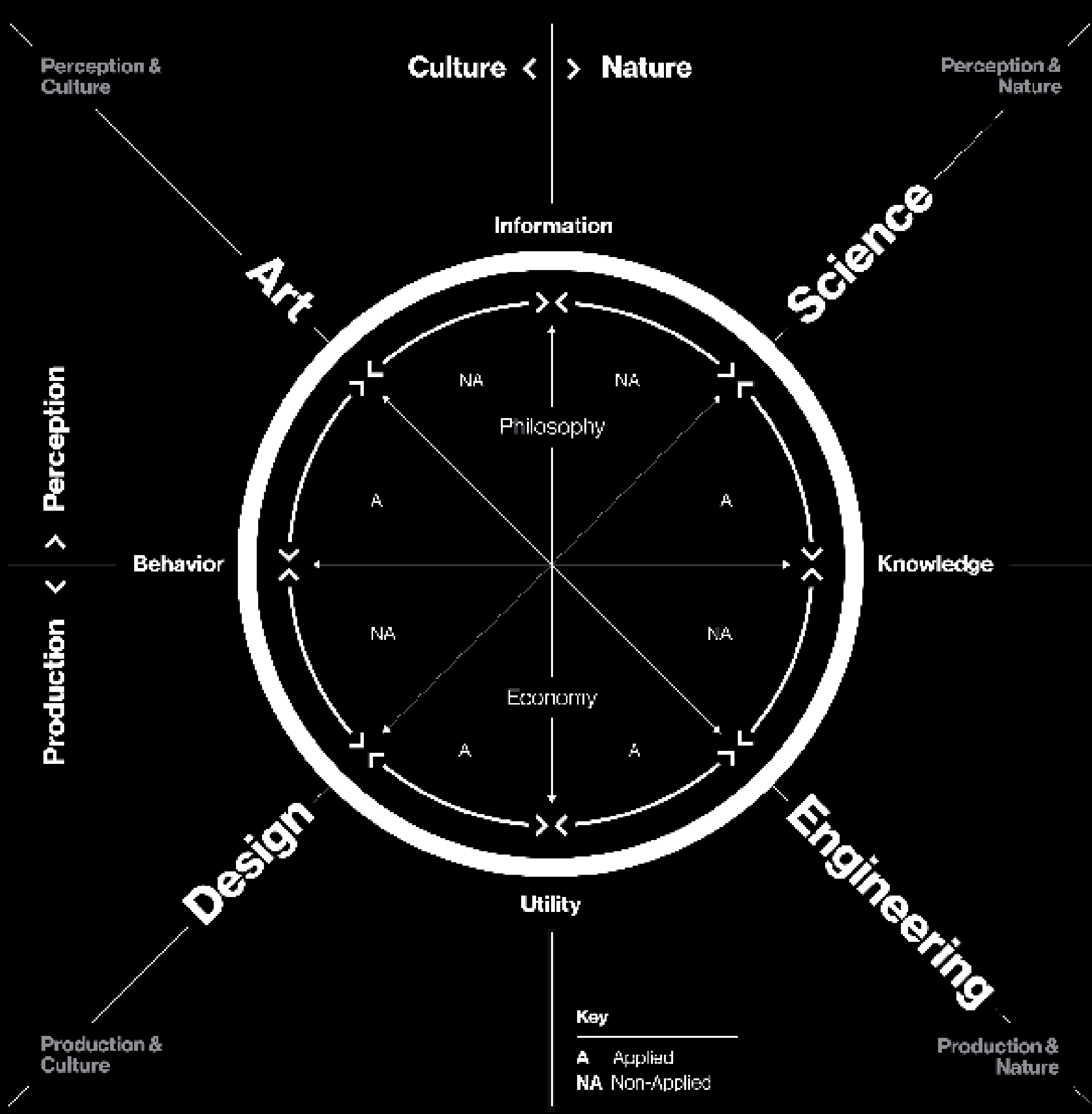
> Not only do managers, engineers, and scientists increasingly want to have a designer in the room from the beginning—often, they want to look through the lens of design themselves.

manipulates physical and computational materials in service of novel experiences. His recent work includes the design of the Rio 2016 Paralympics Opening Ceremony and an architectural scale pavilion collaboratively assembled by humans and robots. Rosenkrantz, who double-majored at MIT in architecture and biology, is a cofounder of Nervous System, known for its intricate housewares and fashion inspired by natural phenomena such as coral reefs, and for its online applications that allow customers to co-create their purchases.

In 4.031, Rosenkrantz and Coelho challenged their students with three projects that would add up to "an overview of design as the giving of form, order, and interactivity to the objects that define our daily experience." Students began by building their own take on a simple wooden chair (with personalized touches ranging from practical: a frame that comfortably accommodates a backpack; to whimsical: a cushion into which you can stuff your rejected brainstorming notes). Next, the students created 3-D-printed wearable textiles; their final project required them to create an interactive clock for an alternative measurement of time.

Design minor Lucia Liu '18, a MechE major who aspires to a career in product design, says 4.031 increased her appreciation for the process that will get her there. "The path to a good design solution is almost never straightforward," Liu observes. "It is easy to be attached to one design idea, but I have learned that it is better to value the fluidity of design."

This fluidity, believes Sarkis, will be one of the MIT community's greatest assets as it continues to take on the planet's toughest challenges. "There's never one solution to a problem. There are always many," he says. "There isn't one world, but many possible worlds that are imagined, invented, and created by design." —Nicole Estvanik Taylor



The Krebs Cycle of Creativity, by designer, architect, and MIT Media Lab faculty member Neri Oxman PhD '10, was featured in the *Journal of Design and Science* in January 2016. The illustration refers to the Krebs cycle, the sequence of reactions by which organisms generate energy; and to previous matrices put forth by designers John Maeda '89, SM '89, a former Media Lab professor, and the late Rich Gold—both of which located Art, Science, Design, and Engineering in quadrants with distinct boundaries and specialized missions. In an essay accompanying this illustration, Oxman names her own goal: "to establish a tentative, yet holistic, cartography of the interrelation between these domains, where one realm can incite (r)evolution inside another; and where a single individual or project can reside in multiple dominions." Oxman suggests multiple ways to view the graphic: as a clock, a microscope, a compass, a gyroscope. However the space is navigated, she imagines an output of creative energy—not unlike the output of chemical energy in living cells—resulting from the fluid movement from one realm to another.

Constraints and Viewpoints

The Integrated Design and Management program blends creativity, analysis, and empathy

MIT has an established tradition of graduate education that combines engineering and management. A new master's program has developed a third component: the integrated design process and the power it brings to solving not just management and engineering problems but social problems as well.

The Integrated Design and Management program (IDM) is an outgrowth of the graduate course Product Design and Development, which brought together MIT students in engineering and management with industrial design students from the Rhode Island School of Design (RISD). For several years, Professor of Management Science and Innovation Steven Eppinger '83, SM '84, ScD '88, who is the co-author of a widely used textbook also titled *Product Design and Development*, taught that course with IDM program director Matt Kressy (then at RISD), along with various engineering faculty members. The new IDM program, which enrolled its first students in Fall 2015, leads to an SM in engineering and management. IDM is offered jointly by the School of Engineering and MIT Sloan School of Management, and is targeted at early- to mid-career professionals.

IDM aims to attract equal cohorts of students with engineering, business, and industrial design backgrounds. The program's admissions criteria emphasize the attribute of altruism along with creativity and achievement. Candidates are rated on test scores and a portfolio, but also on what Kressy calls the "love metric."

"Shouldn't we be predisposed to select people with compassionate, loving visions?" Kressy says. "You can't test for that, but I think it's important."

IDM prepares its graduates to become leaders in industrial design, engineering, or innovation at large firms, as well as entrepreneurs who create things that are profitable while also improving the world. One of the goals is for students to use what they've learned to bring new perspectives to deeply complex social problems. Suppose the desired "product" were a method or approach for ending violent encounters between police and black men. Using the integrated design process, a team composed of experts from several disciplines would "embed" with all the stakeholders (police officers, black citizens, policy makers, and others), and propose a solution that takes into account the full array of constraints and viewpoints.

"In design thinking, we use the word 'empathy' all the time," Kressy says. "The design process starts with developing a deep connection with your customer. You make an emotional connection to a problem, and with that connection comes insight."

Along with engineering and management foundation courses and electives, IDM students learn the tools and methods of design in the ID Lab, located in the International Design Center. For their theses, students approach the design of a product or service by researching the market and formulating a business plan.

For example, Huda Jaffer SM '16, the first student to complete IDM, examined investments in renewable energy technologies in the developing world. She researched the needs of various stakeholders—underserved communities, designers of renewable energy technologies, and the potential investors in those technologies—to propose guidelines for investors to gauge an energy technology's "holistic sustainability," that is, its potential to offer a positive social or environmental impact as well as a financial return.

"Engineers' responsibilities have expanded substantially over the last 25 years. They're now expected to understand the entire system that will influence the product they're developing," says Professor of Mechanical Engineering Warren Seering, who is faculty co-director, along with Eppinger, of IDM.

"I've noticed that many industries have begun to emphasize design leadership, and I think the IDM program is perfectly positioned to create those leaders," says second-year IDM student Sara Remsen, whose undergraduate majors were biology and digital arts. Remsen is collaborating with the MIT Media Lab's Responsive Environments group to design new augmented/virtual reality experiences that explain the ecological processes of a recently restored wetland. The idea is to bring the story alive for visitors to help them better understand the benefits of restoration. Learning firsthand about stakeholders' needs in the context of the larger environment "results in a more creative concept generation process," Kressy says. "Combine that with the analytical element we've traditionally taught here at MIT and you end up with a very powerful way to solve problems." —Alice Waugh

IDM Spring 2016 final presentations included one team's proposal for reducing and reusing waste in the production of Camper Shoes.

PHOTO: JOHN PARRILLO

Weaving through the Action

Under one roof at last, MIT's theater program narrows the gap between design and performance

It's the week before the 2016 presidential election, and onstage in MIT's Kresge Little Theater is the shell of an abandoned campaign headquarters, the set for Bertolt Brecht's political parable *The Resistible Rise of Arturo Ui*. The production's cast features more than 20 students, with another 20 working behind the scenes.

What's not apparent, viewing that set between performances, is that it's activated during the show by nine cameras that feed into multiple onstage screens. Another surprise: one wall, marred by a jagged crack, is not just shabby but shatterable. "Someone gets thrown through it. It's pretty classy," jokes Jay Scheib, the production's director and head of the MIT Theater Arts program, sitting on the edge of the deserted stage one afternoon during the show's run. He gestures stage left. "Someone also gets thrown through that window, which we make out of heat-shrink plastic."

These two dynamic elements—the blending of action and live video, and the violent breaching of walls—are bread and butter for Scheib and for the department's director of design, Sara Brown. It's an aesthetic they will continue to explore with their students come spring, under a new roof: the Theater Arts Building (W97), soon to open in a gut-renovated warehouse on Vassar Street.

W97 marks a new era for a growing department where Scheib and Brown have been faculty since 2003 and 2008, respectively. Their collaborations on and off campus include *World of Wires*, a dark tale of virtual reality that opened with the smashing of a literal fourth wall—a moment the *New York Magazine* reviewer called "one of the most thrillingly witty displays of illusion I've ever seen on a stage or a screen." For that production, Brown designed a warren of rooms divided by a narrow central hallway, with hand-held cameras weaving through the action and capturing close-ups.

