Department of Mechanical Engineering

In the Department of Mechanical Engineering (MechE), we are proud of our reputation for doing things a bit differently. Our faculty and students are the best in the world, but it is our spirit of ingenuity and hands-on problem solving that distinguishes us from other mechanical engineering departments. We are makers and innovators, embodying the MIT motto *mens et manus* (mind and hand) through uncompromising analysis, hands-on discovery, and an unparalleled entrepreneurial ecosystem.

Innovation is the cornerstone of everything we do. This quality allows our faculty and students to transform insights and discoveries into progress that carries the potential to change lives for the better. Our faculty conduct fundamental research and develop innovative tools to address the grand challenges of today and tomorrow in the areas of clean water and energy, health, emerging markets, manufacturing, safety, the environment, and transportation.

To meet these challenges, we coordinate research in the department across seven collaborative disciplinary areas: mechanics (modeling, experimentation, and computation); design, manufacturing, and product development; controls, instrumentation, and robotics; energy science and engineering; ocean science and engineering; bioengineering; and micro- and nano-engineering.

Creativity and innovation fuel our research, but they also imbue our classrooms. Our students learn by doing, experiencing a level of understanding that can occur only through creation. They receive not only a rigorous academic education but also first-hand experience and exposure to cutting-edge research.

We are also pioneering online education by bringing web-based learning technologies to our students and spending classroom time on the type of hands-on education that is so fundamental to the MechE curriculum. We were one of the first at MIT to offer our classes as massive open online courses (MOOCs) as part of the online edX platform.

Every year, we attract and enroll the best and the brightest mechanical engineering students. Both our undergraduate and graduate programs continue to thrive, illustrating a sustained and broad interest in mechanical engineering; 548 undergraduate and 591 graduate students were enrolled during AY2014, for a grand total of more than 1,100 students. Our research programs incorporate a growing postdoctoral population of more than 95 fellows and associates.

In this year's report, we provide snapshots of departmental news and contributions over the past year, including a short synopsis of faculty news (promotions, hires, and deaths); selected research highlights across the department; education highlights, with brief overviews of our undergraduate and graduate programs; and finally awards and recognition.

Leadership

This past year Gang Chen, the Carl Richard Soderberg professor of power engineering, was appointed to the position of department head by dean of engineering Ian Waitz. Professor Chen assumed the department's leadership role on July 23, 2013, succeeding interim department head Gareth McKinley and department head Mary C. Boyce before him. Soon after settling into the position, Chen appointed the new department leadership team, as follows:

- Professor John Leonard, associate department head for research
- Professor Anette (Peko) Hosoi, associate department head for education and undergraduate officer
- Professor David Hardt, graduate officer
- Professor Martin Culpepper, maker czar
- Professor Thomas Peacock, media moghul

Faculty

New Faculty

We are very pleased to welcome two new faculty members starting July 1, 2014.

Assistant professor Alberto Rodriguez graduated from the Universitat Politecnica de Catalunya in Barcelona with degrees in mathematics (2005) and telecommunication engineering (2006 with honors). He moved to the United States and earned his PhD in robotics in 2013 from Carnegie Mellon University and then spent a year as a postdoctoral associate at MIT's Computer Science and Artificial Intelligence Laboratory (CSAIL). Dr. Rodriguez is the recipient of La Caixa and Caja Madrid fellowships for graduate studies and won Best Student Paper Awards at the 2011 Robotics: Science and Systems conference and the 2013 International Conference on Robotics and Automation. His main research interests are robotic manipulation, mechanical design, and automation. His long-term research goal is to provide robots with enough sensing, reasoning, and acting capabilities to reliably manipulate the environment.

Xuanhe Zhao received a BE in electrical engineering from Tianjin University in 2003, an MS in materials engineering from the University of British Columbia in 2006, and a PhD in mechanical engineering from Harvard University in 2009. Upon finishing his postdoctoral training in biomedical engineering at Harvard in 2010, Dr. Zhao joined the faculty of the Department of Mechanical Engineering and Materials Science at Duke University. In 2014, Dr. Zhao and his group moved to the Department of Mechanical Engineering at MIT, where he is now an assistant professor and holder of the d'Arbeloff career development chair. Dr. Zhao also holds a joint appointment with the Department of Civil and Environmental Engineering (CEE). His current research goal is to understand and design soft materials with unprecedented properties and functions, such as active polymers, that may replace muscles and hydrogels tougher than cartilages. Dr. Zhao is the recipient of a National Science Foundation (NSF) Faculty Early Career Development (CAREER) Award, an Office of Naval Research (ONR) Young Investigator Award, and an Early Career Researchers Award from the AVS Biomaterial Interfaces Division.

Faculty Promotions

We are also pleased to announce the promotions of Sangbae Kim and Pedro Reis (dual with CEE) from the rank of assistant professor to the rank of associate professor without tenure and the promotions of Tonio Buonassisi, Domitilla Del Vecchio, Nicholas Fang, and Evelyn Wang, each from associate professor without tenure to associate professor with tenure. Each brings a unique signature to the department and the Institute in terms of individual achievements and contributions to research, education, mentorship, and service.

