Department of Mechanical Engineering

Mechanical engineering—in its breadth, depth, and versatility—has never been more relevant to the world's challenges than it is today. Within this field, the Department of Mechanical Engineering (MechE) remains a leader, defining and pushing the frontiers in both education and research. Our mission to educate and mentor the next generation of leaders for industry, academia, and government remains at our core, together with the generation of knowledge and new technologies that will impact society. Our undergraduate enrollment for the 2012–2013 academic year numbers more than 500 students; our graduate program continues to thrive with nearly 550 students and our most competitive admissions year ever; and our research programs incorporate a growing postdoctoral population of more than 80 fellows and associates.

The Mechanical Engineering Department's externally funded research portfolio is diverse, bringing innovative technical solutions to the major issues facing the 21st century, including energy, water, health, transportation, security, and the environment. Our faculty, students, and postdoctoral researchers are sharply focused on defining the next generation of engineering science and engineered processes for a productive and prosperous future.

Mechanical Engineering education and research innovations are increasingly occurring at the interfaces of disciplines. The department's commitment to its interdisciplinary and multidisciplinary nature is captured in a repeating hexagonal tiling motif of the seven core areas of the department. Each hexagon represents one of seven focus 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 nano/micro engineering. Any area can inhabit the central hexagon to illustrate its interface with each of the remaining six areas, which themselves are connected. The societal need-focused research laboratories and centers can be found at the interfaces of these disciplinary research areas, again demonstrating cross-disciplinary research and innovation.

This year's report features snapshots of departmental news and contributions, including a short synopsis of faculty news (promotions, hires, and retirements); selected research highlights across the department; education highlights and curriculum enhancements, with brief overviews of the undergraduate and graduate programs; highlights of completed renovations that enable the department's world-class programs; and finally, awards and recognitions.

Faculty

New Faculty Appointments and Promotions

MechE was pleased to welcome three new faculty members to the department: Alexie Kolpak, Amos Winter, and Jerod Ketcham.

Assistant professor Alexie Kolpak graduated from the University of Pennsylvania, where she earned her BA in biochemistry and her MS in chemistry, both in 2002. She continued her graduate studies at UPenn, earning her PhD in physical chemistry in 2007. Following her PhD, she worked as a postdoctoral associate in the Department of Applied Physics at Yale University, and then as a postdoctoral associate in the Department of Materials Science and Engineering at MIT. Dr. Kolpak's research employs atomic and electronic structure modeling techniques such as density functional theory to elucidate fundamental chemical and physical principles of surface and interfacial phenomena. Her research is highly interdisciplinary in nature and has included strong collaborations with experimentalists whose aim is the engineering of interfacial structures for a variety of important applications, including renewable energy, novel electronics technologies, and integrated nanoscale medical devices.

Assistant professor Amos Winter earned a BS in mechanical engineering from Tufts University in 2003 and an MS and PhD in 2005 and 2010, respectively, in mechanical engineering from MIT. His research interests include design for emerging markets, biomimetic design, fluid/solid/granular mechanics, biomechanics, and the design of ocean systems. He is the founder and director of the MIT Mobility Lab and the principal inventor of the Leveraged Freedom Chair, an all-terrain wheelchair designed for developing countries and winner of a *R&D Magazine's* 2010 R&D 100 Award. He received the 2010 MIT School of Engineering Graduate Student Extraordinary Teaching and Mentoring Award and the 2010 Tufts University Young Alumni Distinguished Achievement Award. He was recently awarded the 2012 American Society of Mechanical Engineers (ASME) Pi Tau Sigma Gold Medal.

Associate professor of the practice Jerod Ketcham earned a BS in mechanical engineering from Wichita State University, an MS in materials science and engineering from MIT, and a naval engineer's degree from MIT. He has served in the US Navy for 10 years, and at present is working as a deputy ship design manager in Replacement Submarine and Naval Sea Systems. Lieutenant Commander Ketcham is an expert in designing, building, overhauling, and operating submarines, having been involved in several submarine projects, including the most recent appointment as an "aft project officer" with the Ohio class replacement submarines. He has extensive experience in naval architecture and systems engineering and is a registered professional engineer in naval architecture in the State of Massachusetts.

MechE had several faculty promotions this year. Each brings a unique signature to the department and the Institute in terms of individual achievements and contributions to research, education, mentorship, and service.

