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Innovation and Entrepreneurship: The MechE Way of Life

Curiosity and creativity, together with a *mens et manus* approach, fuel innovation and entrepreneurship in the department.

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Innovation and Entrepreneurship: The MechE Way

by Alissa Mallinson

Innovation and creativity are concepts that imbue everything we do in the Department of Mechanical Engineering. They're woven into every lab, every experiment, every faculty member and graduate student rooted here. It's who we are.

But as Professor David Wallace teaches his students, innovation and creativity are not the same thing. Creativity is the seed for innovation, and – despite popular belief – it can be learned, according to Professor Ian Hunter. You must learn to think outside the box, to challenge traditional ways of approaching problems, and to develop a full toolbox of knowledge from which to pull.

"Part of the MIT way is to be very knowledgeable and to be able to compute quickly," says Professor Ian Hunter. "That allows you to analyze things around you and unlock opportunities more rapidly than others who might have to take the time to look things up. I find that students who have these skills become more creative."

"I always like to think about solving a problem in a way that might seem counterintuitive," says Professor Kripa Varanasi, "to potentially create something that you wouldn't think could happen, something that gives you a big jump in the ultimate performance."

If creativity is the seed, then innovation is creativity aptly applied. MechE students receive the knowledge and hands-on experience necessary to transform creativity into innovation, into a product that solves a real problem or fulfills a specific need, and the business acumen to turn innovation into entrepreneurship. As Professor Maria Yang explains, technology is just one way to spur innovation; conversely, many great products are driven by a deep understanding of the human needs of end users. It's important for engineers to recognize the difference between "technology push" and "market pull" and to be flexible enough to adjust their ideas as necessary.

The End (Users) Justify the Means

But why is it important for an engineer to know the market, to understand the end users?

"It doesn't matter if people have a second-grade education, they know more about their lives than I will ever know," says Professor Amos Winter. "It's important to start and finish with the end users because they're the ones who have to say, 'I have this need in my life'; and once it's done, it's the end users who have to say, 'Yes! This meets my need.' They're the ones who matter."

MIT mechanical engineers are taught to understand the entire process of product design from beginning to end – to become better innovators, they need to understand who they are innovating for and know how to work with others to get it done. They are taught through experience to appreciate the importance of each person's role in that process and to partner with them to create a cohesive, effective solution that's not only made well, but on time and on budget too.

"The key competitive battleground now is in the area of innovation," says Wallace. "If you have a fantastic hockey team but you show up at the wrong rink, you lose the tournament. Creativity and vision are the right rink. There are a lot of smart people in the world who are very good at executing the details, but ... in order to be competitive, it is also important to be thinking of the next big idea. To be a technical leader, you have to be able to do both."

Course 2.009 students present their invention at this past fall's presentation ceremony.

The Department's curriculum offers a series of undergraduate and graduate product design courses for this purpose – such as Course 2.00b: Toy Lab; Course 2.007: Introduction to Robotics; Course 2.009: Product Engineering Processes; Course 2.013/4: Engineering Systems Design and Development; and Course 2.739: Product Design and Development – as well as programs that integrate elements of fundamental business and marketing ideas, such as the Leaders for Global Operations (LGO) program in conjunction with the Sloan School of Management.

The MIT Entrepreneurial "Ecosystem"

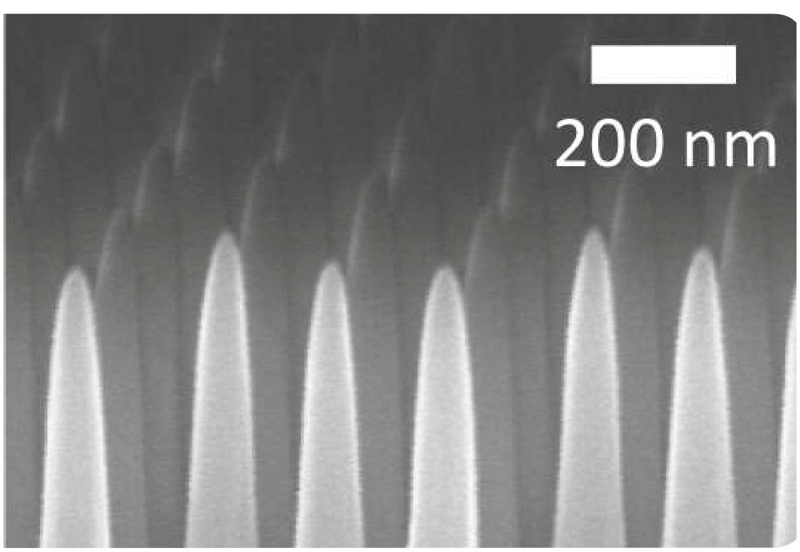
Even so, how could MechE students truly internalize that entrepreneurial drive if MIT as an Institute didn't live it? If our own faculty weren't themselves examples of that renowned MIT entrepreneurial spirit?