Professor Kim is a world leader in biomimetic robotics, the study of the structure and function of biological systems as models for the design and engineering of novel robotic systems. Inspired by the magnificent locomotive capabilities of animals, Kim develops new design methodologies that systematically exploit relevant biological principles and implement them in novel robotic designs. His work analyzes the intersection of animal function and robotic capabilities in order to leverage functionality that is uniquely robotic yet derived from eons of successful animal evolution. In doing so, he has created a series of inspirational, award-winning robots that have attracted both the praise of top academics in the field and worldwide attention from media and students. Kim's signature MIT contribution has been the creation of a robotic cheetah, a fast-running quadruped that combines advances in materials and mechanical components, force and position sensing, and flexible actuation and control over a wide range of scales. The MIT cheetah achieved running with a cost of transport (energy per weight per distance) of 0.51, reaching a gait of 22 kilometers per hour and transitioning from a trot to a gallop. The cheetah's design innovations include a novel actuator that allows for proprioceptive force/impedance control, a bio-inspired tensegrity-based leg structure, and a lightweight composite force-sensing foot. Kim is the recipient of a Defense Advanced Research Projects Agency (DARPA) Young Faculty Award (2013), an IEEE (Institute of Electrical and Electronics Engineers) International Conference on Robotics & Automation Best Student Paper Award (2007), and the King-Sun Fu Memorial Best IEEE Transactions on Robotics Paper Award (2008), and he was recognized by *Time* magazine for one of the best inventions of 2006. Kim brings his passion for design to the MechE undergraduate curriculum as a mentor and teacher in 2.007 Design and Manufacturing I and 2.009 The Product Engineering Process, and he recently introduced a new class on biomimetic robotics into the MechE curriculum.

Over the past several years, Professor Reis has established a leading research group that has pioneered a discovery approach to mechanics, emphasizing instabilities associated with slender structures and geometric nonlinearities with a unique signature to understand the "essentials" of complex problems, test and model them, and exploit them in design. Reis has focused on the mechanics of soft mechanical structures, identification and exploitation of principles for harvesting mechanical instabilities to generate functionality, and use of advanced manufacturing techniques combined with desktop-style experiments to probe different phenomena in an integrated manner. Specific contributions include his work on "Buckligami" and the fracture of thin sheets. While his research tackles fundamental questions, he has successfully initiated collaborations with industry as well. In addition to his service to and leadership in the profession, Reis has served on numerous faculty and other search committees, organized a very successful CEE research speed dating event to catalyze new research collaborations, and led the New England Workshop on the Mechanics of Materials and Structures, which engages younger members of the community and focuses on the participation of graduate students and postdocs. Reis was recently selected as one of the "Brilliant 10" by *Popular Science* magazine.

Professor Buonassisi has emerged as a world leader in solar energy conversion through his fundamental studies on the role of defects in solar cell efficiency, especially crystalline Si solar cells, driven by the goal of reducing the cost of solar cells. His cost analysis of solar cells is helping to shape US policy for the solar industry while guiding his own research in addressing scientific problems that have significant industrial impacts. His work has been applied to industry as well; for example, he helped a large semiconductor company overcome significant roadblocks in its photovoltaic (PV) product launch. Buonassisi has applied this strategy to new low-cost thin-film PV materials, more than doubling their efficiency values, and his work on solar water splitting using Si PV cells to drive electrochemical reactions has game-changing potential. He has brought his drive and enthusiasm for renewable energy to students, introducing a popular subject on photovoltaics as well as actively serving as a resource and mentor to the MIT Energy Club.

Professor Del Vecchio develops control theory and algorithms for multi-agent systems and biological networks. She has made high-impact contributions in each of these areas. Her work in the formal analysis and design of multivehicle safety systems has been translated into practical use by Toyota in a full-scale multivehicle collision avoidance testbed, and her introduction of the concept of retroactivity has had a major impact on systems and synthetic biology. She has been recognized for these contributions with an NSF CAREER Award and the prestigious Donald Eckman Award from the American Automatic Control Council (which recognizes the most outstanding researcher in controls under the age of 35). Del Vecchio has also made strong contributions to education, teaching core controls classes and introducing a new subject on biomolecular feedback systems into the MIT curriculum. She is the coauthor (with Richard Murray) of a new textbook, *Biomolecular Feedback Systems*, to be published in October 2014 by Princeton University Press. Del Vecchio has a vibrant research group, with seven graduate students and three postdocs, and she regularly involves undergraduates in her research projects.

Professor Fang is internationally known for his pioneering and innovative work in metamaterial research. Metamaterials are artificially fabricated materials with extraordinary properties, such as negative optical refractive indexes. Fang's research includes design, fabrication, and manufacturing at small scales, which has led to innovations in these areas and by extension expanded his research into novel micro- and nano-manufacturing methods, including the invention of a new electrochemical nano-imprinting process. He has been recognized with a number of prestigious awards, including an NSF CAREER Award, a TR35 award, the American Society of Mechanical Engineers (ASME) Pi Tau Sigma Gold Medal, and the Chao and Trigger Young Manufacturing Engineer Award. In 2011, Fang was awarded the Ernest Abbe Medal by the International Commission of Optics. He is a fellow of the International Society for Nanomanufacturing.