Promotion to Associate Professor with Tenure

Professor Pierre Lermusiaux has established over the past five years a world-leading research group in the broad area of regional ocean data assimilation. He is a nationally and internationally recognized scholar, whose research has already profoundly influenced the fields of ocean data assimilation and real-time ocean modeling and forecasting, enabling the quantification of regional ocean dynamics on multiple length and time scales. His group creates and utilizes new models and novel methods for multiscale modeling, uncertainty quantification, data assimilation, and the guidance of autonomous vehicles, applying these advances to better understand physical, acoustical, and biological interactions in a wide variety of different regional ocean domains. Many of his group's innovations are being integrated into large-scale ocean forecasting programs and real-time naval coastal monitoring operations. Lermusiaux is recognized as an outstanding lecturer at both the graduate and undergraduate level and has received a School of Engineering Ruth and Joel Spira Award for Distinguished Teaching.

Promotions to Full Professor

Professor Daniel Frey is an international leader in the fields of robust design and design pedagogy. He brings depth and precision to the design process and has made significant contributions to the subfield of design of experiments. His research has rigorously shown that an adaptive one-factor-at-a-time approach to robust design, when coupled with informed engineering choices and used in an ensemble manner, is superior to current up-front fractional factorial design approaches, enabling engineers to effectively utilize engineering knowledge to engage with the design process in contrast to experiencing a loss in intuition and disengagement in "black box" factorial approaches. Professor Frey is also considered a thought leader in design pedagogy. His classroom teaching is recognized in both Engineering Systems Division and MechE as being among the best. In particular, since 2008, he has taken on the lead role in 2.007, a signature undergraduate design subject in mechanical engineering. He is also widely recognized for his work in K–12 outreach and, together with professor David Wallace, played major roles in developing the WGBH television program *Design Squad*.

Professor Nicolas Hadjiconstantinou is a recognized international leader in numerical simulations of micro/nanoscale transport. His interests lie in the scientific challenges that arise from the failure of the traditional macroscopic descriptions when the characteristic length scales become sufficiently small, and in exploiting the opportunities provided by the novel behavior of matter at the nanoscale to develop new concepts, devices, and systems with improved engineering performance. His group has developed a fundamentally new class of methods for simulating nanoscale transport phenomena, referred to collectively as "deviational simulations," which significantly outperform traditional simulation methods in a wide variety of nanoscale applications without introducing any additional approximations. In addition, Professor Hadjiconstantinou is contributing to nanoscale engineering education in MechE and beyond. He is a strong teacher and pedagogical developer of new course materials in the micro/nano engineering areas that have rapidly been integrated into the core undergraduate and graduate curriculum. He has demonstrated leadership through his chairmanship of the graduate admissions committee, of graduate programs within the Computation for Design and Optimization program, and, at the Institute-level, his chairmanship of an Institute-wide task force assigned to the task of updating and streamlining the graduate admissions processes.

Professor Tonio Buonassisi is an emerging leader in solar energy conversion. His goal is to increase the efficiency of energy conversion and to make solar energy cost-competitive with fossil fuels. He spearheads the use of "defect engineering" to achieve dramatic enhancements in efficiency in common semiconductor materials such as multicrystalline silicon, which are cost-effective but defect-laden. Using sophisticated multiscale experimental characterization, Buonassisi's group has revealed the processing history dependence of iron distribution in photovoltaic silicon and its governing role on performance. Informed by data and modeling of the underlying diffusion and gettering mechanisms, his group has developed simulation tools that predict how process parameters vary the defect structure and device performance. These tools enable design of cost- and time-efficient processing histories needed to achieve performance and have already had industrial impact, reducing processing times for one partner by more than 75%. Professor Buonassisi is now initiating new research directions within his group and with collaborators to bring his signature defect engineering approach to hyperdoped silicon as well as thin-film Earth-abundant semiconductors.

Professor Franz Hover is an established leader in the field of complex marine systems design. He is widely respected for his depth and breadth of knowledge across a range of disciplines, including fluid dynamics, control theory, robotics, mechanical design, sensor systems, and data processing, as well as for his ability to synthesize this multidisciplinary background into innovative new technologies. With the autonomous inspection of naval ships having become a high priority for the US Navy as a means to manage the safety and security of the naval fleet, Professor Hover has pursued the challenge of developing a hovering autonomous underwater vehicle capable of autonomously mapping a complete ship hull. The primary technology enablers include the breakthrough idea of using Doppler velocity logs and image sonar sensors to locate the vehicle position relative to the ship, which in turn enabled innovations in navigation, mapping, control, and motion planning. The success and impact of his work is dramatic: the full underside of a 163-meter ship hull, including details of the propeller region, has recently been imaged using his technology. While continuing to push the frontiers of marine robotics, Professor Hover has also initiated an active research program in robust network flows, developing computational tools for early-stage design of power systems for the all-electric ship.