World of Wires, like the rest of Scheib's *Simulated Cities/Simulated Systems* trilogy, was workshopped at MIT before its professional debut. Each installment, according to that show's program notes, emerged "through dialogues with civil engineering and urban planning, computer science and artificial intelligence, aerospace and astronautics." MIT theater students' backgrounds in those and other fields not only influence the dramaturgy of works developed here, but provide a baseline comfort level with the technology that Scheib and Brown bring into the room from the very first rehearsal—building the physical world of the play amid a tangle of microphones, cameras, cables, and computers.

Brown describes one memorable project, from a workshop with visiting theater artist Robert Lepage. The students were asked to devise scenes around the motif of playing cards. "One of the students turned a playing card into a speaker—an actual working speaker—and it told the story for him while he performed silently."

Scheib, too, frequently marvels at his students' ingenuity. "I might say: 'OK, we're going to make a five-minute performance in which there have to be ten exits and entrances, four sentences, two failed kisses, one display of strength, one use of video from your cellphone, three sound cues, a dance solo, and a wrestling match. You have 20 minutes. Get started.' And usually they go: *What?!* And then, they make stuff. And some of the pieces are astonishingly beautiful."

Invention that transcends constraints is practically an MIT sport. But theater education, and theatrical design in particular, injects a bracing dose of aesthetics into the process. As Brown puts it: "Before you can design, you have to *see*. I teach a class where students have to research the history of a particular chair and what else was going on in the world when it was designed. When you put a chair on stage, you're putting that web of references on stage, too."

Above: MIT Theater Arts director of design Sara Brown and program head Jay Scheib.

PHOTO: SHAWN G. HENRY

(↗)
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Theater Arts enrollment has more than doubled in recent years, and a major was established in 2015.

Apparently, MIT students welcome new ways of seeing. Theater Arts enrollment has more than doubled in recent years, and a major was established in 2015. As the program has grown, it has dispersed outside its barebones home base in E33 (the erstwhile Rinaldi Tile Building), making nomadic use of shared facilities for classes, productions, and semester-end exhibitions.

With E33 slated for demolition as part of Kendall Square's transformation, the new building at 345 Vassar Street is an opportunity to consolidate all this scattered activity. Its 25,000 square feet include a two-story, 180-seat, multimedia-equipped venue that can be reconfigured for each use; as well as a rehearsal studio, dressing rooms, and set and costume makerspaces.

Brand-new facilities are a boon for a department used to operating out of an industrial garage, even as W97's design honors the old space's "nothing-is-finished, nothing-is-precious" aesthetic. But the ultimate upgrade is centralization. "It gives us an opportunity to think about programming in a much more autonomous way," Scheib says, "to turn that building into a destination, both for the campus and locally for Cambridge and the greater Boston area." Theater students will move easily between adjacent design, rehearsal, and performance spaces, with ready access to maker tools, and opportunities for immediately trying out what they've made. No longer will the theater be the place "where you show up the day before you open and unpack everything you've been working on and hope it works," says Brown. And no longer will design and acting classes be divided by geography. "We'll be able to bring those things closer together. We really don't think of them as separate items, and this is going to make that ethos, which has always been a goal, much more possible."

If it seems ironic that a program so keen on knocking down walls will flourish thanks to solid new ones—well, drama is fueled by such contradictions. While many MIT buildings are dedicated to solving problems, W97 will in some sense be devoted to creating them: constructing microcosms of conflict to see what transpires. As Brown puts it, "I think a lot of design in other areas is about making something better, more logical, more efficient. And sometimes in theater we have an opposite problem: how do you make it fall apart? How do you make it a challenge for people to navigate the space? There are lots of parallels with theater and architecture, but theater has such a different relationship to time. It has to rewind itself every night."

—Nicole Estvanik Taylor

More than 40 students formed the cast and crew of *The Resistible Rise of Arturo Ui*, staged in November 2016.

PHOTO: JONATHAN SACHS

Digging into Design

Engineering students create new products from the ground (and molecule) up

Pompoms wave wildly in the lecture hall as students gear up for a team challenge in 2.009 Product Engineering Processes, taught by mechanical engineering professor David Robert Wallace SM '91, PhD '95. Today's topic is "design for assembly," and the objective seems simple enough: be the first to screw one piece of wood into another. But Wallace, wearing a striped referee shirt and his trademark Santa Claus beard, impishly explains the catch: while the pink team is using straightforward Phillips-head screws in boards with pre-drilled holes, the orange team has slot screws, the blue team has one of its boards glued upside down in a box, and the red team has its board glued upside down inside a box with eight different screws.

"Go!" shouts Wallace. The cheering is deafening as the students set to work—but it's no contest. The pink team is done in a minute and a half, while red and blue are still working, frustrated, 7 minutes later. "So why do we care about design for assembly?" asks Wallace. But of course, the point has already been made.

Wallace has been driving that point home to students for more than 20 years with this legendary course. Designed to closely mimic a real-world product design experience, from concept generation to assembly and launch, it culminates in a high-energy event in Kresge Auditorium that typically attracts more than 1,000 spectators.

Chemical engineering professor Bradley Olsen '03 may work with his students on a different—and less theatrical—scale, but the goals of 10.00 Molecule Builders are no less ambitious. The new class, which he debuted in Spring 2016, challenges first-year undergraduates to create their own devices using chemical reactions. "When students come to MIT, they always say they want to build something with their hands," says Olsen. "It's easy to imagine how you would do that with software or LEGOs or robots, but hard to envision at the molecular level. And yet, chemical reactions are the core of many devices."

Olsen gave students the choice to engineer one of three projects—a small car powered by a fuel cell; an enzyme cocktail to create biofuel out of switchgrass; and a 3-D-printed microgel for medical applications. Outside of a few parameters, the details on how the students approached the projects were up to them. "It was a very steep learning curve," says Rebecca Grekin '19, who chose biofuels. "We had to figure out what switchgrass was made of, what kind of enzymes we needed to break it down, and how to turn those parts into glucose."

"Students are always surprised when experiments don't work well on the first try," notes Olsen, "because in lab classes, they always do. Those failures mean that students have to take their time to figure out why."

On one try, Grekin's group used the wrong antibiotic, so the bacteria meant to produce the enzymes died; in another, the bacteria contaminated the experiment. Through perseverance, they finally produced trace amounts of glucose. And Grekin carried these lessons to her summer job in a biofuels lab in Brazil. "I was working with a master's student, and I had more hands-on experience in some of the procedures than he did," she says.

In 2.009, "Part of the mission is to build the attitude and motivation to take on challenges and be successful," says Wallace. Each year, he introduces a different theme—this year it's

Left: 2.009 students Kendra Knittel '17 and Jerome File '17 design a prototype release mechanism for their self-deploying wheelchair umbrella; above: Fiona Grant '17 and 2.009 lab instructor Geoff Tsai PhD '16 discuss design details for "Roger," a product enabling better communication for workers wearing respirators in hazardous conditions.

PHOTOS: DABIN CHOE '16

Professor Bradley Olsen '03, center, with Chung-Yueh Lin '19 and Paige Omura '17.

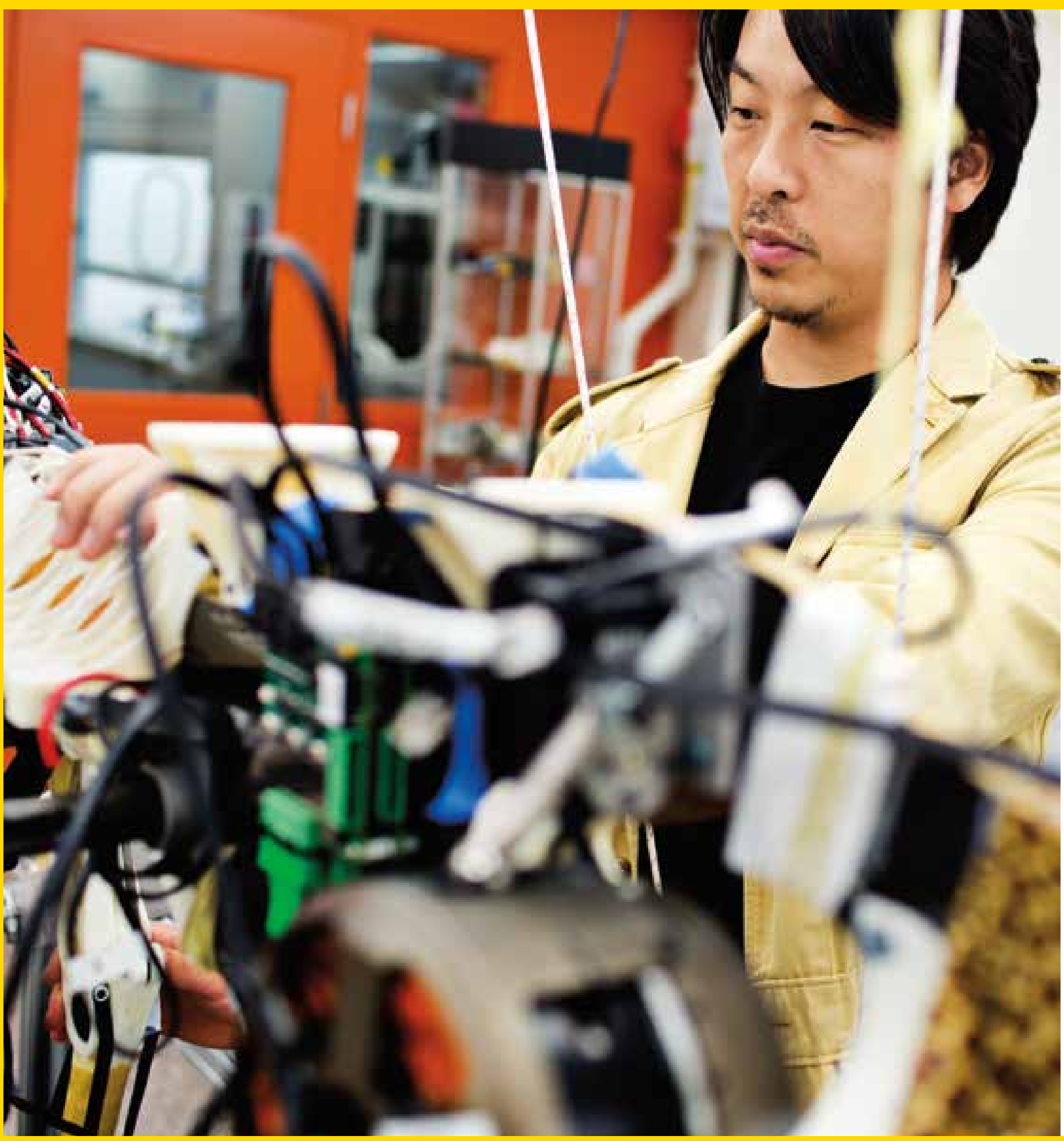
PHOTO: LILLIE PAQUETTE

"Rough, Tough, and Messy"—and students brainstorm products to build within that category. "If you are smart and skilled, you have a good chance of solving a problem—but the important thing is figuring out which problem you want to spend your time on," Wallace says. The student teams pitch six different ideas to a group of advisors that includes MechE faculty, teaching assistants, and mentors from industry. As the semester progresses, they gradually narrow their focus to one product and get a budget of $7,000 to design, build, and assemble it. Over two decades, Wallace's students have designed everything from a rappelling device for caving, to a braille label maker, to a beer-keg dolly. The last two ideas, says Wallace, went on to become commercial products.