Professor Wang has made significant contributions to the understanding of phase change heat transfer on nanostructured surfaces and has become an acknowledged world leader in this field. She has also distinguished herself in the highly active and competitive area of liquid behavior on structured surfaces. She has received Young Investigator Awards from DARPA, the Air Force Office of Scientific Research, and ONR, as well as the ASME Bergles-Rohsenow Young Investigator Award in Heat Transfer and several best paper awards. She is an outstanding mentor with a productive group composed of 17 graduate students and six postdoctoral researchers. Wang has been intimately involved in the MechE undergraduate thermal sciences curriculum, and she has led recitations and lectures in our large core subjects 2.005 and 2.006 (Thermal-Fluids Engineering I and II) as well as the senior-level 2.672 Project Laboratory subject. At the more advanced level, she has taught our 2.51 Intermediate Heat and Mass Transfer elective subject and the graduate core subject 2.55 Advanced Heat and Mass Transfer. In addition, she is a recognized leader in her professional community, serving extensively as a committee member and organizer of national and international conferences.

Faculty Deaths

Ford professor of engineering emeritus Stephen H. Crandall, a pioneer in random vibrations and rotordynamics and a leader in transforming mechanics into an engineering science, passed away October 29, 2013, in Needham, MA. He was 92 years old.

Stephen H. Crandall

After earning his PhD in mathematics from MIT in 1946, Stephen transferred to the Department of Mechanical Engineering. There he was appointed as an assistant professor of mechanical engineering in 1947, an associate professor in 1951, and a professor in 1958. He was named Ford professor of engineering in 1975 and an emeritus professor in 1991. While at MIT, Stephen acted as editor of three groundbreaking texts: *Random Vibrations* (1958), *An Introduction to the Mechanics of Solids* (1959), and *Dynamics of Mechanical and Electromechanical Systems* (1968). He offered the first academic subject on the topic of random vibrations research in 1958 and subsequently directed MIT's Acoustics and Vibration Laboratory for 33 years. He published a total of eight books and 160 technical papers.

Crandall's professional contributions have been widely recognized. He was elected to the American Academy of Arts and Sciences, the National Academy of Sciences, the National Academy of Engineering, and the Russian Academy of Engineering. The Acoustical Society of America awarded him the Trent-Crede Medal in 1978, and the American Society of Civil Engineers awarded him both the Theodore von Karman Medal in 1984 and the Freudenthal Medal in 1996. ASME presented Crandall with the Worcester Reed Warner Medal in 1971, the Timoshenko Medal in 1990, the Den Hartog Award in 1991, and the Thomas K. Caughey Dynamics Award in 2009. He was inducted as an honorary ASME member in 1988.

Research Highlights

Our research funding continues to grow, increasing more than 50% in the past five years. Our funding is increasingly applied to collaborative and multidisciplinary fundamental research programs with significant societal impacts. A snapshot of the varied and diverse research conducted in the department is provided below.

Gareth McKinley: New particle-sorting method breaks speed records. A team of researchers led by Professor McKinley has discovered a new way to sort particles moving at record-breaking speeds. The technique could allow cells to be sorted while hurtling through the channels of a microfluidic device at speeds faster than those of race cars, at least 100 times faster than any existing system. The researchers showed that by adjusting the flow properties of the fluid sample, they could concentrate all of the larger particles at the center of the flow, thus making in vivo sorting and identifying possible. They adapted a high-speed, pulsed-laser imaging system to take snapshots of the shapes, sizes, and orientations of the particles as they fly through the device. Ultimately, the researchers say, the work might lead to a compact, bedside device that could take a blood sample from a patient and provide diagnostic information immediately rather than requiring processing at a lab, which can take hours or even days.

Nick Fang: New ultrastiff, ultralight material developed. Using light to imprint features onto polymer or plastic, Professor Fang's research led his team to disprove the established diffraction limit, proving for the first time that it is possible to print subwavelength features 1,000 times the thickness of a human hair. The design is based on the use of microlattices with nanoscale features combining extreme stiffness and strength with ultralow density. Normally, stiffness and strength decline with the density of any material, which is why fractures become more likely when bone density decreases. But if the correct mathematically determined structures are used to distribute and direct the loads—as with the arrangement of vertical, horizontal, and diagonal beams in a structure such as the Eiffel Tower—the lighter structure can maintain its strength. In addition to its fundamental importance, Fang's discovery allows manufacturers to imprint finer features into items such as DVDs to significantly improve storage capabilities or to probe the traffic of protein or DNA.

Kamal Youcef-Toumi: New robotic system detects leaks in pipes. Professor Youcef-Toumi, in partnership with other researchers at MIT and the King Fahd University of Petroleum and Minerals in Saudi Arabia, has devised a robotic system that can detect leaks at a rapid pace and with high accuracy by sensing large pressure changes at leak locations. The small robotic device he and his collaborators have developed can move as fast as 3 miles per hour through pipes and is almost entirely automated. Produced in various sizes to fit different kinds of pipes and effective in gas, water, and oil pipes, it consists of two parts: a small robot with wheels that propel it through pipes (in some cases, it is simply swept along by flowing liquid) and a drum-like membrane that forms a seal across the width of a pipe. When a leak is encountered, liquid flowing toward it distorts the membrane, pulling it slightly toward the leak site. That distortion can be detected by force-resistive sensors via a carefully designed mechanical system (similar to the sensors used in computer trackpads), and the information is sent back via wireless communications. Ultimately, such devices could be inserted into a system of pipes and left in place indefinitely, conducting automatic, nonstop monitoring of the system.