It's the fact that MIT lives that spirit that gives it the entrepreneurial ecosystem so coveted by others. Since the beginning, MIT's motto *mens et manus* ("mind and hand") has guided the MIT community toward industry partnerships and entrepreneurship through appreciation for the invention of useful ideas and products. According to a 2011 report by the MIT Martin Trust Center for Entrepreneurship, "if the active companies founded by living MIT alumni formed an independent nation, their revenues would make that nation at least the 17th largest economy in the world."*

The MIT support system is one of the best too — including the MIT Enterprise Forum, the Deshpande Center for Technological Innovation, the Martin Trust Entrepreneurship Center, and a multitude of competitions, such as the $100K Entrepreneurship Competition, the Lemelson-MIT Award, and the IDEAS Challenge, all of which award seed money to help grow promising ideas. Just in the past few years, several MechE students were recognized by all three competitions: Nathan Ball and Nikolai Begg, who each won the Lemelson-MIT Student Prize Award (see pages 14 and 20, respectively), Karina Pikhart and Kevin Cedrone, who each won the MIT IDEAS Challenge (see pages 16 and 29, respectively); and the Varanasi Lab team, which was awarded the Audience Choice Prize at the $100K Entrepreneurship Competition for their product LiquiGlide (see pages 17 and 30).

"Our education here doesn't make a distinction between people who are good at theory and people who are good with their hands, because at MIT, you need to be good at both," says Hunter. "That idea permeates our teaching and has become part of our entrepreneurial culture. As a result, our students are people who march across any discipline to find solutions to problems. And that's very much the MIT way. It's not only important for research, it's also important for successful startups."

MechE faculty are crucial links in this ecosystem of MIT entrepreneurial spirit and know-how. Almost all of them have been part of a commercialization process at one point or another, either by licensing a patent or by directly participating in a startup. In the past 10 years, MechE faculty have licensed more than 200 patents. For many faculty, it's an unparalleled feeling to see their creations utilized for the benefit of the planet and the public.



Graduate students working with Professors Gareth McKinley and George Barbastathis discovered a method of replicating nano cones on glass following a class project in Course 2.71: Optics to create anti-reflective, anti-fogging, self-cleaning glass.

*http://entrepreneurship.mit.edu/impact

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Professor George Barbastathis: Multi-Functional Glass

Professor George Barbastathis is no stranger to cool inventions. A co-inventor of the "Harry Potter"-esque invisibility cloak, Barbastathis's newest development is multi-functional glass that is anti-reflective, anti-fogging, and self-cleaning. First developed by two of his optics students as part of a class project, the anti-reflection idea is based on reducing the mismatch that occurs between the properties of air and glass when they meet, causing light to reflect.

The solution to this mismatch was widely known: nano cones placed at the interface of the two media create a gradual transition that smoothens the mismatch and prevents reflection. But they still needed a high aspect ratio to simultaneously meet two requirements: firstly, a diameter that is smaller than half the wavelength of light to make sure the light does not "see" them but rather propagates through them as though they were an effective medium; and secondly, the most length to ensure a slow transition from air to bulk glass to greatly reduce reflection.

In addition to addressing this mismatch, the nano cone shapes also alter the wetting behavior of glass, making it superhydrophilic (meaning that water droplets do not "bead up" on the surface) or, alternatively, after coating it with a very thin layer of an organic fluoro-chemical, making it superhydrophobic (meaning that water droplets form perfect spherical balls on top of the glass).

Post-doctoral candidate Chih-Hao Chang and graduate student Hyung-ryul "Johnny" Choi created a new process for manufacturing the cones using a shrinking mask of silicon that disappears gradually as it and the glass substrate are etched, thus creating an almost linear slope – a cone shape that is also very slender, with the slope determined by the relative etching speed between the silicon and the glass. Along with student Kyoo-Chul "Kenneth" Park and his advisors Professors Gareth McKinley from MechE and Bob Cohen from ChemE, the team soon demonstrated the multi-functionality conclusively in terms of both anti-reflection and wetting behavior.

"I always like to think about solving a problem in a way that might seem counterintuitive."

-Professor Kripa Varanasi

After graduate student Jeong-gil Kim joined the team, their next step was to replicate the cone shapes by impressing the patterned glass onto a polymer substrate. But they ran into another problem: holes were forming instead of cones. Disappointed at first, they soon realized that the holes were actually even more effective in one important way.