Inventing a marketable product, heady as that may feel, is beside the point, says Wallace. "First and foremost, we want students to get excited about the positive and important contributions they can make in society as technical innovators. Secondly, we want to provide them with the skills and knowledge that allow them to work effectively in teams—and those skills are just as applicable to research and many other types of activities."

For Olsen's part, he hopes to expand the very notion of what it means to be a product designer. "I hope they get excited about digging into design and build not just at the macro level or the digital level," he says, "but also seeing the potential that exists at the microscopic level."

—Michael Blanding



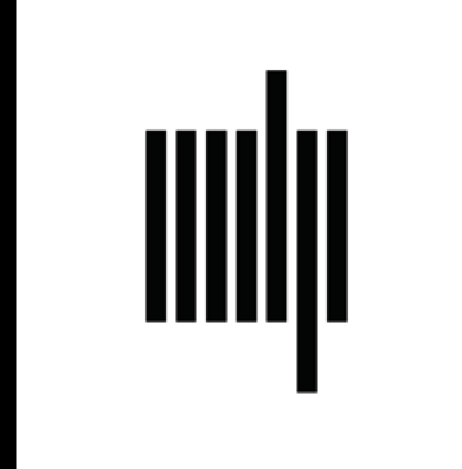
Designing Robotic First Responders

The bounding, four-legged machine known as MIT Cheetah II does wear a few spots in homage to its wild muse. But Sangbae Kim, associate professor of mechanical engineering, isn't aiming to reproduce nature in his work as the head of MIT's Biomimetic Robotics Laboratory. He borrows both liberally and selectively, not only from the biomechanics of the animal kingdom but from the science of human decision making and the cutting edge of mechanical design.

"We have to understand what is the governing principle that we need, and ask: Is that a constraint in biological systems, or can we realize it in an engineering domain?" Kim told MIT News in December. "There's a complex process to find out useful principles overarching the differences between animals and machines." Kim's goal is to design what he calls "robotic first responders" that can cover distances with unprecedented speed and efficiency, capable of maneuvering autonomously past obstacles and performing human-scale tasks. Another of his lab's creations, HERMES, is a two-legged humanoid robot that can be controlled through full-body teleoperation. Such inventions could become essential allies in search-and-rescue missions and other disaster response situations.

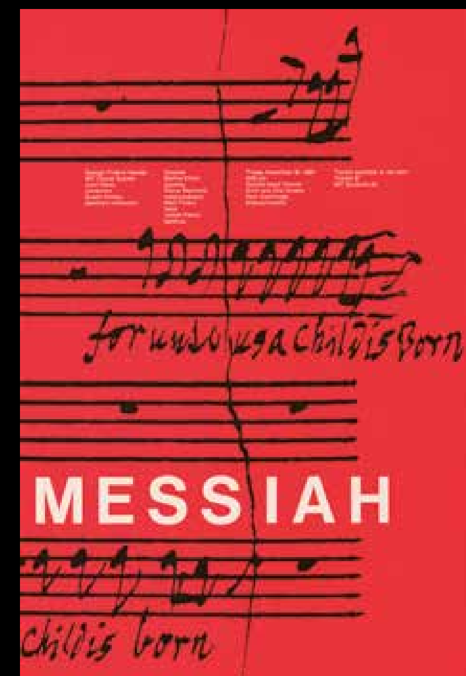
PHOTO: M. SCOTT BRAUER

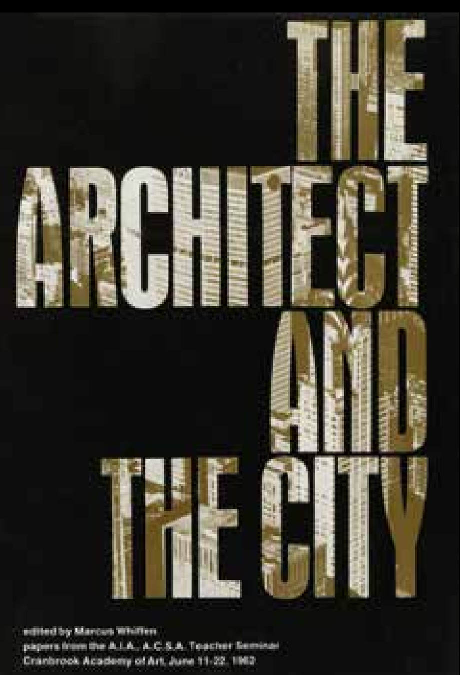
Cooper & Casey at MIT



My job is a constant learning experience. While MIT has its roots in tradition, the University represents all that is experimental, exciting, and future-oriented.

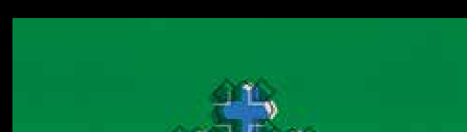
—**JACQUELINE CASEY**

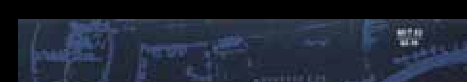


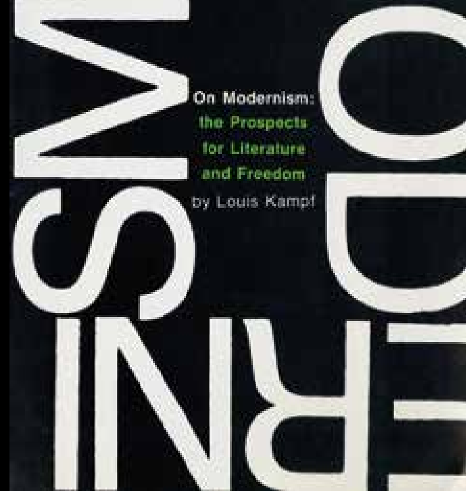


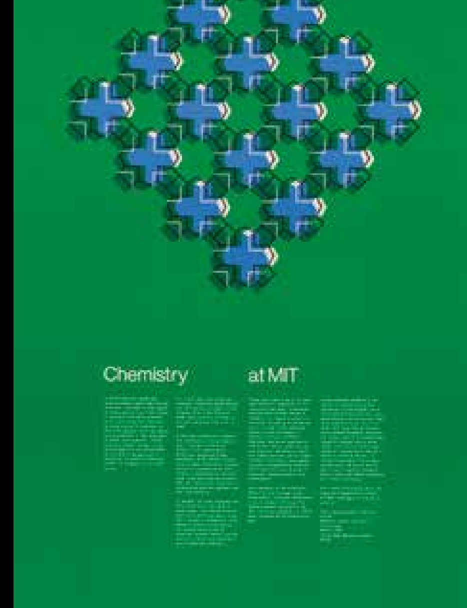
I have a profound disdain for answers... I don't think there are answers. I think there are thoughts.

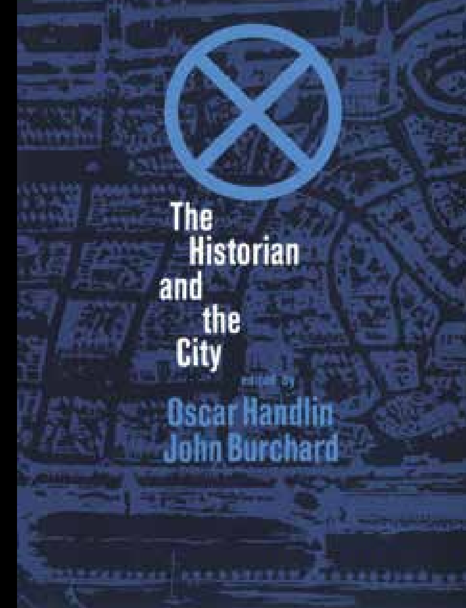
—**MURIEL COOPER**

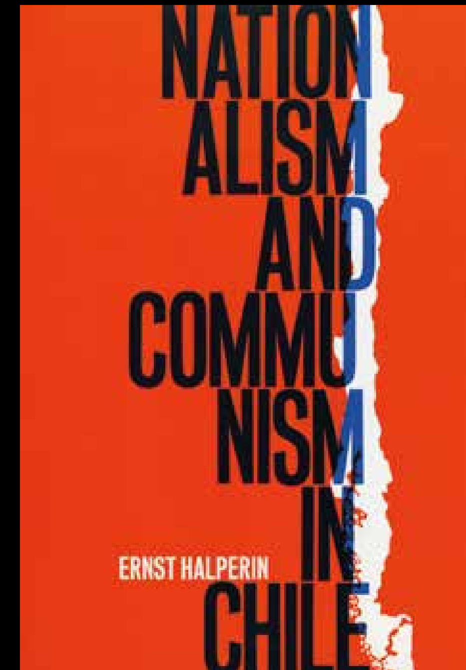












Graphic designers Muriel Cooper and Jacqueline Casey made MIT their creative home and strengthened its visual identity, while elevating design within the Institute's intellectual life. Art school classmates before becoming MIT colleagues in the 1950s, they had much in common: they defied the era's professional gender norms; they influenced countless young designers; and, when both died in the 1990s in their sixties, they left behind extraordinary bodies of work rooted in innovative European design principles. Both arrived at MIT via the Office of Publications (aka Design Services). Casey went on to a long tenure in that office, while Cooper became the MIT Press's first art director. She designed the Press's memorable colophon (see column 4) and some 500 books. In the 1970s, energized by computers' potential to shape graphic communication processes and vice versa, Cooper established the Visual Language Workshop, later a founding group of the MIT Media Lab, with Ron MacNeil '71. Her experiments included an interface immersing users in a 3-D landscape of information. Meanwhile, Casey built a reputation for her striking posters promoting campus arts and academic events. She parlayed Swiss typography and simple graphic elements into designs as playful and brainy as MIT itself, capturing attention with visual puns, puzzles, and metaphors. By engaging viewers' imaginations and endlessly chasing their own, both Casey and Cooper modeled what design could be at MIT: a true act of invention.

All Casey images from the Architecture and Design collections of the MIT Museum.

All Cooper images from the Muriel Cooper Papers, Archives and Special Collections Department, Massachusetts College of Art and Design.

Cooper quote from *I.D. Magazine* (interview by Janet Abrams, 1994). Casey quote from *Top Graphic Design* (F.H.K. Henries, 1983).

COL/1	COL/2	COL/3	COL/4	COL/5
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Above: An assortment of DNA nanoparticle geometries designed by DAEDALUS. Colors represent different classes of geometric objects, including Platonic (blue), Johnson (green), Archimedean (red), Catalan (yellow), and other (purple) complex shapes.

IMAGE: DIGIZYME, INC.

Mark Bathe: The New Shape of DNA

Step into associate professor Mark Bathe's lab in the Department of Biological Engineering and you'll find design and biology merging at the nanoscale. Under an electron microscope you might see a cornucopia of three-dimensional shapes—icosahedra, pyramids, and stars—all assembled from synthetic strands of DNA. "There's no other molecular medium we can design and fabricate with such a versatility of geometries and precision at the nanoscale as DNA," says Bathe '98, SM '01, PhD '04.

And Bathe has added to that versatility: with graduate student Sakul Ratanalert, he recently developed software called DAEDALUS, which captures the complex rules of DNA construction in an algorithm that makes three-dimensional DNA design easier and more accessible to a wide range of scientists and engineers.