John Hart: New way of making graphene might enable advances in display screens, solar cells, or other devices. Associate Professor Hart has led a team in developing a new way of producing graphene through a process—making graphene directly on materials such as large sheets of glass—that lends itself to scaling up. Currently, most methods of making graphene first grow the material on a film of metal, such as nickel or copper; however, according to Hart, the process of transferring the grapheme has become much more frustrating than the process of growing it and can lead to damage and contamination. The new work still uses a metal film as the template, but instead of making graphene only on top of the metal film, it makes graphene on both the film's top and bottom. The substrate in this case is silicon dioxide, a form of glass, with a film of nickel on top of it. Using chemical vapor deposition to deposit a graphene layer on top of the nickel film leaves graphene not only on top of the nickel layer but also on the bottom. The nickel film can then be peeled away, leaving just the graphene on top of the nonmetallic substrate. This way, there is no need for a separate process to attach the graphene to the intended substrate—whether it is a large plate of glass for a display screen or a thin, flexible material that could be used as the basis for a lightweight, portable solar cell, for example.

Rohit Karnik: MIT group shows xylem tissue in sapwood can filter bacteria from contaminated water. There is a simple solution to the problem of running out of drinking water during a lakeside camping trip: break off a branch from the nearest pine tree, peel away the bark, and slowly pour lake water through the stick. The improvised filter should trap 99.99% of bacteria, producing fresh, uncontaminated water. An MIT team led by Associate Professor Karnik discovered that this low-tech filtration system can produce up to 4 liters of drinking water a day—enough to quench the thirst of a typical person. The research team has demonstrated that a small piece of sapwood can filter out more than 99% of *Escherichia coli* from water. According to the team, the size of the pores in sapwood—which contains xylem tissue evolved to transport sap up the length of a tree—also allows water through while blocking most types of bacteria. Karnik believes that sapwood is a promising, low-cost, and efficient material for water filtration, particularly in rural communities where more advanced filtration systems are not readily accessible.

Pedro Reis: Researchers develop first detailed model for a 3D strand of curly hair. Led by Professor Reis, researchers at MIT and the Université Pierre et Marie Curie in Paris have provided the first detailed model for the 3D shape of a strand of curly hair. This work could have applications in the computer animation film industry, but it also could be used by engineers to predict the curves that long steel pipes, tubing, and cable develop after being coiled around a spool for transport. In the field, these materials often act like a stubborn garden hose whose intrinsic curves make it behave in unpredictable ways. Using lab experimentation, computer simulation, and theory, the team identified the main parameters for curly hair and simplified them into two dimensionless parameters for curvature (relating to the ratio of curvature and length) and weight (relating to the ratio of weight and stiffness). Given curvature, length, weight, and stiffness, their model will predict the shape of a hair, steel pipe, or Internet cable suspended under its own weight.

Evelyn Wang: New approach developed at MIT could generate power from sunlight efficiently and on demand. Professor Wang led the development of a new approach to harvesting solar energy that could improve its efficiency. The new process would utilize sunlight to heat a high-temperature material whose infrared radiation would then be collected by a conventional photovoltaic cell. This technique could also make it easier to store the energy for later use. In this case, adding the extra step improves performance, because it makes it possible to take advantage of wavelengths of light that ordinarily go to waste. According to Wang, a conventional silicon-based solar cell does not take advantage of all of the photons because converting the energy of a photon into electricity requires that the photon's energy level match that of a characteristic of the PV material called a bandgap. Silicon's bandgap responds to many wavelengths of light but misses many others. To address that limitation, the team inserted a two-layer absorber-emitter device—made of novel materials including carbon nanotubes and photonic crystals—between the sunlight and the PV cell. This intermediate material collects energy from a broad spectrum of sunlight, heating up in the process. When it heats up, as with a piece of iron that glows red hot, it emits light of a particular wavelength, which in this case is tuned to match the bandgap of the PV cell mounted nearby.

Tonio Buonassisi: Laser-doping method makes silicon devices responsive to infrared light. Researchers have tried a variety of methods to develop detectors responsive to a broad range of infrared light that could form imaging arrays for security systems or solar cells that harness a broader range of sunlight's energy. But these methods have all faced limitations. Now a new system developed by researchers at five institutions, including Professor Buonassisi, could eliminate many of those limitations. The new system works at room temperature and provides a broad infrared response. It incorporates atoms of gold into the surface of silicon's crystal structure in a way that maintains the material's original structure. In addition, it has the advantage of using silicon, a common semiconductor that is relatively low in cost, easy to process, and abundant. The approach works by implanting gold into the top hundred nanometers of silicon and then using a laser to melt the surface for a few nanoseconds. The silicon atoms recrystallize into a near-perfect lattice, and the gold atoms do not have time to escape before getting trapped in the lattice. While others have tried similar methods with materials other than gold, the MIT team's work is the first clear demonstration that the technique can work with gold as the added material.

