MITMECHE

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Massachusetts Institute of Technology

MechEConnects

News from the MIT Department of Mechanical Engineering

Educational Innovation

Dear Friends,

The Department of Mechanical Engineering at MIT has been at the forefront of several educational revolutions over the decades, bringing our hallmark creativity and forward thinking to our classrooms in innovative ways. While we are most renowned for our top-notch research and interest in solving the grand challenges facing our society, our top priority has always been preparing MechE students to go forth and become inventors, innovators, and engineering leaders.

We strive to provide our students with as many meaningful hands-on learning experiences as possible, because we believe that making and doing add a crucial element to the process of learning, putting the science and math behind mechanical engineering into context and engaging students on a level that sparks true creativity and education. That is why we offer so many project-based classes (such as 2.007, 2.008, 2.009, 2.00b, 2.75, 2.78, 2.739) and why we continue to add more of them to the curriculum, such as debut classes 2.S999: Global Engineering and 2.S997: Biomimetics, Biomechanics, and Bio-Inspired Robots. It is also why we were one of the first departments at MIT to introduce online courses into our curriculum via the edX platform, starting with 2.01x: Elements of Mechanics and 2.03x: Dynamics.

Digital learning offers our students several benefits, including instant feedback and online forums, but perhaps even more importantly, it enhances the residential educational programs we offer to our on-campus students by changing the focus of class time from lectures to more meaningful hands-on education.

In this issue of *MechE Connects,* you will read about the innovative educational initiatives the Department has kick-started over the years, from the hands-on robotics competitions of 2.007 that swept the globe to the digitization of residential courses like that of 12.002, the first concurrently run online and on-campus course at MIT.

Our faculty members are award-winning educators and mentors, as well as leading researchers, and have had a big hand in these advancements as they follow their passion for superior education. Professor Sanjay Sarma is leading the online education revolution at the Institute level as the director of the Office of Digital Learning; Professor David Gossard is the first full-time professor to transform a MechE course into an MITx course; and Professor Sang-Gook Kim is teaching a course that incorporates a low-cost 3D printer developed by Associate Professor Nicholas Fang – a great example of our commitment to integrating research into the classroom.

I hope you enjoy reading about our great educational initiatives, and, as always, I thank you for your continued support of the Department of Mechanical Engineering at MIT.

Sincerely,

Gang Chen, Carl Richard Soderberg Professor of Power Engineering and Department Head

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News from the MIT
Department of Mechanical Engineering

► mecheconnects.mit.edu

About MechE

Mechanical engineering was one of the original courses of study offered when classes began at the Massachusetts Institute of Technology in 1865. Today, the Department of Mechanical Engineering (MechE) comprises seven principal research areas:

- **Mechanics: modeling, experimentation, and computation**
- **Design, manufacturing, and product development**
- **Controls, instrumentation, and robotics**
- **Energy science and engineering**
- **Ocean science and engineering**
- **Bioengineering**
- **Nano/micro science and technology**

Each of these disciplines encompasses several laboratories and academic programs that foster modeling, analysis, computation, and experimentation. MechE educational programs remain at the leading edge by providing in-depth instruction in engineering principles and unparalleled opportunities for students to apply their knowledge.

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Innovation in Education

MechE Goes Online to Enhance Residential Learning

by Alissa Mallinson

The online learning revolution isn't the first time that the Department of Mechanical Engineering – nor the Institute as a whole for that matter – has been at the forefront of educational breakthroughs.

From the very beginning, MIT was the natural outgrowth of a different state of mind, one that is inextricably linked to making, building, and doing. The MIT motto *mens et manus* ("mind and hand") was as distinctive a principle in 1865 as it is now on which to build a new kind of higher education. At that time, rote memorization was considered the standard method – and indeed a perfectly respectable one – by which to learn at any level.

MIT's founder William Barton Rogers had a different idea. He founded MIT to think and to do – to teach craftsmen and farmers, as well as engineers and academics, to "democratize science" as Sanjay Sarma, professor of mechanical engineering and director of the recently formed Office of Digital Learning, puts it. And from that moment on, it's been in our destiny to up-end traditional ways of teaching and to democratize science and technology for the betterment of all.

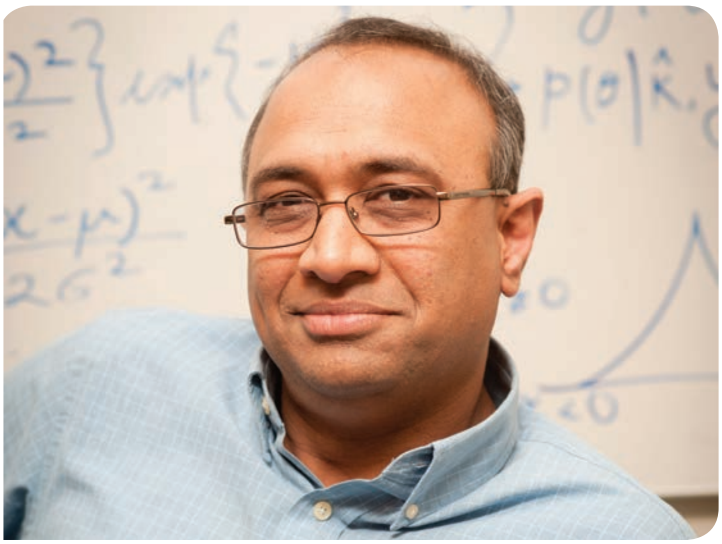
The Department of Mechanical Engineering, the second course of study to be offered at MIT, was a natural leader of the innovative *mens et manus* way. The passion of our faculty and students, both then and now, for pushing boundaries and developing creative solutions to the world's problems has led to a remarkable number of discoveries along the way, from the wind tunnel built by MechE student Albert Wells that launched the field of aeronautics to 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. Several of our faculty have also been the authors of seminal textbooks that codified the framework of fundamental mechanical engineering principles, such as Professor Lionel Marks' *Marks' Standard Handbook for Mechanical Engineers* and Professor Stephen Crandall's *An Introduction to the Mechanics of Solids* (see page 30).

By the time Professor Emeritus Woodie Flowers had transformed Course 2.70 (now 2.007) into the project-based, get-your-hands-dirty, robotics-competition-focused experience in the 1970s, MechE's reputation for innovation was already solidified. Nevertheless, the magnitude of the educational revolution he helped to evolve was profound. By giving an identifiable context to the more academic ideas behind the course – adding a tangible element of fun and community – he triggered a domino effect across the country and then the world, and eventually engineering programs everywhere were emulating his hands-on approach (see page 10).

Let's fast forward to a more contemporary example of MechE's tendency toward innovative educational initiatives: the incorporation of breaking research into the classroom. It's not a new practice to bring ideas that were first discovered in the lab into the classroom after the years-long process of review, approval, and codification. All important phases, of course, but there's just one problem: Once it's complete, the discovery is no longer cutting edge.

In MechE, there are several professors swiftly incorporating cutting-edge research from their labs into the classrooms. Professor Sang-Gook Kim's Course 2.674: Micro/Nano Engineering Lab integrates Professor Nick Fang's low-cost, optics-based 3D printer; Professor Amos Winter's Course 2.S999: Global Engineering builds upon his own inventions for emerging markets; and the foundation for Professor Sangbae Kim's Course 2.S997: Biomimetics, Biomechanics, and Bio-Inspired Robots is his own bio-inspired robotic cheetah.

As the idea of online learning started gaining momentum, it was no surprise that MIT was leading the charge – and, within the Institute, that MechE was an early adopter and pioneer in bringing online learning technologies to its classrooms. While massive open online courses (MOOC) receive a lot of press – and with good reason, as they truly are democratizing education by making learning more open and accessible – 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 time in class to focus on the type of hands-on education that is so fundamental to the MechE curriculum.


Professor Sanjay Sarma, director of the Office of Digital Learning at MIT

"There's nothing more satisfying for a professor than to achieve his or her ultimate goal," says Sarma, "which is to transfer information to students efficiently, in a stress-free, fun way and equip them to go become rock stars. And as it turns out, it's also a lot of fun for the professors too."

Online Learning: A Residential Revolution

According to Sarma, there have been two converging trends in MIT education. The first is this idea of "flipping the classroom" – which means that instead of focusing on reading, listening, and discussing during class time – what Flowers defines as "training" – students focus on *doing* during class time – what Flowers calls "true education." Outside the classroom, students read the textbook; watch video lectures, recitations, and virtual office hours; and engage in online forums. They come to class ready to cut, weld, solder, design, build, make, touch, smell, do. For MIT mechanical engineers, who have a tendency to happily get their hands dirty, this flip works perfectly.