Most people think of the spiraling set of nucleic acids purely as the code of life. The strings of As, Ts, Cs, and Gs (adenine, thymine, cytosine, and guanine) in cells provide the blueprint for how living things behave and reproduce. And for nearly half a century bioengineers have creatively manipulated those sequences to change the way organisms function—breeding new pest-resistant plants, for example, or microbes that ferment medicines and chemicals.

But the double helix of DNA also possesses unique characteristics as a nano-building material. In 2006, Caltech researcher Paul Rothemund discovered that if he synthesized DNA letters in specific sequences, the molecular bonds that glue the As to Ts and Cs to Gs, and which come undone when DNA replicates, could be used to fold the DNA into two- and three-dimensional shapes. With a nod to both the precision and elegance of the technique, scientists dubbed it "DNA origami."

The beauty of DNA origami is that once the components are collected, all it takes is a little shake and some Brownian motion—the random movement of particles in fluid—for these shapes to assemble themselves. The system uses a single long strand of DNA as scaffolding on which to stick smaller strings of letters. The DNA conforms to the shape as the letters bond to each other.

But the rules for designing DNA origami are difficult, if not arcane, and lining up nucleotides to fold into corresponding 3-D shapes can tax even the most brilliant minds. "It's been limited to a small group of experts," Bathe says. His software is changing that.

Rather than manually fiddling with sequences of nucleotides, DAEDALUS users design the target geometric structures they want, and the algorithm generates the corresponding nucleotide sequences to make them. "You

The beauty of DNA origami is that once the components are collected, all it takes is a little shake and some Brownian motion for these shapes to assemble themselves.

give the software a high-level geometric shape, and then it will automatically produce that shape using DNA," Bathe says.

In a sense, Bathe himself may be a perfect researcher for exploring how these geometries translate across scales. He's part of an MIT legacy—the son of longtime engineering faculty member Klaus-Jürgen Bathe. Like his father, the younger Bathe earned his PhD in mechanical engineering; but from childhood, his interests skewed towards biology and medicine. "I've always wanted to build technologies that impact human health, more than cars or bridges, like my father," he says. With DAEDALUS, Bathe has built a bridge of another kind, connecting designers of many disciplines with the tools of molecular biology.

Bathe is now working to harness his DNA nanoshapes to deliver drugs inside the body. Taking a cue from viruses that attach to cells to infect them, Bathe hopes to design a variety of DNA structures that deliver payloads of antibodies or even gene-editing enzymes such as Cas9 to diseased cells within the body. "The holy grail would be to edit the brain for treatment of diseases such as autism or schizophrenia, or cancer cells in malignant tumors," Bathe says. —Daniel Grushkin

Maria Yang: The Prototype Moment

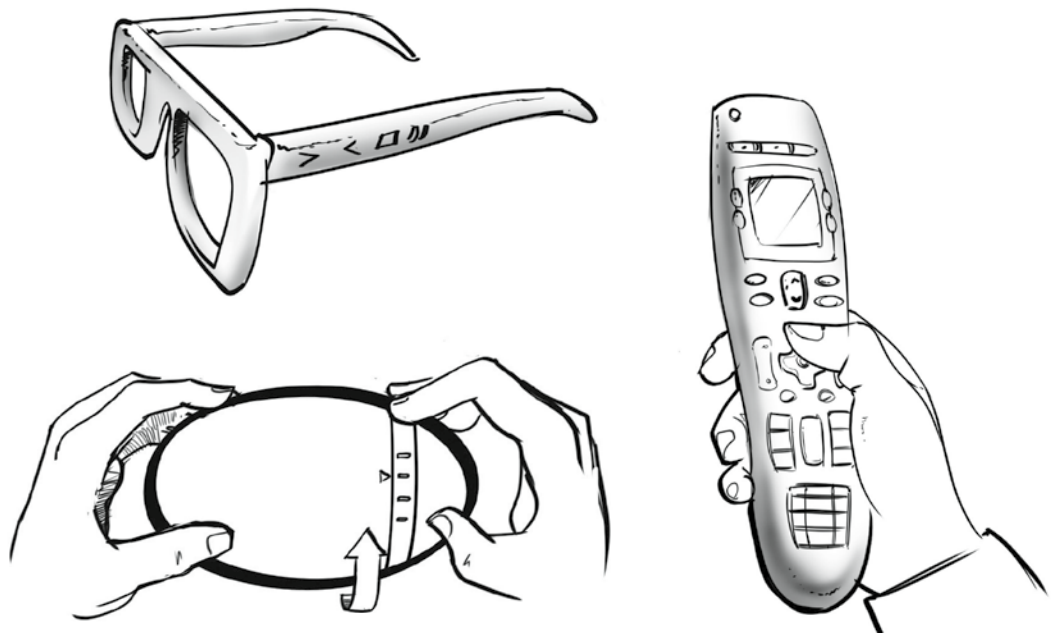
There is a point in the design process where an idea first takes form—where designers move from concept to object, from vague notion to a real volume. If timed correctly, it can be a solid point of departure—a moment when a few small strokes or shades can launch the design and manufacture of products ranging from mobile phones to solar panels to software. If executed prematurely—or too late—it can be a point of no return. This is the point that most interests Maria Yang '91.

"There are literally an infinite number of designs you could create to address a need, and it's not always obvious which are right to pursue," says Yang, associate professor of mechanical engineering. "Designers have to be creative to imagine a space of possible designs, and thoughtfully explore this space. Essential to this process is iteratively making prototypes—a sketch, a foam model, or a 3-D-printed object—and testing them."

Born and raised in West Lafayette, Indiana—her father is also an engineer and college professor—Yang spent her childhood first knitting and crafting, and then, after cajoling her mother to take her to the hardware store, building telegraphs and dismantling transistor radios. During her doctoral studies in mechanical engineering, she took time to work as a designer at Apple, Lockheed Martin, and a startup incubator that helped companies create first-generation prototypes. "I was always torn between engineering and design," she says, "and later, between working as a designer and teaching design."

On the MIT faculty since 2007, Yang teaches introductory and graduate-level product design courses to engineering, business, and industrial design students. "Most of these students fit the classic MIT student profile, with highly developed analytical skills," says Yang. "But they also have a healthy creative quotient that doesn't often get a chance to express itself. Studying product design teaches you to be comfortable with ambiguity. And it teaches you to consider the end user, no matter where you are in the design process. These are incredibly valuable skills to have, particularly for engineers."

At MIT's Ideation Lab, which she founded and directs, Yang leads research on early stage design, and particularly on the role of visual representations and prototypes in that stage. She invites Boston-area designers to the laboratory to participate in controlled studies in which she



Yang's Ideation Lab used a collection of 18 designers' concepts for a remote control, resketched by a single artist, for experiments on user feedback in early stage design.

IMAGES: COURTESY OF THE RESEARCHERS

and her students observe them at work. The research has yielded some surprises, including a strong indication that the early use of digital design tools like CAD (computer-aided design) can in many cases inhibit a designer's creativity. "Technology is powerful, but sometimes it can make you less flexible, especially in the early stages of design," she says. "I find it fascinating that some of our undergraduates still opt to use paper day planners. They say they like being able to flip between pages."

Yang acknowledges that every designer has his or her preferences, priorities, and quirks. Her research aims to identify certain core practices that can benefit all designers. One of those practices is quantity; she believes designers should suspend skepticism and compile a long list of solutions, however improbable. Another is the prototype. "So many of us have this romantic notion about design," she says. "Someone has a great idea and then a team of hardworking engineers somehow makes it happen. The reality is very different. And that reality starts with making something real. That, and coming up with a good idea. Because no matter how good you may be at math or engineering, it's hard to make a bad idea into a good product." —Ken Shulman

"Technology is powerful," says Yang, "but sometimes it can make you less flexible, especially in the early stages of design."

Harrell

Fox Harrell: Models of Identity

Some expressions of bias in software—sexual objectification in video games, bigoted rants on social networks—are all too obvious. Others, unfortunately, are harder to see. *MIT Technology Review* recently reported on implicit sexism in some of the vast word sets engineers use to "train" artificial-intelligence applications—which can lead to objectionable associations in those applications, such as being more likely to connect the word "woman" with "homemaker" than "programmer."

D. Fox Harrell, a tenured associate professor of digital media dually appointed in MIT's Comparative Media Studies Program and Computer Science and Artificial Intelligence Laboratory (CSAIL), detects such invisibly coded-in bias across a range of computational systems, using tools and practices from machine learning, cognitive science, and social criticism. As director of MIT's Imagination, Computation, and Expression Laboratory (ICE Lab), he also invents new types of digital media to help us do better—not only by avoiding negative bias, but by supporting more powerful ways to represent ourselves in computational systems. "I'm interested in figuring out how we can best capture the kind of nuances that are most empowering to users," explains Harrell, author of *Phantasmal Media: An Approach to Imagination, Computation, and Expression* (MIT Press, 2013).

Using frameworks from the Advanced Identity Representation (AIR) Project—an initiative the ICE Lab launched six years ago to develop virtual identity technologies—Harrell has "empirically demonstrated gender and racial discrimination within certain hit mainstream video games," he says. By identifying and quantifying such biases, he hopes to make it easier for developers—himself included—to design games that avoid them, and to produce games that encourage and support social critique. One AIR creation, Chimeria, is a platform implementing "a model of identity that does not just place people in demographic boxes." The system treats the elements of a user's identity (such as visible information in a social-media-style profile, or invisible attributes like a map of what genres of music the user prefers) as dynamically evolving, rather than fixed—which is much closer to how people cognitively categorize in real life.

Most recently, Harrell is collaborating with photojournalist Karim Ben Khelifa on "The Enemy," a virtual- and augmented-reality experience which invites users to empathize with characters on either side of major global conflicts

The ICE Lab's interactive narrative game Mimesis models experiences of microaggression, everyday small acts of discrimination.

IMAGE: © D. FOX HARRELL

By identifying and quantifying biases, Harrell hopes to make it easier for developers—himself included—to design games that avoid them, and to produce games that encourage and support social critique.

(including the Israeli-Palestinian conflict, warfare in east Congo, and gang conflicts in El Salvador). Using Chimeria's approach, Harrell and Khelifa are expanding the expressivity of "The Enemy," enabling the system to sense and respond to users' body language. Harrell is also conducting NSF-supported research on how avatars can help students' ability to learn computer science. "We run public school workshops supporting students from groups currently underrepresented in STEM," he says. "We learned that if people use abstract avatars to represent themselves [while learning], like a dot or geometrical shape, they often do better. We've shown that dynamic avatars we call 'positive likenesses' are even more effective—digital representations that look like you when you're doing well, but then appear as an abstract shape when you're not."

If binary 1s and 0s seem fundamentally ill-equipped to contend with the fuzzy borders of identity, Harrell suggests taking a wider view. "In the 17th century, you could have just as easily asked how one can ever hope to capture the nuances of human experience with 'just oil paint,'" he says. "All technical systems—like computers—are also cultural systems. It's just that some of these systems are very explicit about the values they embody, while in other systems, the values are more implicit. A lot of my work is about trying to extract and make clear what some of those 'hidden' values are."