Kripa Varanasi: Droplets break a theoretical time barrier on bouncing. Those who study hydrophobic materials—water-shedding surfaces such as those found in nature and created in the laboratory—are familiar with a theoretical limit on the time it takes for a water droplet to bounce away from such a surface. But MIT researchers led by Associate Professor Varanasi have now found a way to burst through that perceived barrier, reducing the contact time by at least 40%. According to the theoretical limit, the minimum time a bouncing droplet can stay in contact with a surface—first spreading out into a pancake-like shape and then pulling back inward due to surface tension and bouncing away—depends on the time period of oscillations in a vibrating drop, also known as the Rayleigh time. The way to achieve that minimum contact time, conventional wisdom holds, is to minimize interactions between the water and the surface, such as by creating low-adhesion superhydrophobic surfaces. But Varanasi's team found that increasing the surface interaction in a particular way can speed the process beyond that previous limit. To facilitate this interaction, they added macroscopic features such as ridges that break a droplet's symmetry and can serve to split it, causing it to recoil in highly irregular shapes. These ridged surfaces can have contact times that are 40% shorter than those of control surfaces.

Cullen Buie: New microfluidic technique quickly distinguishes bacteria within the same strain and could improve monitoring of cystic fibrosis and other diseases. There are good bacteria and there are bad bacteria—and sometimes they coexist within the same species. However, determining whether a bacterium is harmful typically requires growing cultures from samples of saliva or blood, a time-intensive laboratory procedure. Assistant Professor Buie and his research group have developed a new microfluidic device that could speed the monitoring of bacterial infections associated with cystic fibrosis and other diseases. The new microfluidic chip is etched with tiny channels, each resembling an elongated hourglass with a pinched midsection. The researchers injected bacteria through one end of each channel and observed how cells travel from one end to the other. From their experiments, they found that their device is able to distinguish benign cells from those that are better able to form biofilms.

Education Highlights

The online learning revolution is not the first time the department—or the Institute as a whole for that matter—was at the forefront of educational breakthroughs.

As the second course of study to be offered at MIT, MechE was a natural leader of the innovative *mens et manus* way. The passion of our faculty and students, both then and now, for pushing boundaries and developing creative solutions to the world's problems has led to a remarkable number of discoveries along the way, from the wind tunnel built by MechE student Albert Wells that launched the field of aeronautics and the artificial skin developed by professor Ioannis Yannas to professor Dick Yue's idea for the OpenCourseWare program of offering free MIT course materials online and many in between.

Fast forward to a more contemporary example of our propensity toward innovative educational initiatives: online education. As the idea of online learning started gaining momentum, it was no surprise that MIT was leading the charge—and, within the Institute, that we were early adopters and pioneers in bringing online learning technologies to its classrooms. While MOOCs receive a great deal of press, it is the application of some of these technologies to residential learning (on campus) that is the real revolution in higher education. The online component frees up class time to focus on the type of hands-on education that is so fundamental to the MechE curriculum.

We were also one of the first departments at MIT to offer an "x" course via MITx. Taught by Dr. Simona Socrate, 2.01x Elements of Structure was offered in spring 2013. It is an online version of 2.01, the introductory-level solid mechanics class in the department's flexible 2-A program.

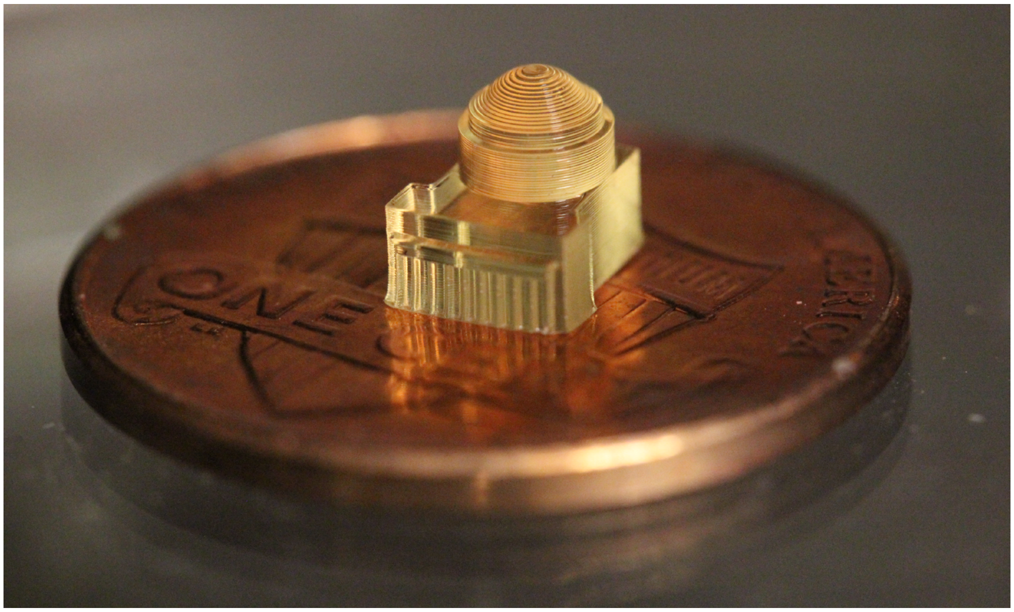
In fall 2013, we offered our second MITx course on the edX platform, 2.03x Dynamics. This six-unit, half-semester course is an online version of 2.03, the introductory-level dynamics class taught by professor David Gossard as part of the 2-A curriculum. Professor Gossard, along with two graduate students and five Undergraduate Research Opportunities Program (UROP) students, spent the summer of 2013 encoding all of 2.03's nonlecture materials, including problem sets, solutions, and exams, on the edX platform.