The other trend according to Sarma is the technical advancement of automatic tutors at MIT. Automatic tutors are like simple video games in which you can answer questions digitally and know immediately if you got them right. MIT pioneered both the idea and the technology, refining it over the past 20 years to the point where it has now evolved into a sophisticated tool. It offers the capability for students to do their homework online and receive instant feedback on whether or not they answered correctly, and if not, get an idea of where they went wrong.

Think about the current, standard way. "Let's say you're in a lecture on Monday," explains Sarma. "As the professor, I hand out the assignment on Friday, you turn it in the following Friday. I grade it and return it the Friday after that – that's three weeks later. That means that the time that passes between your doubt and its resolution is three weeks. Within the first day, you've forgotten your doubt and it gets baked into your concrete understanding of the idea. It's like a crack in the foundation. And you're building three weeks' worth of material on it."

If you bring the two trends together, says Sarma, it enables a powerful new twist in residential learning.

"The moment you have all this, you can legitimately flip the classroom," he continues. "Students have to prove they understood the material and get instant feedback. If they didn't understand something, the professor knows what they didn't understand. And lecture time can now focus on those few unclear ideas, and the remaining time can be focused on hands-on activities."

Collecting data about what and how the students understand and learn empowers educators to make informed teaching decisions and assess what topics need additional attention and which topics are being belabored, and ultimately use teaching time much more efficiently. All of which is to say that the students have *learned better.*

"There's nothing more satisfying for a professor than transferring information in a fun and efficient way."

-Professor Sanjay Sarma

Senior Lecturer and Principal Research Scientist Simona Socrate, who this past spring taught the first MechE course to be offered on the edX platform, says, "Because the online students were so diverse and outspoken, it helped us understand a lot of things about the ways we teach the course to residential students. When you have so many students, there is a statistical value to what confuses people, and it helps you figure out how to present things better for everybody."

Democratizing Higher Education with MOOCs

At the same time that residential learning is being turned upside down by the unfolding of these enabling technologies, those same technologies rebundled allow the indiscriminate, global spread of higher education in the form of MOOCs, allowing anyone in the world with an Internet connection to take a high-quality course. With the nonprofit organization edX leading the charge, thousands of people from all over the world can take the same course from a long list of excellent universities, colleges, and institutes that partner with edX.

MechE was one of the first departments at MIT to offer an "x" course via MITx, the internal organization that develops actual MIT courses for the edX platform (a technology platform that hosts an advanced system of MOOCs, developed by an MIT professor of computer science, Anant Agarwal). Course 2.01x: Elements of Structure was offered this past in spring 2013, taught by Socrate. It is an online version of 2.01, the introductory-level solid mechanics class in the department's flexible 2-A program.

Professor Dave Gossard records weekly virtual office hours.

This past fall, MechE offered its second MITx course on the edX platform – 2.03x: Dynamics. The 6-unit, half-semester course is an online version of Course 2.03, the introductory-level dynamics class taught by Professor David Gossard as part of the 2-A mechanical engineering curriculum. Professor Gossard, along with two graduate students and five UROPs, spent the summer of 2013 encoding all of 2.03's non-lecture materials, such as problem sets, solutions, and exams, on the edX platform. The online problem set materials were also used by residential students during the regular fall offering of 2.03, so they benefitted from the instant feedback as well.

Another benefit of MOOCs is the ability to scale, a direct result of the edX platform, which enables indexed video lectures, e-textbooks, automatic and instantaneous homework submission and feedback, video recitations, and virtual office hours. Since each of those features is web-based, they only have to be produced once before they are able to accommodate almost an infinite number of students and achieve an unprecedented global reach. Both 2.01x and 2.03x had approximately 10,000 registrants, and in the case of 2.01x, about 10% of them finished the entire course (at the time of this writing, results from 2.03x weren't available). About 140 students achieved a perfect score; approximately 250 of them received a 95% or better; and more than 850 earned a certificate of completion, which requires the student to earn a 52% or better overall.

"It was amazing," says Socrate. "For online students, this is totally based on their own motivation. A lot of the students could barely wait for the new lectures to post and were really excited to do the problem sets – and many of them are doing other things at the same time like working and raising children. The level of enthusiasm, commitment, and love for this class from all walks of life was totally unexpected."

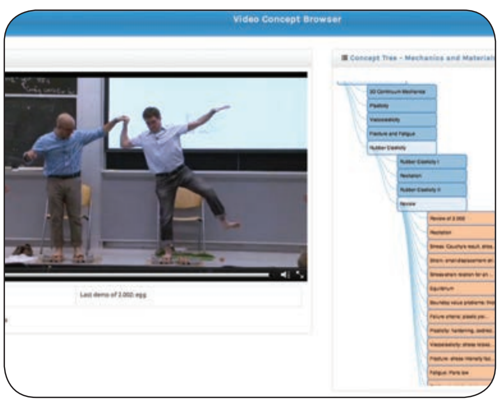
Online and On-Campus Blend: i2.002

Before MITx and edX were even announced, previous Department Head Mary Boyce and Associate Head Gareth McKinley asked Professors Ken Kamrin and Pedro Reis to conduct an educational experiment in online teaching. They asked them to take the Department of Mechanical Engineering's fundamental Course 2.002 on mechanics and transform it into something that residential students could take online and on campus simultaneously. It became the first concurrently run online course at MIT.

"We were tasked with devising a way for MIT students who are off-campus, whether for a study abroad or otherwise, to take an MIT course, and we had to come up with a solution," says Professor Reis. "We went about this very much like we would go about doing research. We had an unknown and were trying to solve a new problem. And when you do that, there are often solutions available that you weren't expecting. We realized halfway through the first offering that it would be a very useful tool for residential students as well."

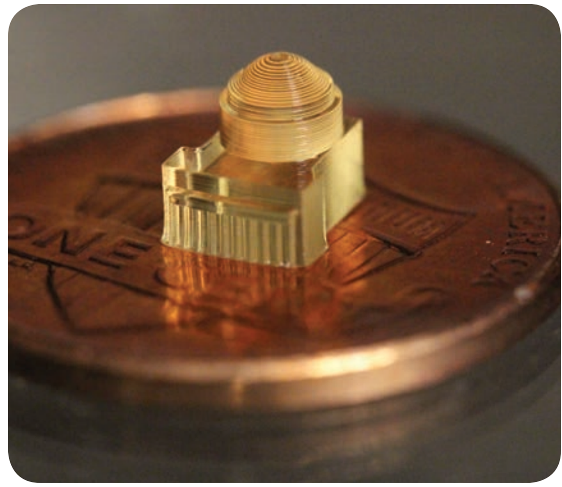
It's now two years later and the experiment has gone well beyond the original scope. Professors Reis and Kamrin did solve the problem, of course, figuring out how to videotape and edit the lecture very quickly (they received a grant and hired a video editor, Brandon Muramatsu, from the Office of Educational Innovation and Technology); finding a way for students to turn in problem sets (they gave them portable scanners), take exams (they proctored them using video conferencing software), and ask questions (they offered office hours via Skype and developed an online student forum); and making sure the students were still learning all the material at a level equivalent to those sitting in the classroom (they found that the distance students in year 1 performed consistently with their respective previous performance and slightly better than those students taking the course simultaneously on-campus.)

But along the way they also asked how they could build upon their solution, a question that led them to develop a portal for their video lectures, allowing students to search by topic as well as their relationship to other topics. In essence, an indexed video textbook.



A screen shot of Reis and Kamrin's indexed video textbook.

"The class follows a tree-like structure," says Professor Kamrin, "where ideas grow off other ideas, which grow other ideas, and so on. So we devised a way that students could follow along through the tree all the way back to the most basic concepts and see how it built up that way. In addition to searching by topic alone, you can also just click through the tree."



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

Lab-to-Board Learning

Just as MechE has been at the forefront of online training and hands-on education, the Department has also been leading the pack in "lab-to-board" learning. It is one of the first mechanical engineering programs to swiftly incorporate its research discoveries and innovations into the classroom.

Professor Nick Fang's simple and low-cost 3D printer is a great example. As a professor of 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 Course 2.674, for which he's converted what Fang's group built in the lab – a desktop micro fabrication system – into an educational module that the students use as an in-class fabrication platform.

The system is quite simple, consisting only of a digital projector, digital slides, a micro elevator, a magnifying glass, a beaker, and some chemicals. Compared to a commercial 3D printer, which requires about $20,000 to maintain manually, Fang's printer costs about $300 annually for replacement lamps. It works by digitally projecting images of cross-section layers of an object via slides, one at a time, through a magnifying glass and into a beaker of polymer. During the darkness between each slide, the elevator moves the beaker down at a preset distance to begin fabricating the next layer until the object is complete. The students spend time programming the elevator and experimenting with different polymers and colors. The class attracts students interested in robotics, optics, and chemistry.