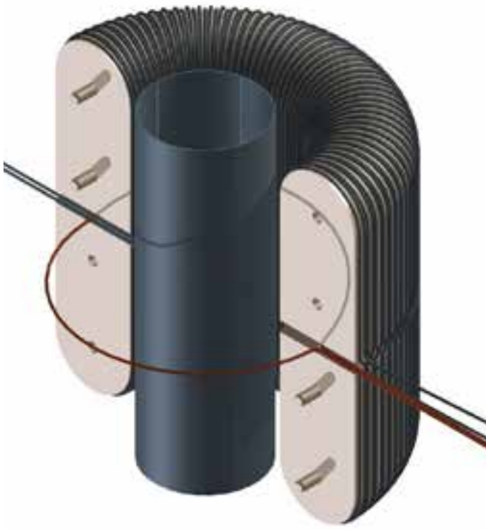
—John Pavlus

Lindley Winslow: Building for the Big If

"The universe presents me with a problem," says Lindley Winslow PhD '08, "and my job is to design the experiment that can address it."

Sounds straightforward enough—except that Winslow, MIT's Jerrold R. Zacharias Career Development Assistant Professor of Physics, is tackling one of the biggest problems our universe has to offer. Once and for all, she and her team want to detect dark matter.

There's regular matter, of course—the stuff that makes up everything from sweaters to iced tea to air (i.e., solids, liquids, and gases). And then there's dark matter, which accounts for just over a quarter of the mass in our universe…but no one's ever seen it or touched it (that's why physicists call it "dark"). We know it has to be out there because its gravitational influence would explain why galaxies and stars move and orbit the way they do. That is to say, the evidence that dark matter is real is only indirect; we're able to observe its influence on the matter we *can* see.



Numerous physicists are working to prove dark matter's existence, using a wide range of methods. For example, Nobel laureate Samuel C.C. Ting, MIT's Thomas Dudley Cabot Professor of Physics, heads up a team analyzing cosmic rays captured by a large particle detector mounted on the International Space Station.

Taking a much different tack, Winslow's experiment to directly detect the dark stuff involves creating a remarkable magnet here on Earth. The brainchild of MIT theoretical physicists Ben Safdi and Jesse Thaler and Princeton's Yonatan Kahn PhD '15, the magnet will be built by coiling hundreds of loops of metal wire into the shape of a doughnut that's several inches across. Winslow will then place it in a special refrigerator, dial down the temperature to near absolute zero, and run a current through the doughnut.

With this arrangement, you'd expect a magnetic field within the doughnut only; "you should have zero magnetic field," explains Winslow, "in the doughnut hole."

Which means that if—and this is a big if—Winslow and her colleagues are able to measure a magnetic field in that hole, something else must be creating it. The job facing her team, which also includes MIT professors Janet Conrad, Joseph Formaggio, and Kerstin Perez, would then be to prove the "something else" is due to dark matter. The experiment, which goes by the acronym ABRACADABRA (seriously), is no simple feat. The design challenge most worrying Winslow is how to keep her doughnut perfectly still. "How do we isolate this magnet," she asks, "from things like construction of the new building next door? These are very precise experiments where small vibrations can lead to effects that you don't expect."

Winslow says the process behind making a magnet to such exacting specifications relies on trying something smart, and then, when it fails (which it inevitably will), looking to see what went wrong, revising it, and trying something smarter. "We'll build version one, and we'll have to iterate that design again and again." But Winslow admits that sometimes you hit a roadblock you just can't maneuver around, which means "you have to completely scrap the design you're working on and try a different approach."

With the setup so delicate, the reasons for failure so abundant, and her dark target so elusive, Winslow's experiment is no slam-dunk. But there are likely to be big payoffs along the way. For instance, by making "one of the strongest and most precisely known magnetic fields ever built," Winslow expects the project could improve MRI technology. Of course, she's not in this for the MRIs. Rather, Lindley Winslow is in this to cast the bright light—of a magnet pulsing with current, of iterative trial-and-error design, of sheer human ingenuity—on dark matter, that invisible something. —Ari Daniel PhD '08

Winslow's experiment to directly detect dark matter involves creating a remarkable magnet by coiling hundreds of loops of metal wire into the shape of a doughnut.

A cross-section of the proposed design for the ABRACADABRA magnet.

IMAGE: DANIEL WINKLEHNER

Wide-Open Spaces

Want creative thinkers? Help kids create, says Mitch Resnick

The Lifelong Kindergarten group at the MIT Media Lab, led by Mitchel Resnick SM '88, PhD '92, is known for its educational innovations: the Computer Clubhouse Network, an after-school environment where kids from underserved communities learn to express themselves creatively with new technologies; a 30-year collaboration with the LEGO company begun by Resnick's mentor, the late MIT professor Seymour Papert, which yielded the robotics kits branded as LEGO Mindstorms; and Scratch, a visual programming language and online community where kids construct and collaborate on interactive stories, games, and animations. Driving all the group's endeavors is a fervent belief in the power of learning through design. Resnick will expand on these ideas in a forthcoming book for the MIT Press titled *Lifelong Kindergarten: Cultivating Creativity Through Projects, Passion, Peers, and Play.*

—Nicole Estvanik Taylor

How do you describe your group's design-oriented approach to learning?

MR: The best learning happens when people are designing meaningful projects that build on their passions in a playful spirit—starting with an idea, making a prototype, getting feedback, iterating, experimenting. There's something special about making and creating things. A former MIT professor, Don Schön, famously talked about design as "a conversation with materials." When you create something based on your ideas, that gives you new ideas.

PHOTO: SAM OGDEN

What is the difference, educationally speaking, between a kid building what's on the LEGO box, versus making whatever's in his or her imagination?

MR: Too often, kids are led into situations where there's one correct solution and one path for getting there, and that's not a very good foundation for developing as a creative thinker. But a blank slate can also be intimidating. We're always trying to provide kids with opportunities to decide on their own goals and pathways, but also enough structure to help them succeed. For example, we currently have a National Science Foundation grant to develop what we call microworlds—a hip-hop dance microworld, for example—with collections of Scratch programming blocks well-designed for creating a particular type of project. This is based on an idea from Seymour Papert about simplified, constrained worlds that still have flexibility within them. Design always has constraints, but we don't want it to be a straightjacket.

What is Lifelong Kindergarten's main focus now?

MR: The Computer Clubhouses started almost 25 years ago in Boston and now there are about 100 of them around the world. We still act as advisors and try out new ideas there. And we're still actively collaborating with the LEGO company, exploring how kids learn through play. Right now, though, our group is most focused on supporting the rapid growth of Scratch.

Every month there are more than 10 million unique visitors to the Scratch website, half of whom are from outside the United States, and every day 20,000 new projects are shared in the Scratch online community. It keeps us busy. We're constantly adding new features and possibilities—developing a mobile version of Scratch, localizing Scratch to fit the needs and interests of kids from different parts of the world, and connecting Scratch to the physical world with robotics and sensors.

That raises an interesting point. Scratch and LEGO both involve designing and building, but one output is virtual and one is tangible. How does that change the learning experience?

MR: I don't think virtual versus physical is the most important issue. I'm more focused on whether the child is in charge of the design process. If I go to a toy store and see a dinosaur that dances when you sing to it, I figure the designers at the toy company must have learned a lot creating that toy, but I'm not so sure the kids are learning a lot by interacting with it. Similarly, online, some kids might be playing pre-packaged games, while other kids are creating their own stories, games, animations. Kids will have the richest learning experience when they're the ones doing the designing. It matters less what the medium is. Ideally, we want to provide kids with opportunities to design in different media and contexts; that way, they'll get a deeper understanding of the design process.

A student and mentor confer at MIT's Scratch Day, an annual event gathering kids and adults on campus to share projects and learn from one another.

PHOTO: KELLY LORENZ

Plural Urbanism

In his 2012 book Design After Decline, *Brent D. Ryan, an associate professor in MIT's Department of Urban Studies and Planning, called for new design approaches in deindustrialized cities struggling to rebuild. Ryan expands his urban design thinking to propose a worldwide theory of "plural urbanism" in* The Largest Art *(forthcoming from the MIT Press), from which this excerpt is taken.*

In a 2006 essay, "The End(s) of Urban Design," architectural critic Michael Sorkin declared that the discipline of urban design was at a "dead end." [...] Sorkin depicted urban design not only as intellectually bankrupt, but also as shamefully unable to confront the urgent problems of the day.

The decade or so since Sorkin wrote his essay has been one of turmoil, at least superficially, in the urban design discipline. Events like continued urbanization and the world's warming climate pose challenges for urban designers in tandem with other professions. But within the discipline itself, the fundamental dilemma posed by Sorkin, of a discipline unable to reconcile "theoretical debate" with "human needs," has remained unresolved. The "end(s)" of urban design remain where they were 10 years ago.

The Largest Art provides a new theoretical and practical understanding of urban design. It does so by reexamining the discipline's relationship to urban space and urban populations and by reframing urban design as a "building art" that accepts those elements of cities that are beyond designers' direct control—other buildings, other owners, other actors—and that then incorporates these elements into urban design. By incorporating the city's plural elements—those many elements imagined for more than a single design or by a single designer—urban design becomes a plural art that is more powerful and wide-ranging, more influential and beneficial, even as it becomes more democratic, participatory, open-ended, and infinite. Understanding urban design as a plural art may sound utopian, but it is actually the opposite—it is eminently practical. [...]

Many theorists and practitioners have recognized elements of urban design's plural nature in the past. Famed urbanist Jane Jacobs identified urban design's plural qualities when she called for redevelopment to reconcile "life with art," as did MIT professor Kevin Lynch when he spoke of "city design" instead of urban design. [...] Ultimately this book may be understood as a manifesto, a call for urban design's true plural nature to be understood and acknowledged, and for urban design's independence from other building arts, particularly architecture, to be recognized once and for all. In doing so, this book moves urban design past its "ends" and reopens the door for an urban future in which design can encompass all cities.

PHOTO: CASEY ATKINS

Designing with (Not Just for) Communities

For nearly a decade, a program with roots at MIT D-Lab has been empowering communities around the world to create and implement practical solutions to the problems they face.

The brainchild of MIT senior lecturer and D-Lab founder Amy Smith '84, ENG '95, SM '95, the first International Development Design Summit (IDDS) was held on MIT's campus in 2007. Its goal: to teach a diverse gathering of students, carpenters, mechanics, doctors, and other aspiring makers how to develop lasting, localized solutions for people living in poverty, in close collaboration with members of the communities they aimed to help. When the month-long conference ended, participants returned home to continue work on their projects.

The program has since blossomed into a global consortium of thinkers and doers, formalized in 2012 as the International Development Innovation Network (IDIN) through a grant from the US Agency for International Development. Comprised of 12 international partners and headquartered at D-Lab, IDIN provides year-round support to summit participants as they continue developing prototypes and products and launching their own social ventures.

To date, there are more than 800 IDIN network members making an impact in 65 countries around the world. Thanks to just a few of the 100-plus projects developed through IDIN, women in India have access to safer birthing techniques and reproductive care; low-income communities in Brazil have tools to help them save money and achieve their financial goals; and farmers in Tanzania are producing high-quality avocado oil from excess crops that would otherwise go to waste.