Professor David Gossard records weekly virtual office hours for 2.03x.

Just as we have been at the forefront of online training and hands-on education, we have also been a leader in "lab-to-board" learning. We offer one of the first mechanical engineering programs to swiftly incorporate its department's research discoveries and innovations into its classrooms.

Professor Fang's simple and low-cost 3D printer is a good example. As a faculty member in mechanical engineering at the University of Illinois at Urbana-Champaign teaching manufacturing, Fang realized that the 3D printer his research group was working on would be a great way to illustrate some of the fabrication concepts he was teaching his students. It is now a major element of professor Sang-Gook Kim's 2.674 Micro/Nano

Engineering Laboratory: Kim converted what Fang's group built in the lab—a desktop micro-fabrication system—into an educational module that his students use as an in-class fabrication platform.



A model of MIT's dome built by students in 2.674 using professor Nicholas Fang's low-cost 3D printer.

Our early adoption and development of disruptive educational innovations ultimately serves to strengthen our ability to offer students meaningful hands-on experiences. We often refer to our most popular hands-on subjects, such as professor David Wallace's renowned 2.009 Product Engineering Processes capstone subject and the ever-influential 2.007 Design and Manufacturing I subject (which just this year passed from professor Dan Frey to associate professor Kim and assistant professor Amos Winter), but there is also a long list of hands-on classes that often go unsung. One example is 2.739 Product Design and Development; this graduate subject, taught by professor Warren Seering and professor Steven Eppinger of the Sloan School of Management, teams mechanical engineering students with designers from the Rhode Island School of Design and business students from Sloan to produce market-ready prototypes.

At the same time, a renewed interest in building and making is sweeping the globe and transforming mechanical engineering into an activity that people everywhere are embracing with incredible spirit and enthusiasm. As we watch this maker movement gather momentum and mass, we think about how many of its roots took hold in our classrooms and how strong those roots still are today (for more information on the many ways MechE is supporting the MIT maker community, see the "We Are Makers" section below).

Undergraduate Enrollment, AY2010–AY2014

	AY2010	AY2011	AY2012	AY2013	AY2014
Sophomores					
2	76	94	78	84	87
2-A	67	64	62	98	86
2-OE	5	4	5	3	4
13	0	0	0	0	0
Subtotal	**148**	**162**	**145**	**185**	**177**
Juniors					
2	112	88	90	80	94
2-A	50	58	67	61	102
2-OE	6	5	3	6	4
13	0	0	0	0	0
Subtotal	**168**	**151**	**160**	**147**	**200**
Seniors					
2	80	104	79	87	73
2-A	49	57	64	68	66
2-OE	6	7	3	4	8
13	0	0	0	0	0
Subtotal	**135**	**168**	**146**	**159**	**147**

Graduate Enrollment, AY2010–AY2014

	AY2010	AY2011	AY2012	AY2013	AY2014
Master's	183	212	240	232	230
Doctoral	255	268	255	299	310
MEng	20	13	17	15	18
MechE	0	2	0	0	0
Eng (naval)	31	30	30	33	33
Total	**489**	**525**	**542**	**579**	**591**

New Subject Highlights

This past fall, we also debuted two new project-based subjects on emerging topics in mechanical engineering: product design for developing markets, taught by Assistant Professor Winter, whose own research in the area is the cornerstone of the class, and bio-inspired robotics, taught by Associate Professor Kim, itself inspired by his own robotic cheetah. In both cases, the new subjects are the first of their kind in engineering education.

2.S999 Global Engineering

Professor Winter, principal inventor of the Leveraged Freedom Chair, is teaching 2.S999, a design subject that partners graduate students with organizations that are developing new or updated products specifically for emerging markets. The subject builds on machine design and product design subjects in the MechE curriculum, focusing on the points where they converge. It combines engineering rigor and theory with a contextual understanding of market dynamics, end user dynamics, and the design requirements of emerging markets.

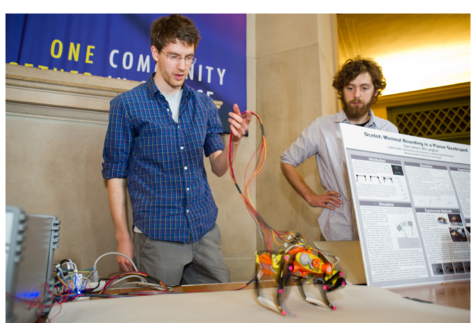
2.S999 students work on their drip irrigation prototype.

Throughout the course of a semester, students work together with teammates and companies to identify what Winter calls “the technological keystone” of a product—the crux of a successful emerging market design. They then move on to the design and prototyping phases, offering their final product during an end-of-semester presentation. One example from this past semester was a team that worked with Mahindra Tractors to redesign an engine platform that reduces sound vibration.