According to the course's technical instructor, Dr. Benita Comeau,

"The addition of a 3D printer from Professor Fang's research group to the 2.674 lab class was a great example of how we update the course to keep it exciting and relevant. The students are very interested to work with a stereolithographic 3D printer. They not only have fun building the tiny models, they also gain a much better understanding of patterning materials with light, which is fundamental to engineering at the micro/nano scale."

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

Winter, principal inventor of the Leveraged Freedom Chair (http://www.gogrit.org/lfc.html), is teaching Course 2.S999: Global Engineering, a design course that partners graduate students with organizations that are developing new or updated products specifically for emerging markets.

"One of the graded elements of the course is how the student teams demonstrate their ability to collaborate with partner companies and exchange information," says Winter. "Each team has to meet with their partner organization on a regular basis, which often involves Skype calls to India. These companies already have a lot of insight on the stakeholders and can help teach the students about that aspect of their design."

Global Engineering builds on the abundance of machine design and product design courses in the MechE curriculum, focusing on the convergence between them. It combines engineering rigor and theory with the contextual understanding of market dynamics, end user dynamics, and the design requirements of emerging markets.

"I'm putting a very different spin on it," says Winter. "Students have to think about how to design for a consumer who's completely different from them. The design requirements are not laid out clearly so just the process of ascertaining them is tricky."

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 move on to the design and prototyping phases, presenting their final product at the end of the semester. One example from this past semester was a team that worked with Mahindra Tractors to redesign an engine platform that reduced sound vibration.

Students of 2.S999 work on their drip irrigation pumping prototype.

"Most product design texts and classes are focused on Western markets because that's where industry has focused their efforts throughout the past 50 years. But that's changing because there is an enormous number of middle-class customers in developing markets that weren't there previously, and they're buying things. By and large, companies in this country don't sell to them, and that's a failure."

Unlike engineering for developing markets, biomechanics is not a new focus for mechanical engineers, but Assistant Professor Sangbae Kim's research takes a unique approach by combining it with robotic engineering.

"We're not looking to copy anything in the animal," he says. "There's a very interesting inspiration exchange between biology and robotics engineering...We look at an animal in the world and see what it can do in a robot, and then we test those ideas with robots in ways we could not test on an animal. Biology gives us new ideas for engineering, and engineering fuels new questions for biologists.

"That's what I want my students to be able to experience: to learn from animals and test ideas using robotics that biologists are unable to test."

The students he's referring to are upper-level undergraduates and first-year graduates in the new Course 2.S997: Biomimetics, Biomechanics, and Bio-Inspired Robots. The goal of the course is to present basic principles of biomimetics and robotics, and to develop students' abilities to combine the two into a creative design.

A 2.S997 student showcases his bio-inspired robotic ocelet at a final presentation.

Through a major hands-on robot-building project, students explore the ways that 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 (http://biomimetics.mit.edu:8100/wordpress) lays the groundwork for the portable kit: a miniature cheetah that the students can build and program in less than a month.

"Looking at an animal," says Kim, "only an abstract principle can be taken and applied to a robotic system. So how do we learn from that?"

In the end, MechE's early adoption and development of disruptive educational innovations ultimately serves to strengthen its dedication to our students and the ability to offer them meaningful hands-on experiences. We often refer to our most popular hands-on courses – such as Professor David Wallace's renowned capstone Course 2.009: Product Engineering Processes and the ever-influential Course 2.007: Design and Manufacturing I, which just this year was passed from Professor Dan Frey's hands to those of Winter and Kim. But there is also a long list of hands-on classes that often go unsung, such as Professor Warren Seering and Sloan School of Management Professor Steven Eppinger's graduate Course 2.739: Product Design and Development, which teams mechanical engineering students up with designers from the Rhode Island School of Design and business students from the Sloan School of Management to produce market-ready prototypes.

At the same time, there has been a renewed interest in building and making that's sweeping across the globe and transforming mechanical engineering into an activity that people everywhere are tuning into 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 MechE classrooms and how strong those roots still are today. For MIT mechanical engineers, it's just another day of doing what they love.

Meet the MechE Maker Czar: Professor Martin L. Culpepper

Professor Culpepper received his PhD in mechanical engineering from MIT, then became a professor here in 2001. He has received several awards since then, 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. Most recently, he was named Maker Czar of MechE, overseeing builder space for the department.

Alumni Spotlight: Professor Woodie Flowers

SM '68, MEng '71, PhD '73

by Alissa Mallinson

For Professor Emeritus Woodie Flowers (SM '68, MEng '71, PhD '73), engineering is all about having fun. But it wasn't always that way.

As a high school student from a poor family, Flowers unexpectedly received a scholarship to college.

"I was planning to get a job in the oil field and buy a Corvette. But then I found out in the last part of my senior year that I could go to college. I was not prepared for that, so I knew I had to work hard. And I worked hard, and it turned out well. And for my whole professional career I've felt appropriately insecure about being surrounded by people who were more capable than me.

"But that is partially why I think about education in a particular way. I just didn't know any better than to work really hard, and I was too stubborn to accept that the sub-optimal learning methods I saw couldn't be fixed, and so I followed my own convictions about that."

His convictions led him to become a major force in the transformation of mechanical engineering education. Having been advised by MechE professor Robert Mann, who had similar beliefs in a hands-on, modern pedagogy, Flowers breathed new life into the MIT way of learning engineering by doing, a reinvigoration at the right place and the right time that ultimately had a butterfly effect on the popularity of STEM (science, technology, engineering, and math) around the world.

Flowers developed one of the first hands-on courses with 2.007, turning it into a project-based experience for undergraduate students that culminated in an end-of-semester robotics competition. It placed robots – each built by a singular student using a universal kit of tools and components – head to head during an event that quickly became one of the most highly attended at the Institute. He also helped to evolve a spin-off robotics competition for high school students with Segway inventor Dean Kamen called The FIRST Robotics Competition. It is one of many competitions that imitated Flowers' original idea.

His father, Abe, who Flowers describes as "a terrible businessman

(continued on page 12)

Alumni Spotlight: Professor David Hu

SB '01, PhD '06

by Alissa Mallinson

Have you ever wondered how flying insects survive in the rain?

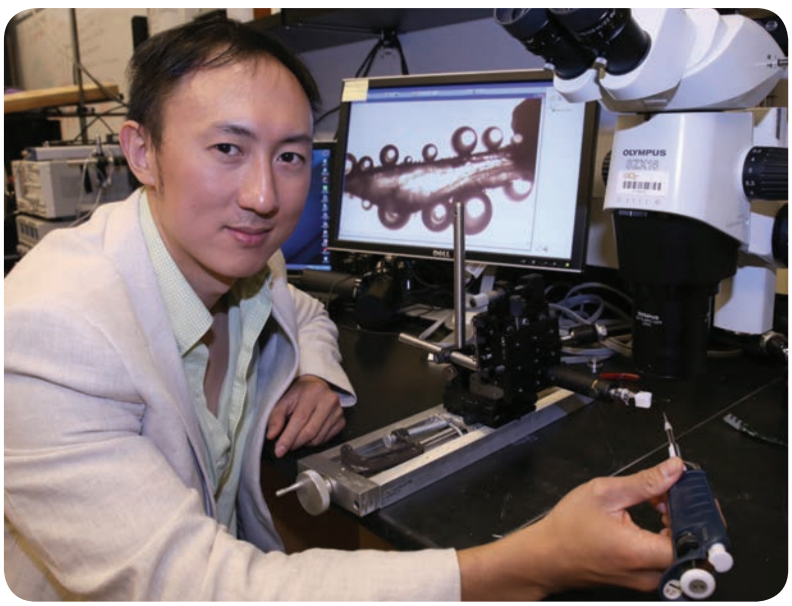
With a weight about 50 times that of a mosquito, a raindrop has a considerable force in comparison, similar in ratio to a Volkswagen Beetle falling on a human being. So why don't insects get crushed by rain?

This is a question that David Hu (SB '01, PhD '06), a professor of mechanical engineering and biology at Georgia Institute of Technology, asked himself a few summers ago as he sat on his porch watching a rainstorm.

It wasn't an unusual question for Professor Hu to be asking. A 2-A student as an undergrad in MechE, he got hooked on fluid mechanics after taking a course with Professor Gareth McKinley. "I always wanted ways to teach people fluid mechanics – and I think there is no better way to learn fluid mechanics than to mix it with some biology. Zoos, zoo animals, zoology – they have no problems attracting crowds from all sorts of ages and disciplines. It's just fun."

He discovered that the force of raindrops on insects is greatly influenced by their respective mass, based on the concept of conservation of momentum. When a raindrop hits a dragonfly, the dragonfly is so massive that there is a high impact force that causes the raindrop to lose about 98% of its speed. But when it hits something as lightweight as a mosquito, the raindrop actually moves with the mosquito so that it loses only about 5% of its original speed and applies very little force on the mosquito.