Nearly two-thirds of IDIN network members go on to teach others what they have learned about co-creation. After attending IDDS, Johana Sanabria left her career in industrial wastewater treatment to help start an IDIN-supported innovation center in her native Colombia. Its mission includes community design education. "In many of our workshops, it's the first time for a student to think that way," she explained in a recent interview. "That we can create something that we think is useful, but if it's not affordable to someone else, then it's not actually useful." She added, "Working to open C-Innova helped me find my passion for working with the community...to help them leverage the resources they have, and build solutions with them, side-by-side." —Stephanie Eich

An industrial design student and a community member in Huite, Guatemala, use a corn sheller.

PHOTO: COURTESY OF MIT D-LAB

FULLY INVESTED

PHOTO: Joe Pugliese/August Image, LLC

From fighting cancer to promoting stability, Andrew Lo harnesses the tools and technologies of finance for the common good

A few years ago, while preparing to participate in a roundtable conference on finance, Andrew Lo happened upon the website of the American Psychological Association. "Their mission statement focuses on applying their knowledge of psychology for the benefit of society," says Lo, financial economist, hedge fund manager, and the Charles E. and Susan T. Harris Professor at the MIT Sloan School of Management. "Reflexively, I compared it to the mission statement for the American Finance Association, which simply focuses on what we do and how we do it. It was quite a contrast. And I began to reflect, as a financial economist, on what our true mandate was."

Lo has spent the better part of his professional life exploring that mandate. He is best known for his Adaptive Markets Hypothesis—a theory that incorporates human behavior, emotion, and even Darwinian evolution to better understand financial markets and assist investors in making constructive choices. Much of his research is aimed at mediating the impact of technology, global markets, and conflicting human emotions in an effort to make the world's financial infrastructure more shock resistant: building safeguards that can avoid or mute the effects of computer-driven "flash-crashes"; drafting viable and effective regulations for an increasingly complex and technology-driven global financial infrastructure; and developing algorithms that can predict and ultimately help curb irrational and potentially damaging investment decisions.

But Lo's boldest proposal to date may be his bid to help fight cancer. In 2012, he and his research collaborators launched the idea of a megafund that would use collateralized debt instruments to help bring life-saving cancer therapies to market swiftly and safely. On the business end, it was the type of proposal one might expect from a finance professional who oversees some $7 billion—the amount Lo manages in a series of mutual funds and managed accounts at AlphaSimplex Group, where he is chairman and chief investment strategist. What was novel was his analysis—and remedy—for the roadblocks that keep vital cancer therapies from reaching patients in timely fashion.

"The drug development and approval process is increasingly challenging," says Lo, who has lost several friends, colleagues, and family members, including his mother, to cancer. "The average cancer drug costs $200 million to develop, takes 10 years, and has only a 1 in 20 chance of being approved. Even if approval means large profits, the odds are just too risky for most investors."

Troubled as he was by Big Pharma's slow incubation periods and low success rate, Lo was even more disturbed to discover that many drug development decisions were driven by financial considerations, and not by science or patient need. "As the son of a

An Incubator for Ambitious Innovation

Entrepreneurs with truly big ideas need a new kind of machine to accelerate them. That's the premise of The Engine, an MIT enterprise announced in October that provides "patient capital," space in Cambridge, and an array of resources to startups devoted to transformative scientific and technological innovation.

The Engine is designed to meet an underserved need. Some of the most visionary ideas for new companies—particularly in such sectors as biotech, robotics, manufacturing, medical devices, and energy—have difficulty finding the stable support and resources their pursuit requires. As President Reif wrote in a *Boston Globe* editorial: "Our society's current system for funding and commercializing new ideas—so effective with relatively quick-to-market digital products—leaves many 'tough technology' solutions permanently stranded. In that context, we see an exciting opportunity to advance MIT's mission by investing in a new model of startup support that nurtures such high-impact ideas and speeds them into the world while helping our regional innovation ecosystem flourish and grow through a self-sustaining cycle of success."

Along with financial support through its venture-investing arm, The Engine will provide selected startups with affordable space in the Central and Kendall Square neighborhoods, access to specialized equipment and business services, and a network of fellow entrepreneurs and established companies that want to support them. "We want highly disruptive entrepreneurs to stay in Greater Boston," MIT Executive Vice President and Treasurer Israel Ruiz SM '01 said in the MIT News announcement of The Engine's launch, which he has led. "This is where the boldest ideas in the world should find their home."

"The Engine builds on work MIT has undertaken in recent years to stoke innovation on and near our campus—including starting up the MIT Innovation Initiative in 2014," MIT Provost Martin Schmidt SM '83, PhD '88, told MIT News. "Our faculty, alumni, and student entrepreneurs directly serve the Institute's mission of using science and technology to make a better world, because the problems they pursue tend to be the hardest ones they can find."

The Engine plans to open its Central Square headquarters in the spring. "We've received very strong interest from startups, investors, and established companies within Greater Boston's innovation ecosystem," says Ruiz. "There is a feeling of electricity in this community."

cancer patient, I was outraged," he says. "But I understood that a basic financing problem needed to be solved. Investors don't like risk, whereas truly innovative therapies are usually very risky investments. You tend to strike out more often when you're swinging for the fences."

Lo's solution to the drug-development riddle involves a pooling of risk, clever debt structuring, and, most importantly, enlightened leadership to ensure that drug development choices are dictated by patient need, and not just by investor greed. "As a financial economist, I'm not qualified to lead this effort," says Lo. "A cancer patient needs a financial economist like a fish needs a 401(k) plan."

Lo's bold idea has since been explored in a series of "CanceRx" conferences at MIT. The blueprint calls for investors in the cancer megafund to purchase debt securities—the majority being long-term bonds, along with a smattering of derivative instruments. The capital would then be channeled into a pool of promising cancer research projects selected by a multidisciplinary team, including physicians, researchers, biopharma experts, and financial engineers. "If there are 150 statistically independent projects in your pool, your chances of picking at least three winners is 98 percent," he explains. "This is a very low-risk investment that can offer investors an attractive rate of return. More importantly, it's a formula that will create a fast lane for the some of most transformative treatments for cancer patients."

The Power of Financial Engineering

The concept of using megafunds to spread the financial risk of costly and innovative research also holds potential, Lo believes, in myriad fields including manufacturing, energy, and even in confronting climate change. "We definitely need a new financial model to help finance longshots," he says. "MIT recently announced a breakthrough in nuclear fusion. We'll probably need another 10 years and about $5 to $10 billion in additional investments. We could use these new financing methods to reach the goal of the 'gift of Prometheus'—bringing the power of the sun to the Earth."

Lo's range of activity stretches well beyond socially beneficial investment vehicles. As director of MIT's Laboratory for Financial Engineering, Lo conducts research in two fundamental elements of contemporary finance: the explosion of technologies and instruments that have transformed the way money is measured and moved; and the idiosyncrasies of human behavior that dictate our often-irrational financial decisions. Technology, Lo notes, now enables automating trading programs to execute millions and millions of trades per day. This high-frequency trading—which is estimated to account for 50% of all global trading activity—provides investors with the liquidity they need in a financial universe where shares can be exchanged in a matter of milliseconds. Yet the rapid proliferation of trading tools, automation, and sophisticated financial instruments has also left the entire system more vulnerable than ever to wild fluctuations and potentially catastrophic crashes.

> Lo conducts research in two fundamental elements of contemporary finance: the explosion of technologies and instruments that have transformed the way money is measured and moved; and the idiosyncrasies of human behavior that dictate our often-irrational financial decisions.

"Our global financial system has become so complex that no one individual is capable of conceptualizing it," says Lo. "And this is frightening. But it also presents us with an opportunity to come up with a series of measures to assess systemic risk and to minimize or prevent it. There is no single measure that will tell us everything we need to know. But by bringing together all relevant stakeholders and developing multiple systemic risk measures, we can draft a series of regulations based on those measures that do the greatest good for the greatest number of people."

While Lo believes that financial technologies need human oversight to be most effective, he also thinks that humans—in this case individual investors—could benefit from a little bit of cyber-shepherding. Too many investors, he observes, sell assets during moments of panic, only to regret not having stayed the course. Lo believes the industry can engineer a series of algorithms that can help investors better assess their long-term goals, their true tolerance for risk, and even communicate with them in moments when emotion might cloud their better judgment. Imagine a robo-call from your investment advisor telling you to sit tight during a sharp market dip.

"The science of human emotion is much more evolved than it was 10 years ago," he says. "Neuroscientists are now beginning to map the biological basis for decision making and emotion. Once we understand these things better, we can come up with algorithms that can recognize the circumstances when you as an investor might be contemplating a rash decision, and call or text you to help you keep steady."

Technology, Lo believes, is a two-edged sword; it's up to us to ensure it's used and not abused. The same goes for emotion, particularly in finance. "The emotion of greed, for example, can be good," he says. "But only if it's properly channeled and managed. Left to its own devices, greed can be incredibly destructive. The same is true for powerful technologies. I believe we, as financial economists, have the means and the responsibility to help people apply technologies and manage our emotions wisely, to their own benefit and to the benefit of society. This, if anything, should be our mission statement. We can do well by doing good, and finance doesn't have to be a zero-sum game if we don't allow it."

—Ken Shulman

Surfacing Solutions

In search of materials equal to the needs of a sustainable energy future

Yildiz's work to understand and tailor surface chemistry sets the stage for a new generation of high-efficiency devices in both energy conversion and information processing.

For Bilge Yildiz, associate professor of nuclear science and engineering, and associate professor of materials science and engineering, unleashing novel properties in materials means taking a penetrating look at surfaces. Her work to understand and tailor surface chemistry sets the stage for a new generation of high-efficiency devices in both energy conversion and information processing.

"Much of what we do is basic science. We focus on fundamental problems related to surface behavior of materials in important technologies," says Yildiz. "We are always motivated by improvements and new applications we can see coming out of the work."

Since she joined the MIT faculty in 2007, Yildiz's lab has produced a stream of notable discoveries. She points to one area of long-standing interest: designing surfaces for oxides that put these materials into play as active materials in highly efficient and durable fuel cells, electrolyzers, and thermochemical fuel synthesis.

The surfaces of these reactive oxides are important for the functionality of the material in thermochemical and electrochemical energy conversion. For example, these oxides are used for reducing oxygen and oxidizing hydrogen while producing electricity in solid oxide fuel cells, or for thermochemically splitting water and CO_2 for conversion to synthetic liquid fuels.

Above: Yildiz uses an array of tools in her research, including scanning tunneling microscopy, X-ray photoelectron spectroscopy, and low-energy electron diffraction.

PHOTO: BRYCE VICKMARK

But they also degrade in the presence of high temperatures and reactive gases. "If the surfaces are not ideal, more energy is required to drive reactions, making the process more costly," Yildiz says. Yildiz's research revealed that the surface forms an insulating layer. She got to the bottom of the problem: oxygen vacancies at the surface—a type of defect in the atomic lattice of an oxide—create an imbalance in charge and drive a chemical segregation at the surface. Based on that insight, she figured out a fix: "doping" the surface with metal cation additives that rebalance the surface charge. Ultimately, the approach could stabilize the material, and significantly reduce energy losses in surface reactions.

Her treated oxide surfaces are promising for making solid-oxide fuel cells and electrolyzers that are both more durable and substantially more efficient than the currently available devices. Although practical application is years away, Yildiz envisions installations of units slightly larger than air conditioning compressors "providing for all the electrical needs of a home."