2.S997 Biomimetics, Biomechanics, and Bio-Inspired Robots

Unlike engineering for developing markets, biomechanics is not a new focus for mechanical engineers, but Professor Kim’s research takes a unique approach by combining it with robotic engineering. The goals of the 2.S997 subject are to present basic principles of biomimetics and robotics and to develop students’ abilities to merge the two into a creative design.

Through a major hands-on robot-building project, students explore the ways in which animals can inspire a higher-performance robot. The three-hour lab gives them time to test their hypothesis using an inexpensive robotics kit provided by Kim, whose own current research on a robotic cheetah laid the groundwork for the portable kit: a miniature cheetah that the students can build and program in less than a month.



A pair of 2.S997 students showcase their bio-inspired robotic ocelot at a final presentation.

Honors and Recognition

Faculty

Professor Lallit Anand will receive the 2014 ASME Drucker Medal.

Professor Cullen Buie was recognized as a 2013 Stanford Distinguished Alumni Scholar. He also received a DARPA Young Faculty Award.

Professor Gang Chen was named an academician of the Academia Sinica and received the Nukiyama Memorial Award from the Japan Heat Transfer Society.

Professor Nicholas Fang was elected a fellow of the International Society for Nanomanufacturing.

Professor David Gossard received the Keenan Award for Innovation in Undergraduate Education.

Associate professor Rohit Karnik was honored recently by his alma mater IIT Bombay with the Young Alumni Achiever Award, which recognizes outstanding achievements in mechanical engineering by alumni under the age of 40. He was one of four alumni to receive the award.

Associate professor Sangbae Kim recently received an NSF CAREER Award to pursue his research on gait transition principles in quadruped robots.

Professor Mathias Kolle was named d'Arbeloff career development chair.

Dr. Hermano Igo Krebs has been named a fellow of IEEE for his contributions to rehabilitation robotics and the understanding of neuro-rehabilitation.

Associate head of research John Leonard has been named a fellow of IEEE for his contributions to navigation and mapping for mobile robots and autonomous underwater vehicles.

Associate professor Pedro Reis recently received an NSF CAREER Award for his project "Smart Morphable Surfaces for Aerodynamic Drag Control." *Popular Science* magazine recently named him to its 2013 "Brilliant 10" list of young stars in science and technology.

Professor Alexander Slocum was recently selected for the 2014 ASME Thar Energy Design Award.

Professor Amos Winter was named one of the top innovators under the age of 35 by the *MIT Technology Review*.

Associate professor Maria Yang received the 2014 Capers & Marion McDonald Award for Excellence in Mentoring and Advising and the 2014 Ruth and Joel Spira Excellence in

Teaching Award. She was recently named an ASME fellow and was selected for the 2014 American Society for Engineering Education Fred Merryfield Design Award.

Undergraduate Students

Alfred A.H. Keil Ocean Engineering Development Award (Excellence in Broad-Based Research in Ocean Engineering): Beckett Colson and Lampros Tsontzos

AMP Inc. Award (Outstanding Performance in Course 2.002): Antonia Warner

BP Women in Research Innovation: Kirsten Lim and Georgia Van De Zande

BP Women of Academic Excellence: Hannah Barrett and Emma Nelson

Carl G. Sontheimer Prize (Creativity and Innovation in Design): Jonathan Slocum

Department Service Award (Outstanding Service to the Department of Mechanical Engineering): Jad El Khoury, Rohun Kulkarni, Jacqueline Sly, and Katherine Spies

Ernest Cravalho Award (Outstanding Performance in Thermal Fluids Engineering): David Bian

International Design Competition (Outstanding Performance in Course 2.007): Clare Zhang

John C. and Elizabeth J. Chato Award (Excellence in Bioengineering): Shirley Mao and Jonathan Rea

Lauren Tsai Memorial Award (Academic Excellence by a Graduating Senior): Erin Meyer

Lockheed Martin Prize (Outstanding Sophomore in Mechanical and Systems Engineering): Nicholas Kwok

Louis N. Tuomala Award (Outstanding Performance in Thermal Fluids Engineering): Sarah Fay

Luis de Florez Award (Outstanding Ingenuity and Creativity): Michael Farid

MIT Lincoln Laboratory Beaver Works Barbara P. James Memorial Award (Excellence in Project-Based Engineering): Lucille Hosford, Jacqueline Sly, and Katelyn Wolfenberger

Park Award (Outstanding Performance in Manufacturing): Josh Queeney and Yasmin Inam

Peter Griffith Prize (Outstanding Experimental Project): Marta Krason and Rashed Al-Rashed

Robert Bruce Wallace Academic Prize: Jaya Narain

Society of Naval Architecture and Marine Engineering Award (Outstanding Undergraduate Student in the Marine Field): Sarah Brennan, Priyanka Chatterjee, and Rosalind Lesh

Thomas Sheridan Prize (Creativity in Man-Machine Integration): Kristine Bunker

Whitelaw Prize (Originality in Course 2.007): Joshua Born, Michael Cheung, Emma Steinhardt, and Jacob Wachlin

Wunsch Foundation Silent Hoist and Crane Awards: David Christoff, Brian Foley, Julia Hsu, Manuel Romero, and Hazel Zengeni