"There's a lot of interest in this because there are a lot of people who can build really small devices now," says



Professor Hu. "Studying how insects work in these dangerous environments is becoming more important because we can actually build things to emulate what insects do."

When Richard Larson – the Mitsui Professor of Engineering Systems and Director of the Center for Engineering Systems Fundamentals at MIT – read Professor Hu's article in the *New York Times* about how mosquitos fly through raindrops, he recognized its potential to teach kids about science and engineering.

Professor Larson is the co-founder and principal investigator of the MIT BLOSSOMS Initiative (our own Professor Dan Frey is a co-principal investigator). BLOSSOMS is a series of free interactive video modules taught by "guest teachers" meant to supplement a high school teacher's standard curriculum. Each video is designed for viewing in brief segments, allowing the in-class teacher to engage the students in an active, goal-oriented exercise between segments. (To see an MIT BLOSSOMS video in action, watch teacher John Bookston's statistics class at Arlington High School in Arlington, Mass: http://bit.ly/1ajDsk6)

Professor Larson invited Professor Hu to record himself teaching his mosquito-in-the-rain research for high school students. He thought it would be a great way of achieving the multi-state Next Generation Science

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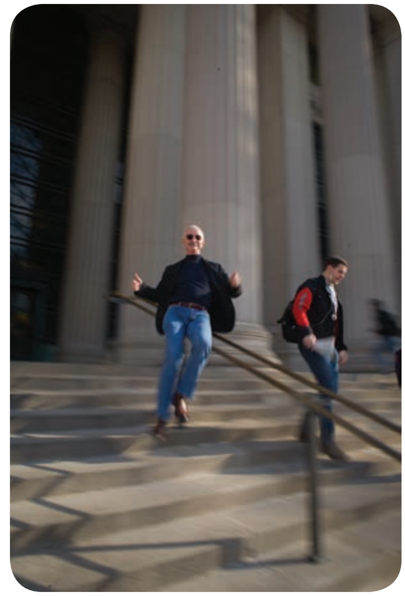


(Hu, continued from previous page)

Standards (NGSS), which requires an interdisciplinary approach to high school education.

"It's not easy to boil down university research to a high-school level," says Professor Hu, "but the question of how mosquitos fly in the rain is a great problem because it makes people think about mechanics and surfaces. It also teaches kids to think about the importance of scale. It combines some biology with some math, and some engineering with a bit of robotics. If a mosquito gets hit by a raindrop, it really is a very different thing than if you or a car gets hit by a raindrop. As we have shown in the video, raindrops don't break when they hit mosquitoes. The two just fall together. All of these things combine, and I think it's just great for [high school] students."

BLOSSOMS isn't the first time Professor Hu has worked on a project geared toward students. In fact, as a matter of course he does one every couple of years. Two years prior to his mosquito video, he did a video on the frequencies dog shake at to dry. He filmed 35 different animals and discovered what he and his grad student coined "the wet-dog shake rule" – the frequency at which animals need to shake to dry. It was such an interesting question that their findings were featured on "Good Morning America."

Watch Professor Hu's MIT BLOSSOMS video: http://bit.ly/KEnB5Q.

(Flowers, continued from page 10)

but a very interesting and creative guy," was also a huge influence on Flowers' vision for engineering education. He was a welder, repairman, and self-made inventor who taught Flowers not only how to be creative and productive with his hands but also that through the success of building something you didn't think possible, you can transform yourself.

"I learned from my father that doing things in a different way was often fruitful, and the underpinnings of all my educational efforts is to allow people a path to change their self-image. Students might have struggled with equations and other rigorous elements of an MIT education, but in 2.007 they could be superstars."

The creativity that both MechE and Flowers are known for is proportionate to their dedication to hands-on education. The ability to devise creative solutions and think outside the box as you're making and building shows students that good engineers need to be creative too and then gives them that experience. Knowledge is of course essential, Flowers says, because uninformed imagination can be quite dangerous, but at the same time, "nobody is getting hired to solve the multiple-choice problems at the end of the chapter."

"I think you have to just jump in and do it [...]," he continues. "For example, I hated math all my life until I took Calculus in conjunction with some engineering courses. Then all of a sudden, I got it. It meant something to me because I had spent a lot of time bending metal with a hammer, so the math had context.

"If you experience an idea and then go back and learn the abstraction, the abstraction makes sense. But if you do the opposite, it doesn't work so well because there's no context yet."

"Nobody is getting hired to solve the multiple-choice problems at the end of the chapter."

-Professor Emeritus Woodie Flowers

Course 2.678: Electronics for Mechanical Systems

Hands-On Electronics for Mechanical Engineers

by Alissa Mallinson

If you had to pick one word to describe the Department of Mechanical Engineering curriculum, you'd be hard-pressed to choose anything other than "hands-on."

The department boasts numerous well-known project-based classes such as 2.007, 2.008, 2.009, 2.00b, 2.72, 2.75, 2.737, and 2.739.

Most of them are focused on product design and development, as you would expect, but there are others that are focusing on the interface between mechanical engineering and other engineering fields.

One of them is Professor Derek Rowell's 2.678: Electronics for Mechanical Systems, which focuses on giving undergraduates experience and familiarity with integrating electronics into their designs of systems and products. The course was created three years ago in response to an Undergraduate Office student survey that reported a significant interest in learning electronics as mechanical engineers.

"The field of mechatronics – the integration of electronics into mechanical engineering – has been a creeping idea for many, many years now," says Professor Rowell. "It has broadened significantly and is necessary for mechanical engineers to understand in order to integrate all these new technologies into mechanical design."

2.678 students gather around an obstacle course where they release the autonomous robotic cars they've built as part of their final project.

In typical MechE fashion, 2.678 emphasizes learning by doing, with weekly labs that are the cornerstone of the course. Each lab is structured around a particular project that utilizes the concepts presented during the week's lecture; for example, students build a digital scale to learn how to use operational amplifiers for electronic processing and an audio amplifier to learn about how transistors work. They also learn how to drive a motor at different speeds going both forward and backward, how to do power conversions, use microcontrollers, and interface Arduino with mechanical systems.

"I don't think you can teach electronics out of a book," says Professor Rowell. "It's important to burn your fingers when you burn out resistors, to learn to solder, and to learn what physical components look and feel like."

The course, which is now required for the department's customizable Course 2-A program and may be required for all mechanical engineering students in the future, is a 6-unit course offered each semester to about 80 students. It comes at a very useful time in the undergraduate curriculum, helping to prepare students for Course 2.671: Measurement and Instrumentation and Course 2.007: Design and Manufacturing I, which utilize control systems and micro controllers, respectively. The ability to prepare students for these courses in advance could mean that they study more advanced material during the semester.

Faculty Research: Gareth McKinley

How to Get Fresh Water Out of Thin Air

By David Chandler, MIT News Office

In some of this planet's driest regions, where rainfall is rare or even nonexistent, a few specialized plants and insects have devised ingenious strategies to provide themselves with the water necessary for life: They pull it right out of the air, from fog that drifts in from warm oceans nearby.

Now researchers at MIT, working in collaboration with colleagues in Chile, are seeking to mimic that trick on a much larger scale, potentially supplying significant quantities of clean, potable water in places where there are few alternatives.

Fog harvesting, as the technique is known, is not a new idea: Systems to make use of this airborne potable water already exist in at least 17 nations.

But the new research shows that their efficiency in a mild fog condition can be improved by at least fivefold, making them far more feasible and practical than existing versions.

The new findings have just been published online by the journal *Langmuir*, a publication of the American Chemical Society, in a paper by MIT postdoc Kyoo-Chul Park (PhD '13), MIT alumnus Shreerang Chhatre (PhD '13), graduate student Siddarth Srinivasan, chemical engineering professor Robert Cohen, and mechanical engineering professor Gareth McKinley.

Fog-harvesting systems generally consist of a vertical mesh, sort of like an oversized tennis net. Key to efficient harvesting of the tiny airborne droplets of fog are three basic parameters, the researchers found: the size of the filaments in those nets, the size of the holes between those filaments, and the coating applied to the filaments.

Most existing systems turn out to be far from optimal, Park says. Made of woven polyolefin mesh – a kind of plastic that is easily available and inexpensive – they tend to have filaments and holes that are much too large. As a result, they may extract only about 2 percent of the water available in a mild fog condition, whereas the new research shows that a finer mesh could extract 10 percent or more, Park says. Multiple nets deployed one behind another could then extract even more, if so desired.

While some of the organisms that harvest fog do so using solid surfaces – such as the carapace of the Namib beetle, native to the Namib desert of southern Africa – permeable mesh structures are much more effective

Similarly, the veins of nasturtium leaves, unlike those of most leaves, are on top, where they serve to break up droplets that land there. The MIT researchers found that drops bounced off both butterfly wings and nasturtium leaves faster than they bounced off lotus leaves, which are often considered the "gold standard" of nonwetting surfaces.