Professor Rohit Karnik's research is in the interdisciplinary field of micro/nanofluidics, dealing with fundamental studies of fluid flows at submicron length scales, as well as the design of microscale systems that exploit such flows. Within this field, his research focuses on the discovery and elucidation of novel transport phenomena that can enable micro/nanofluidic systems with superior performance in the areas of health care, energy systems, and biochemical analysis. His group has made a number of key contributions to the advancement of micro/nanofluidic systems, including the demonstration of a new paradigm in cell separation by the steering of cells in continuous flow via cell-surface molecular interactions involving both chemical and topographic patterning strategies. They have also led the development of microfluidic systems for controlled nanoprecipitation of polymeric drug-delivery nanoparticles. This enables high-throughput and precise tuning of their properties—something that cannot be achieved by bulk mixing. Professor Karnik's group is also building on a core expertise in the design and fabrication of nanofluidic channels to create a new class of osmosis membranes that employ vapor-trapping nanopores to provide selective transport of water molecules. He is a co-recipient of the Joseph Henry Keenan Award for Innovation in Education.

Professor Kripa Varanasi is recognized as an emerging leader at the crossroads of thermal sciences, nanotechnology, and manufacturing. The principal theme of his research is the discovery and development of novel nanoengineered surfaces and coating technologies that can fundamentally alter thermal-fluid-interfacial interactions for transformational efficiency enhancements in various industries, including energy, water, agriculture, transportation, electronics cooling, and buildings. His activities are embodied in an interdisciplinary research framework focused on nanoengineered interfaces, thermal science, and new materials discovery combined with scalable nanomanufacturing that will have impact on multiple industrial segments. His group's work spans various thermal-fluid and interfacial phenomena, including phase transitions, thermal and fluid transport, separation, wetting, catalysis, flow assurance in the oil and gas industry, nanomanufacturing, and synthesis of bulk and nanoscale materials guided via computational materials design. His group's studies involve insightful combinations of how surface morphology at multiple scales can be used to control interfacial interactions and scalable manufacturing of such structures, fundamental studies of the physical chemistry and transport processes at the interface, and atomistic- and electronic-structure-level understanding of interfacial interactions guiding the synthesis of new materials.

Faculty Retirements

Emanuel (Ely) Sachs, the Fred Fort Flowers and Daniel Fort Flowers professor of mechanical engineering, has a long history of invention and development. He is the co-inventor of three-dimensional printing, which is one of the founding technologies of the field of additive manufacturing, and has made many valuable contributions to the photovoltaic industry, including string ribbon technology for making low-cost silicon wafers for solar cells. Most recently, he cofounded 1366 Technologies, based on cell technology that improves the efficiency of silicon cells to potentially cut the cost of wafers to one-third the current level. Sachs is also well known for his passion and commitment to education and, in particular, discovery-based learning and was recognized for this dedication with the Joseph Henry Keenan Innovation in Undergraduate Education Award in 2006. He retired last fall to pursue his work at 1366 Technologies as chief technology officer.

Faculty Deaths

Elias Gyftopoulos, Ford professor emeritus of nuclear engineering and mechanical engineering, was considered by many to be one of the foremost thermodynamicists of his time. Professor Gyftopoulos received numerous awards recognizing his contributions to research and education, including the Ruth and Joel Spira Award of the School of Engineering for Teaching Excellence, the James Harry Potter Gold Medal of ASME, the Edward F. Obvert Award of ASME, the Robert Henry Thurston Lecture Award of ASME, and the Commander of Order of Merit of the Republic of Greece. Professor Gyftopoulos was a member of the National Academy of Engineering and a corresponding member of the Academy of Athens, as well as a fellow of the American Academy of Arts and Sciences, the American Society of Mechanical Engineers, , the American Nuclear Society, and the American Association for the Advancement of Science.

Research Highlights

Research funding continues to grow across the Department of Mechanical Engineering, with an increase of well over 50% in the past four years. Funding focuses on high-impact fundamental research programs with societal impact and is increasingly collaborative and multidisciplinary. Expansion into new fields of research has necessitated and been enabled by space renovation, and more than 25% of research space in the past four years has been renovated. A snapshot of the varied and diverse research conducted in the department is described below.

Marine Engineering: Innovations at the Interfaces of Design, Controls, Robotics, Fluid Dynamics, and Ocean Engineering

Franz Hover: Autonomous robots map ship hulls for mines. For years, the US Navy has employed human divers, equipped with sonar cameras, as well as animals to search for underwater mines attached to ship hulls. But there is considerable risk involved using those methods. Now, Franz Hover and his group have designed algorithms that vastly improve such robots' navigation and feature-detecting capabilities. The robots are able to swim and hover around a ship's hull to view complex structures such as propellers and shafts. The goal is to achieve a resolution fine enough to detect a 10-centimeter mine attached to the side of a ship.