Graduate Students

Carl G. Sontheimer Prize (Creativity and Innovation in Design): Michael Stern

Department Service Award (Outstanding Service to the Department of Mechanical Engineering): Daniel S. Dorsch and Joseph Sandt

Clement F. Burnap Award (Outstanding Masters of Science in the Marine Field): Brian Heberley

Luis de Florez Award (Outstanding Ingenuity and Creativity): Yi Chen, Jiahui Liang, Luke Mooney, and James Schulmeister

Martin A. Abkowitz Travel Award: Derya Akkwaynak, Audren Cloitre, Barry Scharfman, and Yu Zhang

Meredith Kamm Memorial Award (Excellence in a Woman Graduate Student): Leah Mendelson

Rabinowicz Tribology Award (Outstanding Research in Tribology): Adam Paxson

Wunsch Foundation Silent Hoist and Crane Awards: Athanasios Athanassiadis, Eric Heubel, Seung-Hyuck Hong, Bavand Keshavarz, Matthew Klug, Andrej Lenert, Tapovan Lolla, Nikhil Padhye, Jean-Phillippe Peraud, Douglas Powell, Stephanie Scott, Nicholas Sondej, Brooks Reed, and Zhiting Tian

2014 Phi Beta Kappa Inductees: Bruce Arensen, Sean Cockey, and Grace Young

Space Renovations

In continued support of the department's world-class education and research environment, we have undertaken several major space renovations over the past year to expand existing labs and to create new lab space for incoming faculty. The renovation of approximately 1,000 square feet of space for Professor Hart provides a highly visible nanomanufacturing cluster on the fourth floor of Building 35 and will benefit the Laboratory for Manufacturing and Productivity, the Department of Mechanical Engineering, and the School of Engineering. We have added 500 square feet to Professor Varanasi's lab, for a total of 1,000 square feet, to accommodate his quickly increasing research volume. We have also completed renovations to Room 5-012, which will serve as lab space for recently hired assistant professor Mathias Kolle, who works on bio-inspired photonic engineering, as well as Rooms 3-070 for incoming assistant professor Alberto Rodrigues and 3-072 for Professor Kim.

We Are Makers

In fall 2013, we created a new position to support and encourage MechE's and the Institute's large and ever-growing community of makers. We appointed professor Martin Culpepper, himself a renowned maker, as maker czar. Professor Culpepper earned his PhD in mechanical engineering from MIT and then became a professor here in 2001. He has since received several awards, including the R&D 100 Award for his HexFlex—a structure used for very fine positioning—the Ruth and Joel Spira Award for Distinguished Teaching, and the TR100 award for top young innovators. He is a fellow of ASME and a member of the American Society for Precision Engineering and the European Society for Precision Engineering and Nanotechnology. In his new role, Professor Culpepper has already initiated and implemented several projects and programs to support the vibrant maker community at MIT. He has hired four new "master makers" to staff various MechE machine shops; initiated an equipment assessment/upgrade program for shops; led the implementation of the Edgerton Center's flashlight training for MechE students to enable universal machine shop training and cross-shop use; initiated preliminary development of the Maker Passport program, a mobile application that will verify students' machine shop training and further enable cross-shop use; seeded the idea for MIT's first Mini Maker Faire (taking place October 2014); conceived, planned, and coordinated MechE's new MakerWorks program; initiated MIT-wide shop meetings to discuss tactical/strategic maker issues and collaborate with other MIT departments; and planned and began construction of MIT's new Mobius web application for the larger MIT maker community.

We Are Communicators

We have also expanded our support for media and communications by appointing professor Thomas Peacock as the department's media moghul and centralizing the communications team under Professor Peacock's oversight. An all-encompassing media resource for the department, the media team promotes and brings greater visibility to the department and its faculty through both traditional and new methods of communication. Communications coordinator Alissa Mallinson supports the department in the areas of resource development and alumni communications, public relations, video and event promotion, and social media communications through writing, editing, design, consulting, project management, and overall strategic planning. John Freidah, the department's multimedia specialist, has filmed, edited, and produced 25 high-quality videos over the past year showcasing faculty research, students, PhD dissertations, popular department subjects, and more. He has created a MechE YouTube channel to host departmental videos, garnering more than 1,000 subscribers in the past year, and enhanced access to and understanding of the department's activities and accomplishments through the increasingly popular medium of video. His videos have been used as collateral content by major news organizations throughout the world. Finally, the media team, through the technical skills and insight of MechE's web master Harris Crist and under the leadership and management of Professor Peacock, began a significant website overhaul that is slated for completion by the end of the 2014 calendar year.

Continuing the Department's Work

It was a smooth transition from the leadership of professor Mary Boyce and her team of professors Gareth McKinley and David Hardt to our new leadership team, even as we hit the road running. The Department of Mechanical Engineering as a whole continues to represent *mens et manus* in everything it does, upholding all of the principles that make it one of the strongest such departments in the world: an unyielding dedication to research and educational excellence, a passion for hands-on learning, a flair for innovation, and a real desire to do good in the world—all supported by a strong network of ecosystems.

Gang Chen
Department Head
Carl Richard Soderberg Professor of Power Engineering

John Leonard
Associate Department Head, Research
Professor of Mechanical and Ocean Engineering

Anette "Peko" Hosoi
Associate Department Head, Education
Professor of Mechanical Engineering