Varanasi points out that creating the needed surface textures is actually very simple: The ridges can be produced by ordinary milling tools, such as on the surface of an aluminum plate, making the process scalable to industrial levels. Such textures could also be created on fabric surfaces, he says, as a potential replacement for existing waterproof coatings whose safety has been called into question by the Environmental Protection Agency.

Howard Stone, a professor of mechanical and aerospace engineering at Princeton University who was not involved in this work, says, "This paper provides new ideas and new insights for how a surface texture can reduce the contact time of a bouncing drop. ... It will be interesting to see possible ways these ideas might be applied in the future."

In addition to waterproofing and prevention of surface icing, the technique could have applications in other areas, Varanasi says. For example, the turbine blades in electric power plants become less efficient if water builds up on their surfaces. "If you can make the blades stay dry longer, you get a bump up in efficiency," he says. The new technique could also reduce corrosion on surfaces where droplets, especially if they are acidic or contain contaminants, contribute to degradation.

The research received support from the Defense Advanced Research Projects Agency, the MIT Energy Initiative, the National Science Foundation, and the MIT-Deshpande Center for Technological Innovation.

Find out more ►

Read the full MIT News article:
http://bit.ly/1aMscs3

Faculty Research: Tonio Buonassisi

Making Silicon Devices Responsive to Infrared Light

By David Chandler, MIT News Office

Researchers have tried a variety of methods to develop detectors that are responsive to a broad range of infrared light – which 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 MIT, could eliminate many of those limitations.

The new approach is described in a paper published in the journal *Nature Communications* by MIT graduate student Jonathan Mailoa, associate professor of mechanical engineering Tonio Buonassisi, and 11 others.

Silicon, which forms the basis of most semiconductor and solar-cell technology, normally lets most infrared light pass right through. This is because the material's bandgap – a fundamental electronic property – requires an energy level greater than that carried by photons of infrared light. "Silicon usually has very little interaction with infrared light," Buonassisi says.

Various treatments of silicon can mitigate this behavior, usually by creating a waveguide with structural defects or doping it with certain other elements. The problem is that most such methods have significant negative effects on silicon's electrical performance; only work at very low temperatures; or only make silicon responsive to a very narrow band of infrared wavelengths.

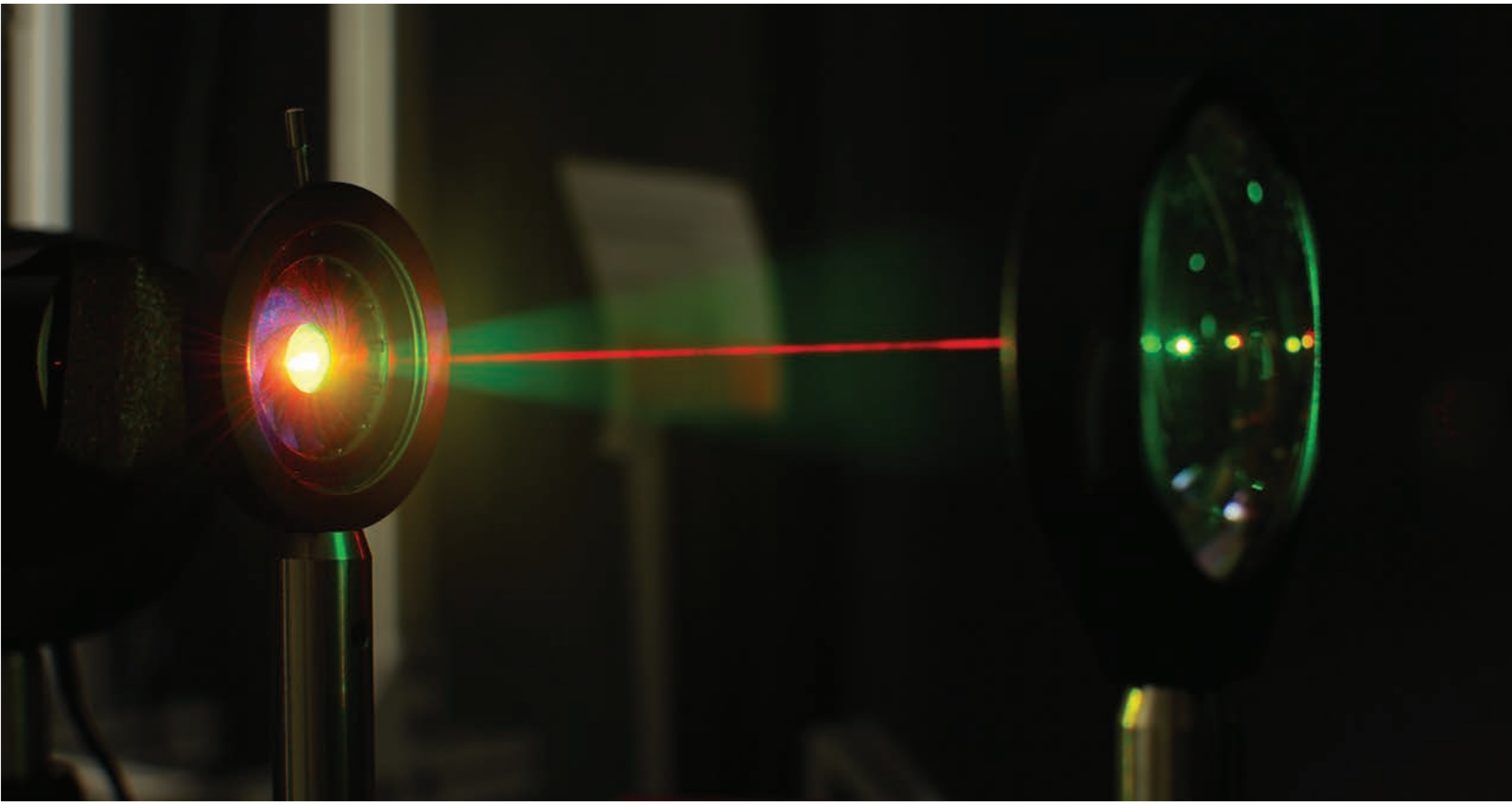
Professor Tonio Buonassisi

The new system works at room temperature and provides a broad infrared response, Buonassisi says. It incorporates atoms of gold into the surface of silicon's crystal structure in a way that maintains the material's original structure. Additionally, it has the advantage of using silicon, a common semiconductor that is relatively low-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 don't have time to escape before getting trapped in the lattice.

In fact, the material contains about 1 percent gold, an amount more than 100 times greater than silicon's solubility limit: Normally, this is as if one put more sugar into a cup of coffee than the liquid could absorb, leading to accumulation of sugar at the bottom of the cup. But under certain conditions, materials can exceed their normal solubility limits, creating what's called a supersaturated solution. In this case, the new processing method produces a layer of silicon supersaturated with gold atoms.

"It's still a silicon crystal, but it has an enormous amount of gold near the surface," Buonassisi says. 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, he says.



A laser beam is used in the lab to test the gold-hyperdoped sample of silicon to confirm its infrared-sensitive properties.

"It's a big milestone, it shows you can do this," Mailoa says. "This is especially attractive because we can show broadband infrared response in silicon at room temperature." While this is early-stage work, for some specialized purposes – such as a system for adjusting infrared laser alignment – it might be useful relatively quickly.

This use of gold was a surprise: Usually gold is incompatible with anything involving silicon, Buonassisi says. Even the tiniest particle of it can destroy the usefulness of a silicon microchip – so much so that in many chip-manufacturing facilities, the wearing of gold jewelry is strictly prohibited. "It's one of the most dangerous impurities in silicon," he says.

But at the very high concentrations achieved by laser doping, Buonassisi says, gold can have a net positive optoelectronic impact when infrared light shines on the device.

While this approach might lead to infrared imaging systems, Buonassisi says, its efficiency is probably too low for use in silicon solar cells. However, this laser processing method might be applicable to different materials that would be useful for making solar cells, he says.

The research was funded by the U.S. Army Research Office, the National Science Foundation, the U.S. Department of Energy, and the MIT-KFUPM Center for Clean Water and Energy, a joint project of MIT and the King Fahd University of Petroleum and Mining.

Find out more ► **Read the full MIT News article:**
http://bit.ly/L5gX8W

Student Spotlight

Guangtao (Taotao) Zhang (Candidate SB '14)

by Alissa Mallinson

Six years ago, Guangtao (Taotao) Zhang had just moved to the US from China during her junior year of high school, and she didn't speak a word of English.

Now, a senior majoring in mechanical engineering at MIT, she is preparing to graduate and begin a new job at Apple as an iPad product design engineer.

The path she took to get from A to B wasn't the most direct one, nor did it all go as planned, but it was undoubtedly a series of challenges overcome. For someone with such distaste for uncertainty, Zhang embraced change and opportunity with grace and excitement every step of the way.