Pierre Lermusiaux: Sometimes the quickest path is not a straight line. Sometimes the fastest pathway from point A to point B is not a straight line, but figuring out the best route can be a monumentally complex problem. Pierre Lermusiaux together with his group of collaborators has developed a mathematical procedure that can optimize path planning for automated underwater vehicles (AUVs), even in regions with complex shorelines and strong shifting currents. The system can provide paths optimized either for the shortest travel time, the minimum use of energy, or to maximize the collection of data that is considered most important. The work is described in "Path Planning in Time-dependent Flow Fields Using Level Set Methods": Tapovan Lolla, Mattheus Ueckermann, K. Suleyman Yigit, Patrick Haley, and Pierre Lermusiaux. Institute of Electrical and Electronics Engineers International Conference on Robotics and Automation, May 2012.

Sangbae Kim: Helping robots hold on. An underwater robot tasked with opening a valve or repairing a damaged pipe needs to anchor itself to a solid surface and be able to detach and move on to its next assignment. But that requires a complex attaching and reattaching process. Esther and Harold E. Edgerton assistant professor Sangbae Kim and his group have designed a "controllable adhesion system" for underwater robots that utilizes controllable electromagnets—magnetic devices that can easily be turned on and off—to offer the needed features: a high holding force on various geometries and textures, low energy consumption, chemical resistance to seawater, and low maintenance requirements.

Surface Engineering: Innovations at the Interfaces of Multiscale Structures, Length-scale Dependent Physics, Transport, Fluids, Optics, and Mechanics

Evelyn Wang: Better surfaces could help dissipate heat. Cooling systems that use a liquid that changes phase—such as water boiling on a surface—can play an important part in many developing technologies, including advanced microchips and concentrated solar-power systems. But understanding exactly how such systems work, and what kinds of surfaces maximize the transfer of heat, has remained a challenging problem. Researchers led by associate professor Evelyn Wang have found that relatively simple, microscale roughening of a surface can dramatically enhance its transfer of heat. Such an approach could be far less complex and more durable than approaches that enhance heat transfer through smaller patterning in the nanometer range. "Structured Surfaces for Enhanced Pool Boiling Heat Transfer": Kuang-Han Chu, Ryan Enright, and Evelyn Wang. *Applied Physics Letters*, June 2012.

Gang Chen: Textured surface may boost power output of thin silicon solar cells. Because highly purified silicon represents up to 40% of the overall costs of conventional solar-cell arrays, researchers have long sought to maximize power output while minimizing silicon usage. A team led by Carl Richard Soderberg professor of power engineering Gang Chen has found a new approach that could reduce the thickness of the silicon by more than 90% while still maintaining high efficiency, decreasing significantly the amount of silicon needed. The secret lies in a pattern of tiny inverted pyramids etched into the surface of the silicon. These tiny indentations, each less than a millionth of a meter across, can trap rays of light as effectively as conventional solid silicon surfaces that are 30 times thicker. "Efficient Light Trapping in Inverted Nanopyramid Thin Crystalline Silicon Membranes for Solar Cell Applications": Anastassios Mavrokefalos, Sang Eon Han, Selcuk Yerci, Matthew S. Branham, and Gang Chen. *Nano Letters,* 2012.

George Barbastathis and Gareth McKinley: Through a glass, clearly. Most functional screens—for optical devices, displays used on smartphones and televisions, and even windshields and windows—are made of glass, but glare, reflection, and fog can often render them unusable. Now, a new way of creating surface textures on glass, developed by the research groups of professors George Barbastathis and Gareth McKinley, virtually eliminates reflections, producing glass that is almost unrecognizable because of its absence of glare—and whose surface causes water droplets to bounce right off, like tiny rubber balls. The new "multifunctional" glass, based on surface nanotextures that produce an array of conical features, is self-cleaning and resists fogging and glare.

"Nanotextured Silica Surfaces with Robust Superhydrophobicity and Omnidirectional Broadband Supertransmissivity." *American Chemical Nano*, 2012.

Kripa Varanasi: New method to prevent undersea ice clogs. Methane hydrates, which can form in the deep ocean, are a chronic problem for sub-sea oil and gas operations. Sometimes these frozen hydrates form inside the well casing, where they can restrict or even block the flow, at enormous cost to the well operators. Researchers led by Kripa Varanasi have found a solution. His team's new method would use passive coatings on the insides of the pipes that are designed to prevent the hydrates from adhering. By using a simple coating, Varanasi and his colleagues are able to reduce hydrate adhesion in the pipe to one-quarter of the value measured on untreated surfaces. "Hydrate-phobic Surfaces: Fundamental Studies in Clathrate Hydrate Adhesion Reduction": J. David Smith, Adam J. Meuler, Harrison L. Bralower, Rama Venkatesan, Sivakumar Subramanian, Robert E. Cohen, Gareth H. McKinley, and Kripa Varanasi. *Physical Chemistry Chemical Physics,* 2012.