Drawing on advanced experimental and computational tools, in part of her own invention, Yildiz can probe and manipulate materials at the nanoscale. This has yielded a wealth of recent insights. For instance, she has discovered that nanoscale oxide thin films under mechanical strain could serve as conductivity and reactivity modulators in miniaturized fuel cells, which might one day replace lithium-ion batteries in mobile devices. Yildiz is also experimenting with using electric fields on thin films to serve as the brains for a new kind of digital memory circuitry. "These devices function at high electrochemical potentials at room temperature, and scale down in theory to the few-nanometer regime," says Yildiz. "Because they switch state with very low voltages, they will also reduce energy consumption."

Yildiz got her start as an undergraduate in Turkey studying nuclear energy. Today, her research also paves the way toward more durable materials for reactors, and could enhance other existing energy technologies as well, such as fossil fuel plants and offshore wind turbines facing the dual insults of salt and cold. "My dream outcome, together with colleagues at MIT, is to find materials that are corrosion- and hydrogen- and radiation-resistant, with good heat transfer properties, and that are safe," she says.

Yildiz has a new home for her wide-ranging ambitions: the Center for Materials in Energy and Extreme Environments, one of the MIT Energy Initiative's eight Low-Carbon Energy Centers announced in 2015 as part of MIT's Plan for Action on Climate Change (see page 31). Yildiz co-directs the center with Ju Li PhD '00, professor of materials science and engineering.

"We want to provide industry with materials that enable new, clean energy technologies, like fuel cells, and that improve the performance and reduce the CO_2 footprint of existing energy technologies," Yildiz says. "The center brings together faculty, postdocs, and students motivated by energy questions, allowing us to pursue big problems and keep pushing boundaries forward." —Leda Zimmerman

Hot Shots

Two MIT postdocs deliver a disruptive rapid vaccine development platform

Dashing across campus in the pouring rain, Jasdave Chahal had a small cardboard box tucked under his jacket. Inside the box, wrapped in Styrofoam and packed in dry ice, were vials of RNA Chahal had painstakingly produced at the Whitehead Institute. He was en route to the Koch Institute for Integrative Cancer Research, where his friend Omar Khan was waiting. The two were testing an idea for creating synthetic viruses using special self-replicating RNA. To start, the vials contained RNA that coded for a bioluminescent protein. Their plan: to inject nanopackets containing that RNA into the leg muscles of mice to see if they would glow.

Nearly two years have passed since that rainy-day street crossing and first experiment, but the memory remains vivid for a simple reason: "It worked," says Khan. "So well that Jas said, 'We can do big things with this. We can do vaccinations.'"

Khan and Chahal, now both Koch Institute postdocs in the lab of Professor Daniel G. Anderson, have since turned their idea—a collaboration done in their spare time—into a platform for the rapid development of injection-ready vaccines. By rapid, think 7 to 10 days. They have already collaborated with the US Army to develop and test an Ebola vaccine, and they've developed vaccines against influenza and a parasite related to malaria that causes toxoplasmosis. All of these vaccines were 100% effective in mice. Now they are pursuing applications in immunotherapy and prophylactic vaccines for cancer, in collaboration with David H. Koch Professor Tyler Jacks's lab and Dana-Farber Cancer Institute.

"Our goal," says Chahal, "is to get the vaccines to people."

So Chahal and Khan worked with the MIT Technology Licensing Office to patent their technology. They are founding, along with their professors, a company called Tiba Biotech with plans to move the vaccines they are developing for diseases such as Zika and Ebola towards clinical trials in humans.

"We came into this field as non-experts with a completely different take on things," says Khan. "It's fun to take this big step and grow with the technology and the company."

Chahal and Khan may be non-experts in traditional vaccine development, but they are experts in their respective fields. Chahal, a virologist who came to MIT as a postdoc in the immunology lab of Hidde Ploegh, biology professor and Whitehead faculty member, has an eye for understanding viral proteins and a knack for synthesizing RNA instructions for building those proteins. "He's got all these tricks and techniques," says Khan. "It's not trivial."

And Khan's training made him a perfect complement. He'd come to MIT to develop nanotechnology that would hijack a cell and coax it to grow new tissues. This expertise was just what Chahal needed for delivering his self-replicating RNA into cells—a first step toward having the cell safely express viral proteins that would, in turn, trigger an immune response.

Prior to meeting Khan, Chahal had tried a range of commercial products for delivering his RNA into cells. None worked. "I'd had my heart broken a couple of times," says Chahal.

But those disappointments were an asset when a mutual friend introduced him to Khan. "Based on what hadn't worked, I was able to deduce the modes of failure," says Khan. "I used the clues to create design criteria and invent the missing enabling technology."

Both Chahal and Khan want the public to benefit from their technology, so they decided to commercialize it. But neither had any idea how to start a company. So they joined MIT's Innovation Corps and the Venture Mentoring Service. These services helped them develop a business plan and connected them with mentors. "These are freely available MIT programs designed to train people just like us to take the next step so we can be effective not only on the science but also in managing our company," says Khan.

The long-term plan for Tiba, which means "to heal" in Swahili, is to deliver effective and inexpensive vaccines to the developing world. "We're both sort of ethnically ambiguous and have ties to the developing world," says Khan. "We wanted a word that would encompass all humanity and all healing. Tiba was a good fit."

—Elizabeth Dougherty

Khan, left, and Chahal: "We can do big things with this."

PHOTO: M. SCOTT BRAUER

The long-term plan for Tiba is to deliver effective and inexpensive vaccines to the developing world.

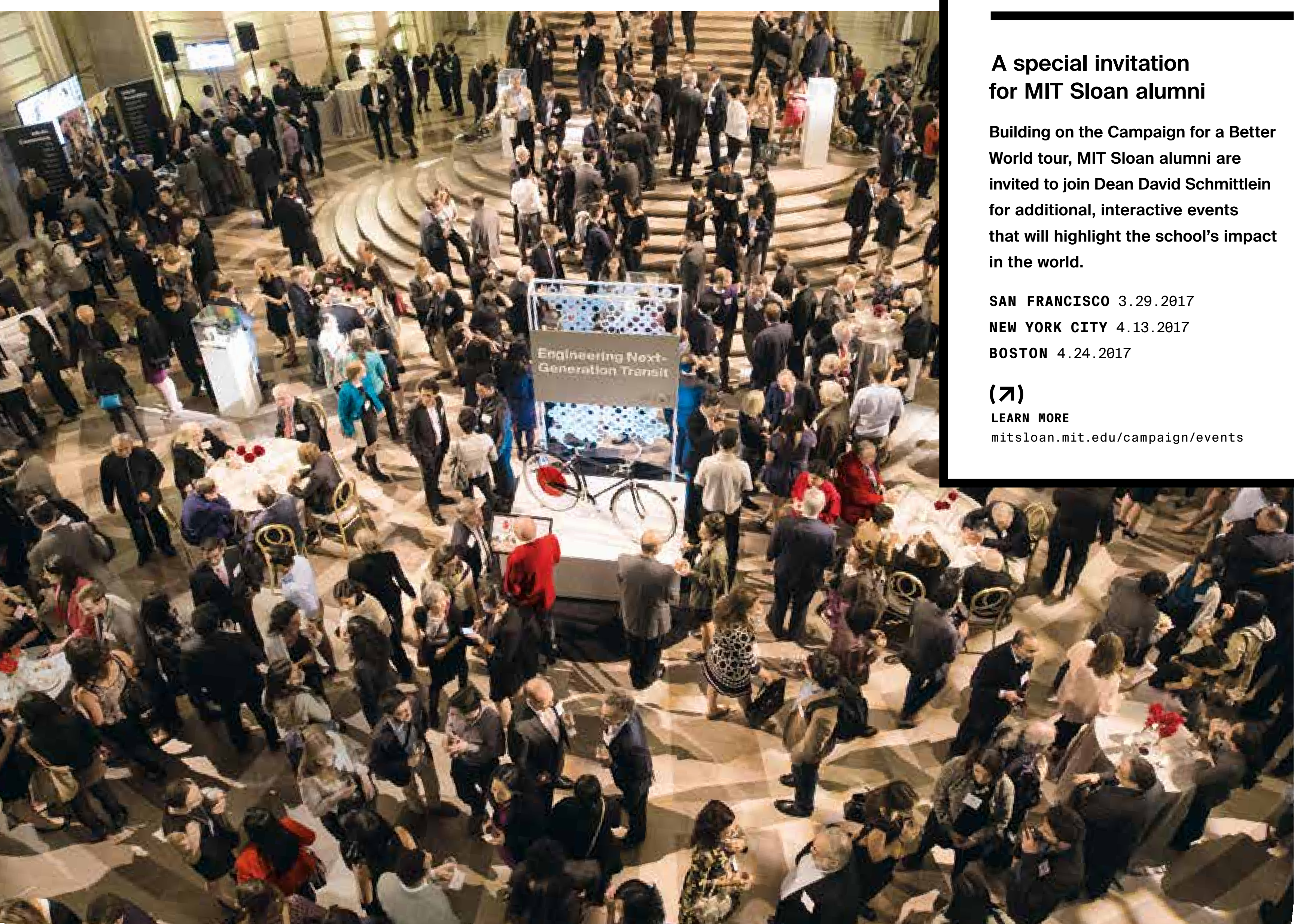
The Better World Tour Continues

MIT ( ) CAMPAIGN FOR A BETTER WORLD

In October, more than 600 alumni and friends of MIT gathered in New York City to hear President L. Rafael Reif share his vision for the future of MIT, quickly followed by a November event in San Francisco that attracted an even larger assembly of 800. MIT's mission, Reif told both crowds, "insists that we bring knowledge to bear on the world's great challenges. Many of you here tonight are leaders in living out this mission. And today, as humanity faces profound challenges and opportunities, I believe that research universities also need to be leaders. Leaders in education, leaders in research—and above all, leaders in solving problems, to make a better world."

These were the first two in a series of regional events celebrating MIT's capacity for such leadership, thanks in great part to its vibrant global community. Segments of that community have since gathered in Hong Kong, London, Tel Aviv, and Los Angeles in support of the MIT Campaign for a Better World—an ambitious fundraising effort to advance MIT's ability to address some of the world's greatest challenges. Already in this Campaign, the MIT community has come together to raise more than $3 billion through 80,000 individual gifts.

Attendees at Better World events have not only heard from President Reif but from faculty, students, and local alumni sharing their own world-changing endeavors: from pursuing a treatment for Alzheimer's, to defining a lab-to-market path for "tough technology" breakthroughs, to inventing the farming of the future. The gatherings are a celebration of what the MIT community has already achieved, and a reminder of the indispensable role every member will play in meeting the bold goals of the Campaign for a Better World.



More than 800 members of the MIT community gathered on November 2 at San Francisco's City Hall.

PHOTO: DONALD NORRIS

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Year Two: MIT's Climate Action Plan

Last summer brought a glimmer of hope in the ongoing buzz of concern over Earth's climate. Scientists at MIT and elsewhere announced they had identified the "first fingerprints of healing" of the Antarctic ozone layer. Led by Susan Solomon, MIT's Ellen Swallow Richards Professor of Atmospheric Chemistry and Climate Science, the team compared ozone hole measurements from 15 consecutive Septembers, and found that the hole has shrunk by more than 4 million square kilometers since 2000. The researchers attributed at least half of this recovery to the decline of atmospheric chlorine originating from chlorofluorocarbons (CFCs), a onetime byproduct of aerosol sprays and other consumer products that was widely banned in 1989 when numerous countries signed the Montreal Protocol. In the words of Solomon—who was the first to characterize the conditions under which chlorine depletes ozone, and whose work spurred that historic agreement, "Science was helpful in showing the path, diplomats and countries and industry were incredibly able in charting a pathway out of these molecules, and now we've actually seen the planet starting to get better."