Her first major obstacle was learning a new language. It hindered her college application process, but she took it with stride. She started her college career at Clarkson University with two years of college credit already under her belt as a result of the AP classes she took in high school. But three semesters in, she felt unengaged with her schoolwork and confused about what do to next. She took a semester off to figure things out, working at GE Transportation in the meantime.

"I felt like I wasn't being challenged and wasn't growing or improving myself," explains Taotao. "That's why I started considering something else. My thought process has always been that if you don't try to reach higher, then you will never reach anything higher."

She decided to apply to MIT as a transfer student, instead of graduating almost two years early. She was accepted and started MIT as a sophomore, starting over for the third time in almost as many years.

With several new and intimidating challenges in front of her, Taotao did what many people would not: She flourished. Not only did she keep her head above water, but she also earned excellent grades; reignited the ASME student chapter at MIT – which now has almost 200 members; and conducted high-level research, working on the mechanical aspects of a pin matrix apparatus for rigid 3D surfaces at the MIT Media Lab (watch a video at http://tangible.media.mit.edu/project/inform), and on the running dynamics of Professor Sangbae Kim's robotic cheetah. Professor Douglas Hart asked her to lead this semester's Course 2.013: Engineering System Design, and Apple offered her a coveted internship – and eventually a full-time job – to work on product design.

"Most of my experience has been in individual-based courses or in small groups. But leading Course 2.013 is forcing me to learn how to live with some uncertainties and be able to delegate. It's been uncomfortable for me, but I think it will be a valuable lesson."

Although Taotao is still interested in attending graduate school to earn a master's degree in mechanical engineering, she couldn't pass up spending a few years at Apple first. "I wasn't planning on spending this past summer doing an internship," says Taotao. "I thought I would spend my junior summer conducting research, but I serendipitously ended up at an Apple info session last year, and before I knew it, they were setting me up for technical interviews and offering me an internship. All of my coursework has focused on control and robots, but my internship was focused on product design. It ended up completely diverging my path, but it worked out."

In the little free time she has after all her other obligations are fulfilled, Taotao relaxes with Chinese dance as part of the MIT Asian Dance Team, picking up where she left off almost 10 years ago as a young girl in China. Well, at least some things haven't changed.

VIDEO: http://bit.ly/1ayHPo6

"Leading Course 2.013 is forcing me to live with some uncertainty and be able to delegate."

-Taotao Zhang

Student Spotlight

Spencer Wilson (Candidate SB '15)

by Alissa Mallinson

It is not unusual for some undergraduate students to start the famously hands-on Course 2 program in mechanical engineering at MIT with little machine experience.

But not Spencer Wilson (candidate SB '15). When he arrived at the steps of 77 Massachusetts Avenue in September of 2011, he already had well formed calluses on his hands.

Growing up in rural South Georgia, Wilson lived with his mother and father on a plot of land that was the aggregate of three separate properties, one of which had previously housed a fully functioning air conditioning factory. Wilson's father is an architect and woodworker, his mother is a small business owner, and his backyard – which contained copious amounts of scrap metal and various piles of other scraps and parts – was a budding engineer's goldmine. His house was in a constant state of flux and renovation, and his father taught him how to use several tools that were none-so-unfamiliar by the time he saw them in lab as an undergraduate in MechE.

"I'm taking a manufacturing class right now, and the topics in the book are things my grandfather taught me in simple terms when I was a kid," says Wilson. "It's interesting to see it now from a scientific point of view....I feel like a lot of people discredit learning those ideas formally, but MIT does a really good job of taking something that's typically informal and imparting it through formal training, taking something that's often learned through apprenticeship and turning it into a class. Courses 2.007 and 2.008 (Design and Manufacturing I and II) are both great examples."

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Although he has little free time these days, dedicating most of it to his studies, as a high school student Wilson spent a lot of his time building science fair projects, helping his father renovate the house, and restoring a Volkswagen bus. One of his science projects was building a refrigerator that is cooled with heat; another was the development of an inflatable chair insert to help seniors or pregnant women rise out of their seat.

"There was always something to do," says Wilson, "I was always occupied. I was focused on school and doing projects on the side. If I thought of something I wanted to do, my parents said, 'OK, we have some huge aluminum triangles in the backyard that you can use as the frame.' And I would just build it."

These days, Wilson is still building on those projects. For his senior thesis, he's working at MIT's Center for Bits and Atoms, focusing on machine design and fabrication projects.

Wilson says, "I would love to do a project along the lines of what Professor Amos Winter did with his Leveraged Freedom Chair (see page 8). I love the idea of building something that's perfect in the US but that I know is going to break when I get it in the context of a developing community, and to be able to deal with that and fix it. That's pure mechanical engineering."

Student Snapshots

New Faculty

John Hart, Associate Professor

During his six years at the University of Michigan, Associate Professor John Hart established a leading research group focused on creating new manufacturing technologies for micro- and nanostructured materials and devices, and for their assemblage and integration at larger scales. Most notably, his research group made signature innovations toward the scalable manufacturing of materials incorporating aligned carbon nanotubes (CNTs). Their groundbreaking understanding of how CNTs can be manipulated into 3D shapes by capillary forces led to the invention of the "capillary forming" process, which enables robust and repeatable assembly of CNTs for use in electronics and micromechanical devices and as a platform for the engineering of robust textured surfaces and high-performance interfaces. Working with both graduate and undergraduate students, Professor Hart also led the realization of several new award-winning machines and instruments. His work has been recognized by two R&D 100 Awards; a CAREER Award from the NSF; and Young Investigator Awards from DARPA, the Air Force, and the Navy.

Mathias Kolle, Assistant Professor

Assistant Professor Mathias Kolle earned his PhD in physics at the Cavendish Laboratories at Cambridge University in 2010, followed by work as a postdoctoral researcher at Harvard University in the School of Engineering and Applied Sciences. His past research was focused on the manufacture of novel photonic structures, optical instrumentation and modeling, biological light manipulation strategies, and material science. In his current research he explores biological photonic systems and the engineering and application of bio-inspired dynamic photonic materials. His scientific background and interests include bioimaging, optical sensing technologies, nanophotonics, photovoltaics, x-ray nanotomography, and plasmonic materials. Professor Kolle's dissertation was published in the Springer series "Springer Theses: Recognizing Outstanding PhD research." He has also received the dissertation prize from the German Physical Society for the best PhD in the field of condensed matter (2010) and the Salje Medal of Clare Hall College, Cambridge, for the best PhD in the sciences.

Themis Sapsis, American Bureau of Shipping Career Development Assistant Professor

Assistant Professor Themis Sapsis graduated from the National Technical University of Athens where he earned his diploma in naval architecture and marine engineering in 2005. He began his graduate studies at MIT in 2006, earning his PhD in mechanical engineering in 2010 under the supervision of Professors Pierre Lermusiaux and George Haller. Professor Sapsis's research is in the areas of stochastic dynamics with applications to the general area of ocean engineering, including uncertainty quantification of engineering flows, probabilistic prediction of extreme events in nonlinear waves, passive protection configurations for mechanical systems, and energy harvesting from ambient vibrations. As an MIT student, he was named the George and Marie Vergottis MIT Presidential Fellow. Professor Sapsis has also received the European Union's Marie Curie Fellowship twice, and he received the Best Paper Award for Young Scientists at the Chaotic Modeling and Simulation Conference in 2009.

Faculty Promotions

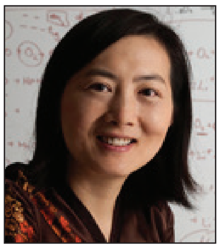
Martin Culpepper, Full Professor

Professor Martin Culpepper is a widely respected leading authority in the field of precision engineering. His research focuses on the design, fabrication, and testing of high-performance machine systems that make, manipulate, or measure parts and features at length-scales and/or precision levels not previously possible or practical. Research from his group has produced landmark achievements in precision machine systems while also laying a foundation for both academicians and practicing designers, providing new tools to enable design of next-generation precision systems. Professor Culpepper's HexFlex Nanopositioner is widely considered a signature achievement in the design and fabrication of small-scale, multi-degree-of-freedom positioning systems. His research group developed a foundational framework, considered by many to be a breakthrough in the field, for the design of multi-degree-of-freedom systems: the FACT (Freedom and Constraint Topology) framework rigorously accounts for the freedom and constraint space of the desired motion and provides families of design topologies that will achieve the required degrees of motion. Professor Culpepper is also widely respected for his commitment to education and mentoring of students. His courses at MIT challenge students in the rigorous design of machine elements based on engineering principles and truly embody the Institute's *mens et manus* motto. Furthermore, he has brought this approach to industry through a series of professional education courses directly impacting the practice of precision machine design. Professor Culpepper has a long history of service to his profession and to MIT. He has played an active leadership role in shaping the Laboratory for Manufacturing and Productivity, and currently serves as Graduate Admissions Officer in Mechanical Engineering. Professor Culpepper has been recognized with several awards, including the prestigious NSF PECASE award and R&D 100 Awards. Most recently, he was named a Fellow of the American Society of Mechanical Engineers, as well as Maker Czar overseeing builder space for the department.