Kenneth Kamrin: Shifting sands. Sand's curious properties—part fluid, part solid—have made it difficult for researchers to predict how it and other granular materials flow under arbitrary conditions. A precise model for granular flow would be particularly useful in optimizing processes such as pharmaceutical manufacturing and powder processing, where tiny pills and grains pour through industrial chutes and silos in mass quantities. Kenneth Kamrin, class of '56 career development assistant professor of mechanical engineering, has come up with a model that predicts the flow of granular materials under arbitrary conditions. The model improves on existing models by taking into account one important factor: how the size of a grain affects the entire flow. "Nonlocal Constitutive Relation for Steady Granular Flow." *Physical Review Letters*, 2012.

Biomedical Devices: Innovations at the Interfaces of Design, Instrumentation, Physics, Biology, Chemistry, and Fluid Mechanics

Ian Hunter: Device may inject a variety of drugs without using needles. Often patients do not fully comply with their doctor's orders because of the discomfort associated with needle injections. But now, researchers led by professor Ian Hunter have engineered a device that delivers a tiny, high-pressure jet of medicine through the skin without the use of a hypodermic needle. The device, which is silent and has been shown in animal studies to be painless, can be programmed to deliver a range of doses to various depths—an improvement over similar jet-injection systems that are now commercially available. The researchers say that among other benefits, the technology may help reduce the potential for needle-stick injuries. "Needle-free Jet Injection Using Real-time Controlled Linear Lorentz-force Actuators." *Medical Engineering & Physics*, January 2012.

Rohit Karnik: Rolling in the chip. Cell rolling is a common mechanism cells use to navigate through the body, but for scientists and doctors who want to sort cells quickly and affordably, it is not an easy task. Researchers led by Rohit Karnik have designed a cell-sorting microchip that takes advantage of the body's natural cell-rolling mechanism. The device takes in mixtures of cells, which flow through tiny channels coated with sticky molecules. Cells with specific receptors bind weakly to these molecules, rolling away from the rest of the flow and out into a separate receptacle. The cell sorters, about the size of postage stamps, may be fabricated and stacked one on top of another to sift out many cells at once. "Cell sorting by deterministic cell rolling": Sungyoung Choi, Jeffrey M. Karp, and Rohit Karnik. *Lab Chip*, 2012.

Education Highlights

Educating future leaders in mechanical engineering and preparing them to achieve the highest level of success, whether they pursue careers in industry, academia, or government, is as much a priority for our department as supporting cutting-edge, world-changing faculty research. MechE attracts the best and brightest undergraduate and graduate students by offering them unparalleled opportunities for hands-on learning and in-depth instruction, both inside and outside the classroom, rigorous courses of study, and competitive fellowships. Courses that require students to plan, design, and fabricate tools and products are a hallmark of our programs.

A testament to the effectiveness of MechE's educational programs is the progressively increasing enrollment numbers. Enrollment in the undergraduate program has almost doubled in the past decade, and the number of graduate applications has grown by approximately 50% since 2005. There has also been a steady increase in enrollment of women as well as underrepresented minorities.

Several innovations and developments in the undergraduate curriculum have been introduced recently, most notably in the newly revamped 2-A flexible degree program, in which students can focus on a particular engineering-based specialty by taking a larger range of technical electives related to their specific interests. The student response and interest in this degree has been overwhelming, increasing almost tenfold since 1998, with a notable increase for the upcoming 2012–2013 academic year, for which the revamped 2-A degree has been introduced.

Undergraduate Enrollment, AY2008–AY2012

	AY2008	AY2009	AY2010	AY2011	AY2012
Sophomore					
2	93	114	76	94	78
2-A	41	51	67	64	62
2-OE	5	6	5	4	5
13	0	0	0	0	0
Subtotal	139	171	148	162	145
Juniors					
2	99	95	112	88	90
2-A	20	44	50	58	67
2-OE	3	4	6	5	3
13	0	0	0	0	0
Subtotal	122	143	168	151	160

Undergraduate Enrollment, AY2008–AY2012 (Continued)

	AY2008	AY2009	AY2010	AY2011	AY2012
Seniors					
2	99	90	80	104	79
2-A	27	26	49	57	64
2-OE	5	4	6	7	3
13	0	0	0	0	0
Subtotal	131	120	135	168	146
5th-year students					
2	12	7	4	5	5
2-A	2	5	5	4	10
2-OE	0	0	0	1	0
13	0	0	0	0	0
Subtotal	14	12	9	10	15
Total	**406**	**446**	**460**	**491**	**466**