However, there are countless steps still to be taken toward our planet's health. That's why MIT's Plan for Action on Climate Change, released in October 2015, remains more urgent than ever in year two of its five-year scope. The plan positions MIT to play a critical leadership role in the fight against climate change. Its stated goal: "to minimize emission of carbon dioxide, methane, and other global warming agents into the atmosphere, and to devise pathways for adaptation to climate change, through the active involvement of the MIT community, proactively engaged with industry, government, academia, foundations, philanthropists, and the public."

In October 2016, Vice President for Research Maria Zuber, who oversees the plan's implementation, released a report outlining its progress within five pillars:

- improving understanding of climate change and advancing novel, targeted mitigation and adaptation solutions;
- accelerating progress toward low- and zero-carbon energy technologies;
- educating a new generation of climate, energy, and environmental innovators;
- sharing knowledge about climate change, and learning from others around the world;
- using the MIT community as a test bed for change.

According to Zuber's 2016 report, outcomes of year one include new rounds of research grants from MIT's Environmental Solutions Initiative, which is also developing a student minor in environment and sustainability; a new Climate Action Advisory Committee that includes several students and other members of the broader MIT community; and the creation of eight Low-Carbon Energy Centers within the MIT Energy Initiative, each of which is focused on a key technology area for addressing climate change (see page 28). The centers are actively engaging with industry: companies including Exelon and GE have committed to supporting research through the centers as members.

Following conversations with the student group Fossil Free MIT, Zuber recently noted that a 32% reduction in carbon emissions on campus is a minimum goal, and that the campus will strive to be carbon neutral. According to Office of Sustainability director Julie Newman, carbon reduction is a major consideration in all new campus projects. "It's becoming integrated into the decision process," she recently told MIT News. "I don't think I've seen a campus move so quickly to incorporate changes."

(↗)
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IMAGE: NASA

A Bright New Beginning for the Samuel Tak Lee Building

At the start of the academic year, the Department of Urban Studies and Planning (DUSP) and the Center for Real Estate (CRE) gathered to celebrate the result of extensive renovations to the Samuel Tak Lee Building (Building 9). The rejuvenated 1967 building, now boasting 21,000 square feet of bright new classrooms, offices, and workshops, has brought together everything to do with urban development and real estate under one roof. In the words of Eran Ben-Joseph, faculty head of DUSP: "We used to have a department that resembled urban sprawl, with groups scattered all around. Now we have one that finally feels like a downtown."

A historic 2015 gift from alumnus and global real estate developer Samuel Tak Lee '62, SM '64, presented the Institute with an opportunity to refurbish the 1967 building's outdated infrastructure and configuration. In addition to major overhauls to the HVAC system, windows, and accessibility, improvements include replacing dark classrooms with learning spaces filled with natural light, and common spaces, such as a west-facing counter with stools that students have dubbed the "sunset bar." There's also a new multimedia-enhanced open space called the City Arena, designed to facilitate interaction with participants in cities across the globe.

Lee's gift also established within the building a lab bearing his name dedicated to socially responsible real estate entrepreneurship, with a particular focus on China. The Samuel Tak Lee MIT Real Estate Entrepreneurship Lab (STL Lab), in conjunction with CRE and DUSP, recently announced its second round of faculty research grants, awarding $1.1 million to nine MIT researchers and their teams. STL Lab grants are supporting such projects as Urban-Scale Social Responsibility in China: Behavioral Perspectives in Real Estate and Transportation, under principal investigator Jinhua Zhao MCP '04, SM '04, PhD '09, the Edward H. and Joyce Linde Assistant Professor of City and Transportation Planning; and Rebuilding the Social Compact: Urban Service Delivery and Property Taxes in Pakistan, led by economics professor Benjamin Olken.

Extensive renovations to the Samuel Tak Lee Building in summer 2016 created open, welcoming spaces for learning and collaboration.

PHOTO: JUSTIN KNIGHT

PHOTO: GREG KAHN

DAVID ’77 AND LUCIA BACON

Formative Research

“Those who read by lamps’ late-night glow, teach themselves only what other people know.”

This aphorism, from Danish scientist and thinker Piet Hein, has stuck with Dr. David Bacon ’77 for 50 years and explains why research is a basic necessity for moving forward. Instead of studying what other people have already discovered, Bacon prefers to “push the envelope and see what else might exist in the world through original research.” This is why he came to MIT in the first place—the Undergraduate Research Opportunities Program (UROP). Starting in the fall semester of his freshman year, UROP “allowed me to explore research at a depth that I had not been able to before.” In UROP, one of the earliest programs of its kind in the United States, undergraduates fully participate in research as the junior colleagues of Institute faculty. MIT students use their UROP experiences to get to know the faculty, learn about potential majors, and investigate areas of interest.

Motivated by his own student experience at MIT, his background in physics, and his research into weather forecasting, Bacon and his wife, Lucia, decided to support the Department of Earth, Atmospheric and Planetary Sciences (EAPS) and the Department of Physics. He believes that the sooner students engage in research, the greater an impression those experiences can have: “When you catch the imagination early, you can make a bigger, longer-lasting impact.”

As the director of the Leidos Center for Atmospheric Physics in Virginia, Bacon’s area of interest aligns with the work of the EAPS department, specifically the research of a former classmate, Kerry Emanuel ’76, PhD ’78, Cecil & Ida Green Professor of Atmospheric Science. “Kerry was doing work in hurricanes and I was doing work in hurricane tracking,” Bacon recalls. “I wanted to help attract students to this important area. Understanding our environment in terms of meteorology and changes in the climate of a specific geographic area could make a significant difference in certain regions of the world.”

In reconnecting with the physics department, Bacon wanted to support both UROP and Junior Lab, a two-semester sequence in experimental physics usually taken by third-year physics majors. His gift helps make it possible for students to create new experiments in the lab to further enhance their learning. “The original experiments, which date back to the 1800s, are important building blocks,” he says. “MIT has added some new experiments, but the physics department had no mechanism for continuing that, so I wanted to support students in continuing this work and buying the necessary equipment.”

“Early exposure to research can shape a student’s learning experience,” Bacon says. Not only do student researchers explore new ways of thinking, they also learn the important lesson of how many failed experiments it takes to achieve a single success. “Understanding and knowledge,” he believes, “always improve the human condition. Education is everything.”

—Stephanie Robbins

PHOTO: ROBERT EVANS

Students Piece Together the Impact of Annual Giving

On December 14, lighthearted chatter filled Lobby 10 as nearly 400 graduate and undergraduate students took part in the first annual MIT “Punt & Hunt,” a fact-finding game about the impact of MIT’s worldwide community of annual donors. On the last day of classes, and before the start of exams, students took a breather to learn about the most popular programs, grants, and opportunities that alumni, parents, students, and friends support at MIT each year.

To complete the hunt, students collected data from posters detailing how the Institute’s committed donors strengthen the core of MIT. Their giving fuels need-based undergraduate scholarships and funds fellowships that enable graduate students to pursue the work about which they’re passionate. With unrestricted gifts, donors also equip MIT with the flexibility to seize new opportunities and address unforeseen challenges. The data revealed that donors value programs that focus on students, from established resources like the Undergraduate Research Opportunities Program (UROP) to such new initiatives as MIT Sandbox and MindHandHeart. Several of the game’s participants expressed surprise upon learning how many of MIT’s generous annual donors are still students themselves—that last fiscal year, for example, 1,363 student donors funded their peers’ efforts to make a better world through six D-Lab Fieldwork Grants.

Moving from poster to poster, participants and passersby in Lobby 10 saw a fact-filled picture emerge of how their MIT experiences, and future MIT opportunities, are directly connected to the generosity of the Institute’s annual donors.

DANIEL SM ’68, PHD ’72 AND GAIL RUBINFELD

Attracting and Supporting the Best

Daniel Rubinfeld SM ’68, PhD ’72 shares a story from his days as a fledgling PhD economics candidate that he thinks will sound familiar to many who have been graduate students at MIT. “I was taking econometrics with Franklin Fisher [the Jane Berkowitz Carlton and Dennis William Carlton Professor of Microeconomics, Emeritus], a very good, very intimidating teacher. He called me into his office; I was extremely nervous. He said, ‘I noticed you were in the back of the class most of the semester. You didn’t say much. But I want to let you know your work is terrific—and my office is always open.’

“That moment marked a big change for me,” Dan recalls. “That’s when I thought, ‘I can really do this.’”

More than four decades later, Dan, a professor of economics and law at the University of California at Berkeley, and his wife, Gail, a retired lawyer, remain in touch with Fisher, plus a number of other MIT economics heavy hitters who helped shape Dan’s MIT experience and his career. That group includes Nobel laureate and Institute Professor Emeritus Robert Solow, whom Dan refers to fondly as “one of the great people at MIT who were very personally encouraging.”

For the Rubinfelds, enduring student-faculty relationships are one of the Institute’s most powerful and distinguishing traits. “I had a small but brilliant faculty who really cared about their students and took them seriously—and I believe it is the same today,” Dan says. “I don’t think I would have had the same experience anywhere else.” Gail adds that at MIT, “Dan learned to love to teach. Doing great research is important, but so is reaching out to students. And MIT faculty hold themselves to a very high standard in that regard.”

It is into this environment that the couple—who met while Dan was at MIT (“Gail helped me survive,” he says)—wanted to give back. They established the Daniel and Gail Rubinfeld Fellowship in the Department of Economics, which they proudly believe is the best department of its kind in the country.

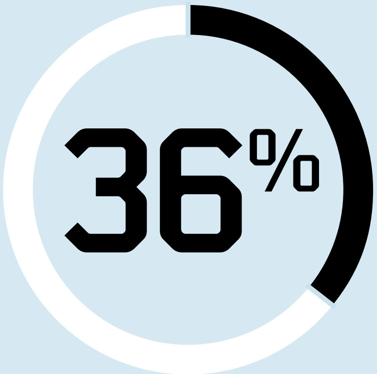
PHOTO: ROBERT CAPLIN

“It’s getting tougher financially for graduate students, and MIT has to compete against schools with bigger endowments,” Dan says. “The Institute did a lot to support me, so this gift is special.” Gail agrees: “We wanted to contribute to a place where the money will help attract and support students who could become the best economists in the world.”

During his career, Dan has taken notable detours into public service, including work with the World Bank in postapartheid South Africa and the Department of Justice under President Bill Clinton. On reflection, he says, MIT “encouraged me to undertake these kinds of efforts, because there are so many MIT faculty out there who have done the same.”

In that vein, Gail says that supporting “an organization with really good values” was top of mind for the couple. They also wanted to ensure their gift had real impact.“There are so many MIT students, graduates, and past and present faculty who are actively trying to make the world a better place,” Dan says. “It’s such a long list, even within economics alone. I wouldn’t know where to start.”

—Tracey Lazos



36% of last year’s annual donors gave to the unrestricted fund, supporting MIT’s flexibility and responsiveness.

“As a scholarship recipient, it’s really special to see that almost 5,000 people are giving to support people like me.”

Kate Scott ’18

44,000

In fiscal year 2016, more than 44,000 alumni, parents, students, and friends gave to MIT.

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