Anette Hosoi, Full Professor

Professor Anette "Peko" Hosoi's research contributions lie at the juncture of nonlinear hydrodynamics, microfluidics, and bio-inspired design. She is a world leader in the study of the hydrodynamics of thin fluid films and in the nonlinear physical interaction of viscous fluids and deformable interfaces. A common theme in her work is the fundamental study of shape, kinematic and rheological optimization of biological fluid systems for locomotion, and their application to the emergent field of "soft robotics." A unique mixture of experimental work, numerical simulation, and theoretical analysis characterizes her work, and it combines elements of both engineering design and mathematical optimization. Her work is widely known and internationally respected by physicists, biologists, roboticists, and applied mathematicians, as well as engineers, and is used to guide the engineering design of robotic swimmers, crawlers, burrowers, and other mechanisms. She is also an exceptional and innovative teacher, an inspiring mentor, and an outstanding communicator of science in general. Her pedagogical contributions have spanned several core disciplines in our undergraduate program as well as our graduate program. She has been awarded both the Junior Bose and Bose Award for her teaching excellence in the School of Engineering; she was elected a MacVicar Fellow; and most recently she won our Department's coveted Den Hartog Award for Teaching Excellence. She is extremely active in service to the Department as Undergraduate Officer and Associate Head of Education, to the Institute through the Lincoln Labs Campus Interaction Committee, and to the professional community at large as an elected member of the American Physical Society (APS) Division of Fluid Dynamics (DFD) executive committee and more recently as chair of the APS DFD Media & Science relations committee. Professor Hosoi is a member of the Defense Science Study Group and was recently elected to Fellowship in APS.

Yang Shao-Horn, Full Professor



Professor Yang Shao-Horn is widely recognized as a world-leading authority in electrochemical energy storage and conversion. Her research addresses a grand challenge in electrochemical energy – the identification and design of catalysts with enhanced activity levels that will yield high-energy and efficient energy storage and conversion to enable cost-effective renewable energy. Professor Shao-Horn and her group probe and unravel the underlying molecular-level mechanisms of electrocatalytic reactions and the impact of these mechanisms on device performance. Her group is recognized for deep, fundamental contributions across a range of major challenges in electrochemical energy, including breakthroughs in lithium-ion batteries, lithium-air batteries, PEM fuel cells, and solid oxide fuel cells. Professor Shao-Horn is admired for the creativity, innovation, vision, and leadership that she brings to the field and is also widely respected for her scholarly depth and precision. Most recently, her research has resulted in landmark achievements in understanding the fundamental atomic-level mechanisms governing the catalytic activity of transition metal oxides. She has utilized these mechanistic-based insights to construct design principles and discover new oxides with catalytic performance one order of magnitude greater than the current state-of-the-art. This discovery is considered both profound and practical – profound for its grounding in deep mechanistic understanding that can guide the field, and practical for its potential to replace precious metal catalysts with more cost-efficient oxides. Professor Shao-Horn is also recognized for her excellence in the mentoring of students and postdocs. Her ability to motivate, inspire, and nurture emerging researchers early on in their careers is much admired. She is now utilizing these talents to spearhead professional development activities for our graduate students. Her multidisciplinary course on electrochemistry has attracted students from across the School and the Institute as well as from other universities. Professor Shao-Horn has published over 130 archival journal papers with more than 5,000 citations at MIT. She is also a leader in her profession, serving on the advisory board of leading journals in energy science and physical chemistry, and initiating new conference symposia on this rapidly expanding field. She is a highly sought-out speaker and has been recognized by her professional community with the Charles Tobias Young Investigator Award from the Electrochemical Society, the Tajima Prize from the International Society of Electrochemistry and, most recently, the 2013 Research Award by the International Battery Materials Association.

Maria Yang, Associate Professor

Associate Professor Maria Yang is an emerging leader in early stage design. In the field of engineering design, early stage conceptual design plays a dominant role in determining the functional performance as well as the manufacturing cost of the final product. It is during early stage design that the vision of a product is born. Historically, design process research has led to the development of numerous tools, from CAD to robust design methods, providing the ability to optimize final designs. However, understanding the factors and developing methods to guide and enhance the more ambiguous, yet highly impactful, human-centric aspects of early stage design are just beginning to be addressed from a fundamental perspective. Professor Yang's research focuses on how informal design representations (sketches, physical prototypes, models, discussions) drive early stage design and influence the way a design team engages in the process of design. These informal representations are inherently part of the "language of design" with which engineers generate ideas, communicate early concepts, and select designs for final optimization. Professor Yang's research has identified the important aspects of sketching (timing, quantity, frequency, engineering detail, quality) that govern successful design outcomes as well as

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Department News

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the level and form of sketch refinement needed for effective customer feedback, in contrast to that needed for idea generation. Her work has also identified key attributes of physical prototyping that result in successful design outcomes, where simplified prototypes that build on one another early on correlate with better design outcomes, but premature detailed prototyping is not as effective. Success in this field has the potential to be transformative and to yield more effective and efficient design processes for greater innovation in product development. Professor Yang is recognized for her abilities to educate and inspire the next generation of design engineers, educators, and researchers through her work in the classroom and through numerous project-based design workshops. She has been recognized with an NSF CAREER Award, the MIT Murman Award for Undergraduate Advising, and a best paper award at the 2013 ASME Design Theory and Methodology Conference. She was recently named a fellow of the ASME.

Remembering Professor Emeritus Stephen Crandall

Stephen H. Crandall, the Ford Professor of Engineering Emeritus at MIT, a pioneer in random vibrations and rotordynamics, and a leader in transforming mechanics into an engineering science, passed away Oct. 29, in Needham, Mass. He was 92 years old.

After earning his PhD in mathematics from MIT in 1946, Crandall transferred to the Department of Mechanical Engineering. There, he was appointed to assistant professor of mechanical engineering in 1947, associate professor in 1951, then to professor in 1958. He was named Ford Professor of Engineering in 1975, and an emeritus professor in 1991. While at MIT, Crandall led the transformation of mechanics into an engineering science, acting 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 was a pioneer of random vibrations research, offering the first academic course on the subject in 1958, and subsequently directing 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 awarded Crandall 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.

A memorial service will be held at the MIT Chapel on Friday, Feb. 21, 2014, at 3 p.m., followed by a reception at the Hart Nautical Gallery. If you are unable to attend, but would like to send a story or photograph to share at the service, please email MechE Faculty Affairs Administrator Marion Gross (meg@mit.edu).

In lieu of flowers, gifts in memory of Stephen H. Crandall may be made to MIT to support the Crandall Language Fund, which purchases instructional material for students, or the Crandall Fund for Study in Mechanics, which supports graduate students in mechanical engineering.

Please make checks payable to MIT and note the account: Language Fund (2162200) or Fund for Study in Mechanics (2175900). Checks may be mailed to: Bonny Kellermann, Director of Memorial Gifts, Massachusetts

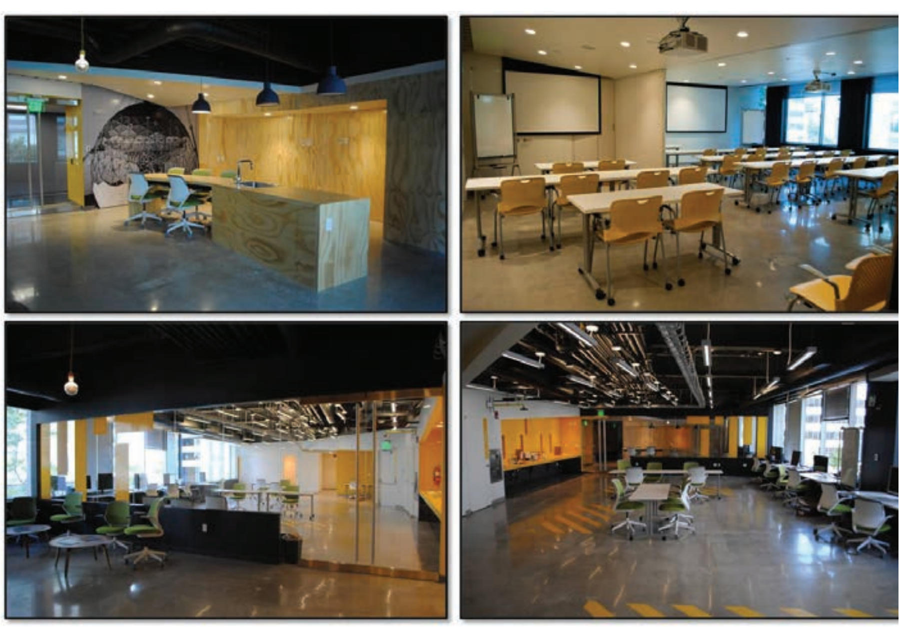
Institute of Technology, 600 Memorial Drive, W98-500, Cambridge, MA 02139. Gifts may also be made by credit card. Please indicate that your gift is in memory of Stephen H. Crandall.