Graduate Enrollment, AY2008–AY2012

	AY2008	AY2009	AY2010	AY2011	AY2012
Master's	170	151	183	212	240
Doctoral	236	244	255	268	255
MEng	21	28	20	13	17
MechE	1	1	0	2	0
Eng R	16	24	31	30	30
Total	**444**	**448**	**489**	**525**	**542**

Selected Undergraduate Course Snapshots

2.00b Toy Product Design

Named one of the "30 Awesome College Labs" by *Popular Science* magazine, Course 2.00b—more popularly known as the Toy Lab—challenges undergraduate students to design, build, and present a toy prototype in just one semester. Toy Lab students are introduced to the product design and development process, including investigating customer needs; brainstorming concepts; sketching, designing, and modeling; and finally, prototyping and presenting the final product. This year, the class partnered closely with the Boston Children's Museum and the MIT Museum for inspiration and testing, as well as with engineering mentors for guidance on design and prototyping. Some of the resulting toys include the Firefly, a smart football that uses algorithms and the ball's rotations to light up the ball in various ways; Soundy, a portable, motion-sensor speaker; and Beat Blocks, a set of musical blocks that are controlled by midair gestures via infrared light.

2.007 Design and Manufacturing I

MIT's Johnson Athletic Center took on the aura of an old-fashioned county fair this past May, complete with popcorn, balloons, jugglers, cotton candy, and pitchmen wearing brightly colored jackets and bowties. But rather than ring tosses and sheep-shearing, the central event was a series of one-on-one matchups between an amazing variety of robots that students spent the entire semester designing, building, and testing. This was the culmination of MIT's renowned course in mechanical engineering—Design and Manufacturing I—better known by its course number, 2.007. A series of tasks set by the designers of this year's competition triggered a wild proliferation of imaginative designs and strategies, but in the end relatively simple, stable, and repeatable approaches won the competition. A variety of tasks for the robots to choose from, on a playing field modeled after a county fair, added to the variety of approaches. Even seemingly simple challenges led to inventive solutions: for example, a "strength tester"—the carnival game in which striking a lever with a mallet sends a projectile upward to strike a bell—was approached quite differently by different students. Some struck the lever with an actual hammer or mallet mounted on a hinge, while some ignored the lever and built miniature elevators to gently lift the projectile up to the bell; others built spring-loaded spatula-like devices to flip the projectile up. Besides the strength test, other challenges teams could choose for their robots included the mechanical removal of tickets from a roll—which turned out to be surprisingly difficult—and the inflating of a balloon, made harder by the difficulty of maintaining a tight seal.

2.671 Measurement and Instrumentation

In Course 2.671 Measurement and Instrumentation, students learn how to design and perform experiments, analyze the resultant data, and communicate their findings in a professional manner. Through a combination of lectures and laboratory experiments, the students are introduced to experimental techniques for the observation and measurement of physical variables such as force, strain, temperature, flow rate, and acceleration. They are also introduced to the principles of analytical techniques such as Fourier transforms, linear and nonlinear function fitting, probability density functions and statistics, uncertainty analysis, auto- and cross-correlation functions, and system identification techniques and transfer function analysis. The centerpiece of 2.671 is the semester-long project Go Forth and Measure, in which students frame and propose an original question of interest from their observations of the physical world, design and perform experiments to study this question using sensors provided to them, analyze their results using the techniques taught in the course, and then present their findings in both a journal-style report and a poster presentation that is open to the MIT community. Examples of recent projects include a study of the color change of leaves in the fall, a map of the force distribution in the foot while wearing high-heeled shoes, assessment of best strategies for arm wrestling, and measurement of the temperature and humidity inside the MIT Tim-the-Beaver mascot costume.

2.013/2.014 Engineering System Design and Development

Last year, in collaboration with Lincoln Laboratory, the Mechanical Engineering Department introduced two new classes, forming a two-part capstone engineering design sequence: 2.013 Engineering Systems Design and 2.014 Engineering Systems

Development. This project-based sequence involves 20 to 30 students working together as a single team to design and develop a complex engineering system. It is structured to as closely replicate a formal industrial design process as is possible in an academic setting. In 2.013, students establish a conceptual design, formalize the system design requirements, produce drawings, and lead design reviews, as well as write an extensive report and present their final design at a formal review at Lincoln Laboratory. In 2.014, students engage outside firms to construct parts; manufacture parts in the shops; and assemble, test, and evaluate the design they developed in 2.013. Engineering staff from Lincoln Laboratory act as both advisors to guide the design process and as members of a review board to evaluate the completed design and system. Last year, 27 students designed and built a hybrid power system that extended the operational time of the Remote Environmental Monitoring Units 600 AUV from 72 hours to four weeks. They also invented and demonstrated a method of reacting aluminum with seawater to generate electricity. This radically new approach to energy storage, involving stripping the passivation layer from aluminum using a liquid gallium membrane, has 20 times the energy storage density of current lithium ion battery technology. The significance of this development is that relatively low-cost AUVs can now be used to monitor the oceans at depth for weeks at a time, eliminating the need for surface support ships that cost upwards of $100,000 per day to operate and maintain.

Space Renovation Highlights

In continued support of MechE's world-class education and research environment, several major space renovations were undertaken this past year. Upgrades were completed to the Experimental Marine Hydrodynamics Laboratory for naval engineering education and research, home to both a propeller laboratory and state-of-the-art three-dimensional imaging of complex fluid dynamics phenomenon. Significant enhancements to the d'Arbeloff Laboratory for Information and Systems have been undertaken by installing chemical and biological hoods for the study of feedback and control of biological cellular networks and systems of biological cells, and ongoing upgrades continue in the department's Center for Energy and Propulsion Research, in Building 31, to support research in oxy-combustion and clean fuel technologies. At the center of this year's space improvements, a major renovation of the third floor of Building 3 has been completed to develop the Energy, Controls, and Mechanics Research Nexus. The department is grateful for the support of the Center for Clean Water and Clean Energy at MIT and King Fahd University of Petroleum and Minerals, together with a major donation from Neil Pappalardo '64, in making this transformation possible. This gut-level renovation encompasses more than 10,000 square feet and creates a contiguous and dynamic space for more than 75 graduate students and postdoctoral staff. The space also includes a new state-of-the-art classroom, a microscopy facility for graduate and undergraduate research, an optics research laboratory, an experimental fluid mechanics laboratory, and a new conference room overlooking Killian Court.

Additional renovations completed this past year include an air quality upgrade for the Pappalardo II Micro/Nano Laboratory, a renovation of the bay/workshop in the Sailing Pavilion for Ocean Engineering–related research and teaching activities, and a major update of the shared student office space in Ocean Engineering Design and Hydrodynamics (Room 5-423).

Honors and Recognitions

Faculty

Professor Lallit Anand was named the 2011 Distinguished Alumnus by the Indian Institute of Technology Kharagpur at the Institute's 57th Annual Convocation in August 2011.

Department head Mary Cunningham Boyce was elected to the National Academy of Engineering for her outstanding contributions to the understanding of the mechanics of deformation in engineered and natural polymeric solids.

Professor Cullen Buie was awarded a National Science Foundation (NSF) CAREER Award for his proposal "Dielectric Phenotyping of Bacteria for Energy and Medicine."

Professor Buonassisi was awarded an NSF CAREER Award for his proposal "Toward Robust, Scalable, and Non-intermittent Solar Power: Silicon-based Multi-junction Devices with Integrated Photocatalysis."

Professor Nicholas Fang was awarded the 2011 International Commission for Optics (ICO) Prize "for his pioneering work in optical metamaterials, optical superlenses, and nanofocusing." The ICO Prize is awarded to individuals who have made outstanding contributions to optics before reaching the age of 40.

Professor Hadjiconstantinou was awarded the prestigious ASME Gustus L. Larson Memorial Award for his international leadership in modeling and simulation across multiple length scales. The award recognizes outstanding achievement in mechanical engineering 10 to 20 years post-graduation. He was also elected a fellow of the American Society of Mechanical Engineers.

Professor Anette (Peko) Hosoi was awarded the J. P. Den Hartog Distinguished Educator Award for excellence in teaching mechanical engineering, for serving as an inspiration for students, and for fostering the development of physical insight and engineering judgment.

Professor Karnik was recently awarded a Department of Energy Early Career Award by the Office of Basic Energy Science for his research project Graphene Membranes with Tunable Nanometer-scale Pores.

Professor Sang Gook Kim was elected a fellow of the American Society of Mechanical Engineers.

Professor John Lienhard was awarded the inaugural ASME Technical Communities Globalization Medal, established in 2011 for an ASME member who demonstrates a sustained level of outstanding achievement in the promotion of international mechanical engineering–related activities.

Professor Derek Rowell was recognized with the Ruth and Joel Spira Award for Teaching Excellence in Mechanical Engineering for his history of excellence in teaching and his introduction of the new course Electronics for Mechanical Systems.

Professor Sanjoy Sarma has been recognized for his exceptional achievements and contributions in research, education, and service with an appointment as the Daniel Fort Flowers and Fred Fort Flowers Professor of Mechanical Engineering.