Beaver Works Center for Hands-On Education

The Lincoln Lab Beaver Works Center – a newly renovated, 5,000 square-foot facility comprised of multiple research areas, classrooms, and a prototyping lab – opened this fall to support project-based research and education in the School of Engineering. The facility is ideally suited for students in MechE taking hands-on courses, pursuing UROP research, or performing graduate activities that overlap MIT Lincoln Laboratory, a joint partner in the venture with broad interests in advanced systems and technology. The center is located at 300 Technology Square in Kendall Square, on the edge of the MIT campus. It offers students flexible space, with an abundance of tools for building and prototyping, including standard wood/machine shop tools, 3D printers, laser cutters, and heavy machine tools, as well as modular work benches that can wheel in and out of rooms as needed.

Several Beaver Works projects – many of which are major elements of capstone courses – have already been completed, such as self-deployed RC aircrafts designed and built by students in Course 2.007 and unmanned underwater vehicle (UUV) propulsion systems, designed and prototyped in Professor Doug Hart's year-long 2.013/4 sequence.

"About three years ago we challenged Professor Doug Hart and students in MechE to develop an energy source for underwater systems that increases endurance by tenfold. The result is a novel method that exploits the energy released when aluminum reacts with water," says Nicholas Pulsone, a senior staff member of Lincoln Laboratory (LL) and LL advisor to Hart's 2.013/4.



"The Beaver Works Center is the perfect environment for bringing together students and faculty from MIT along with engineers from Lincoln Laboratory and Woods Hole Oceanographic Institution to work on this type of exciting project."

From Grabbing Water to Cleansing Palates – Professor Pedro Reis

Professor Pedro Reis's team has developed a floral pipette based on the behavior of certain water lilies, which float at the surface of ponds or lakes while anchored to the floor. As water rises, hydrostatic forces act to close a lily's petals, preventing water from flooding in. Taking the water lily as inspiration, Professor Reis designed an upside-down flower that does the opposite, grabbing water as it's pulled up, thereby reversing the role of gravity.

Reis and John Bush, professor of applied mathematics at MIT, calculated the optimal petal size for capturing a small sip of liquid, such as a palate cleanser, then used

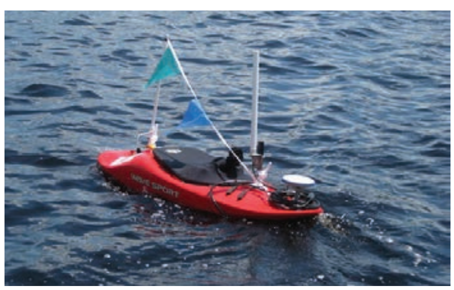
a 3D printer to form molds of the flower, each of which is about 35 millimeters wide – about the size of a small dandelion. "By pulling this out of liquid, you get something that seals shut and looks like a cherry. Touch it to your lips, and it releases its fluid," Bush says. The pipette is now being used by renowned Spanish chef Jose Andres.
-*Jennifer Chu, MIT News Office*

Anklebot – Professor Neville Hogan

The ankle – the crucial juncture between the leg and the foot – is an anatomical jumble, and its role in maintaining stability and motion has not been well characterized. Professor Neville Hogan and his colleagues in the Newman Laboratory for Biomechanics and Human Rehabilitation have developed a way to measure the stiffness of the ankle in various directions using a robot called the "Anklebot." The robot is mounted to a knee brace and connected to a custom-designed shoe. As a person moves his ankle, the robot moves the foot along a programmed trajectory, in different directions within the ankle's normal range of motion. Electrodes record the angular displacement and torque at the joint, which researchers use to calculate the ankle's stiffness. From their experiments with healthy volunteers, the researchers found that the ankle is strongest when moving up and down, as if pressing on a gas pedal. The joint is weaker when tilting from side to side, and weakest when turning inward. The findings, Hogan notes, may help clinicians and therapists better understand the physical limitations caused by strokes and other motor disorders.
-*Jennifer Chu, MIT News Office*

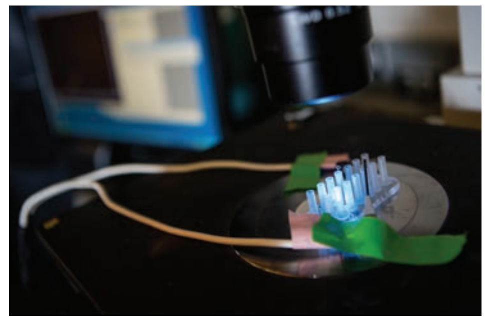
Mission TULip – Professor Franz Hover

Professor Franz Hover and graduate student Brooks Reed have demonstrated a multi-vehicle marine robotic system to track and pursue agile underwater targets such as sharks. The vehicles measure range to the target and collaborate to jointly estimate the target's position and drive to stay in formation relative to it. For wireless underwater communication, acoustics are the only technology suitable for distances more than 100 meters, but they suffer from extremely low bit rates and frequent packet loss. Despite these severe communication



constraints, Hover and Reed's experimental results demonstrate that aggressive dynamic tracking and pursuit is possible underwater, and they quantify some of the tradeoffs involved in designing such a system. They also hope to extend these methods to include the tracking of dynamic ocean features like a flowing oil spill or temperature front, utilizing similar communication and control techniques and additionally leveraging ocean model forecasts.

Good and Bad Bacteria – Professor Cullen Buie



There are good bacteria and there are bad bacteria – and sometimes both 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. Professor Cullen 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. Researchers injected bacteria through one end of each channel, and observed how cells travel from one end to the other. From their experiments, the researchers found that their device is able to distinguish benign cells from those that are better able to form biofilms.
-*Jennifer Chu, MIT News Office*

Talking Shop with David Gossard

Professor Gossard has always had a strong interest in education, and that tendency has directed a lot of his attention throughout the decades as a MechE professor. He was one of the first MechE faculty members to teach an MITx course on the edX platform (last spring, senior lecturer and principal research scientist Simona Socrates taught 2.01x). His fundamental dynamics course, 2.03x, debuted on edX this past October.

What inspired you to be one of the first professors to teach an MITx course on the edX platform?

A very large fraction of my professional life has been focused on education. I care a lot about teaching and how kids learn, and the edX platform is a computer-based technology that appeals to my nature. I'm intrinsically interested in education in general and online education in particular. It is the wave of the future, and I would rather be a part of it than watch it go by from the sidelines.

Looking at this through the eyes of a dedicated educator of almost 40 years, why are MITx courses so beneficial to students?

There are several things. One is that there is a powerful element of scale to this. The MIT classes I teach are about 100 to 150 students each, and to date everything has been done on paper. But my MITx class has more than 9,000 registered students.

The second is instant feedback. When you turn in a problem set, TAs and faculty members do their best to give MIT students some feedback, but of necessity it's delayed by at least a week in time. This platform gives them instant feedback. Not only does it tell them when they're wrong, but it also gives them hints as to why. And that feedback is infinitely scalable.

How does the element of scale affect the quality?

You can ask questions online in a discussion forum, and these forums are monitored by TAs, but there is an aggregating process. You can't respond to 1,000 or 10,000 emails. But you can have TAs read dozens of emails and extract common questions. One of the things we did was experiment with virtual office hours where those questions get extracted and aggregated. Then a single professor creates a video response to the most popular questions, and that response does scale. Is it the same as you sitting across the table from me? No. But to me the questions is: "How do you use technology that is at your disposal to address questions of scale in education?" To me, that is what this is all about. It's a big work in progress.

Professor David Gossard (PhD '75) has been a faculty member of the Department of Mechanical Engineering since he earned his PhD here in 1975, having previously earned his bachelor's and master's degrees in mechanical engineering from Purdue University. He began his tenure in the design and manufacturing group and has remained there ever since, but he has also been very interested in computer science and its intersection with mechanical engineering. His research activities included solid modeling and computational geometry, and when the computer-aided design (CAD) industry was in its infancy, his former students John Hirschtick and Bob Zuffante founded SolidWorks, whose software for desktop 3D solid modeling became an industry leader.

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Coming in the next issue:

- Ocean Engineering

Professor Sanjay Sarma, director of the Office of Digital Learning (left), stands next to Professor Gareth McKinley and Assistant Professor Amos Winter (right) in front of Ferrari's pits at the Formula 1 US Grand Prix in Austin, Texas, this past November.