Professor Wallace was selected to receive the 2012 ASME Ruth and Joel Spira Outstanding Design Educator Award in recognition of his leadership in product development education.

Professor Wang received the 2012 Young Investigator Award from the Office of Naval Research for her development of advanced thin film evaporation and condensation surfaces for high-performance thermal management devices. She was also the recipient of the 2012 ASME Bergles-Rohsenow Young Investigator Award in Heat Transfer, given to a heat transfer engineer under the age of 36 who has a PhD or equivalent and has demonstrated the potential to make significant contributions to the field.

Professor Maria Yang was recognized for her exceptional advising and mentoring of students with the Earll Murman Award for Excellence in Advising by the Office of Undergraduate Education.

Undergraduate Students

American Bureau of Shipping Department Service Award (Outstanding Service to the Department of Mechanical Engineering): Guangtao Zhang and Yazan Al Nahhas

Lockheed Martin Prize (Outstanding Sophomore in Mechanical and Systems Engineering): Sean Cockey

Lauren Tsai Memorial Award (Academic Excellence by a Graduating Senior): Latifah Hamzah

Applied Measurement Professionals Inc. Award (Outstanding Performance in Course 2.002): Jack Wanderman and Ragheb El Khaja

Society of Naval Architecture and Marine Engineering Award (Outstanding Student in the Marine Field): Abhimanyu Belani, Christian Welch, and Leah Hokanson

Robert Bruce Wallace Academic Prize (Academic Excellence in Ocean Engineering): Grace Young

Alfred A. H. Keil Ocean Engineering Development Fund Award (Excellence in Broad-based Research in Ocean Engineering): Leah Hokanson

Louis N. Tuomala Award (Outstanding Performance in Thermal Fluids Engineering): Lauren Kuntz

Ernest Cravalho Award (Outstanding Performance in Thermal Fluids Engineering): Ken Lopez

Luis de Florez Award (Undergraduate Award): Andrew Yang

Peter Griffith Prize (Outstanding Experimental Project): Shen Huang

Thomas Sheridan Prize (Creativity in Man-machine Integration): Brooks Reed

International Design Competition (2.007 Contest): Angela Chu, Kawin Surakitbovorn, Michael Farid, and Sarah Southerland

Whitelaw Prize (Originality in 2.007 Design and Contest): Joseph Church and Samuel Whittemore

John C. and Elizabeth J. Chato Award (Excellence in Bioengineering): Ashley Brown

Park Award (Outstanding Performance in Manufacturing): Cecilia Cantu and Wesley McDougal

Rabinowicz Tribology Award (Outstanding Undergraduate Research in Tribology): Sean Vaskov

Carl G. Sontheimer Prize (Creativity and Innovation in Design): Erich Brandeau, Ian McKay, Julian Merrick, Latifah Hamzah, Richard Larson, and Ruaridh Macdonald

Wunsch Foundation Silent Hoist and Crane Awards:

> Outstanding Teaching Assistant: Paul Ragaller, Joseph Sullivan, Nevan Hanumara, Shane Colton
>
> Exceptional Performance in Dynamics: Wai Hong Chan
>
> Leadership: Daniel Dorsch
>
> Academic Excellence: Ashley Brown, David Parell, Evan Schneider, Ian McKay, Luke Mooney, Kathryn Olesnavage, Nigel Kojimoto, Omar Abudayyeh, Reuben Aronson, Richard Larson

2012 Phi Beta Kappa Inductees: Omar Abudayyeh, Reuben Aronson, Ashley Brown, Latifah Hamzah, Nigel Kojimoto, David Parell, and Theresa Saxton-Fox

2012 Tau Beta Pi Inductees: Sean Cockey, Jisoo Kim, Latifah Hamzah, Nigel Kojimoto, Laura Matloff, and Julia Titarelli

Graduate Students

Meredith Kamm Memorial Award (Excellence in a Woman Graduate Student): Melinda Rae Hale

Clement F. Burnap Award (Outstanding Masters of Science in the Marine Field): Timothy Emge II

Luis de Florez Award (Graduate Design Award): Nikolai Begg

Luis de Florez Award (Graduate Science Award): Christopher Love

Link Foundation Fellowship in Ocean Engineering (Study of Ocean Engineering Instrumentation): Audrey Maertens

Rabinowicz Tribology Award (Outstanding Graduate Research in Tribology): Robert Panas

Mary Cunningham Boyce
Department Head
Ford Professor of Engineering

Gareth H. McKinley
Associate Department Head, Research
School of Engineering Professor of Teaching Innovation

David E. Hardt
Associate Department Head, Education
Ralph E. and Eloise F. Cross Professor of Mechanical Engineering