"The cones are very slender," explains Barbastathis, "and one could reasonably ask if they would shatter, and, in some applications, they might. On the other hand, the holes are not only more robust, but – if you can imagine what the negative of a cone looks like in a pattern – they support each other very well too."

As Barbastathis and his team think about licensing their nano pattern to companies, a number of other potential applications have emerged.

"Once we finesse the nano replication process, we should be able to manufacture them for a few pennies per square inch," he says. "We're quite excited and looking forward to the easy replication for use in applications such as photovoltaics, smart phones, and even building windows."

Professor Doug Hart: 3D Scanning and Imaging

Ending with the largest dental company sale in history even before receiving Series B funding, Brontes Technologies, Inc. began with 3D technology born out of particle image velocimetry that created 3D maps of flows using two cameras. That is what Professor Doug Hart was working on when he was asked to speak to a group of Taiwanese opto-electronics researchers working on 3D imaging for computer animation.

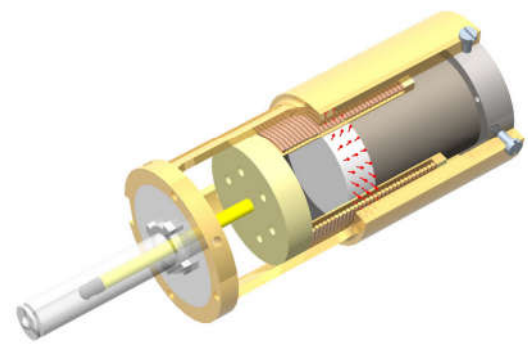
"I went out there wondering what a fluid dynamicist was going to talk to an electro optics group about," Hart says. "But at the last second it occurred to me that you could use the same technology we were using for velocimetry to image objects in 3D by simply projecting a speckled pattern onto an object and imaging it with a camera. Two years later, without my knowing, that group submitted a pre-proposal to the Taiwanese government to work with us on the idea."

After a successful collaboration wherein Hart's team developed a system to take human expression and apply it to animated characters, the two groups went their separate ways. Hart was trying to solve the problem of how to improve 3D processing speed without decreasing the accuracy. The less spatial disparity between the two cameras, the better the processing, but as they approached the limit, they wondered what to do next.

"I was sitting in my office asking myself how we could get them any closer when I realized that we could put an off-axis aperture in the system and rotate it," says Hart. "It was like taking 50 cameras and putting them all in one tiny lens, and then being able to dynamically control the imaging."

They teamed up with the then-newly formed MIT Deshpande Center and entered the MIT $100K Entrepreneurship Competition (then a $50K competition), where they were joined by two MBA students. At the time, Brontes was pitching the system as a facial recognition device, but after a visit to the dentist by a team member, the group changed its mind and decided to develop the technology as a dental scanner instead. What developed as a result was the first video-rate intra-oral dental scanner, which looks like a toothbrush and scans the mouth, replacing the antiquated casting process. It was the right choice, because as they started to search for Series B funding, Brontes received an unexpected bid for purchase. Then a second, higher bid came in from 3M Company, and they decided to sell.

Professor Doug Hart's dental scanning technology.



An illustration of Professor Hunter's needleless injector.

When Hart was approached shortly thereafter about applying the technology to hearing aids, he didn't need much arm-twisting to start another company.

"After we sold Brontes," he says, "I felt like something was missing from my life, because there wasn't this intense excitement and hard work and team building. I had been bitten by the entrepreneurship bug."

The dental scanning technology was too big to fit into ear canals, so Hart created a second 3D system from scratch. The new invention resulted in Lantos Technologies' Lantos Scanner, a portable device that creates perfect-fit hearing aids.

Professor Ian Hunter: Bioinstrumentation

Professor Ian Hunter, director of the MIT BioInstrumentation Lab, is well known for his love of invention and his passion for commercialization. He has founded and/or co-founded 22 companies, the two most recent within the past year. MicroMS and Portal Instruments both spun out of instruments Professor Hunter invented with post docs and students in his lab.

MicroMS was developed in conjunction with Dr. Brian Hemond, one of Professor Hunter's PhD students. Together, the two created a miniature mass spectrometer (MS), an instrument for chemical analysis that is usually very large. The portable device they developed is handheld, with a manufacturing cost possibly as low as $100. It can be used to characterize smells, such as wine and coffee; to detect undesired chemicals such as lead or pesticides; or possibly even to deduce one's health status from breath analysis.

"I consider myself primarily to be an inventor, but I'm also a serial entrepreneur," says Professor Hunter. "I enjoy inventing things, and I like to make sure that if I've got an invention that is going to do good for the planet that it gets out there and gets commercialized. Rather than handing it off to somebody, I like to guide it through its initial stages."

Portal Instruments manufactures a jet injector that delivers drugs through the skin without a needle at specific depths and volumes. Following two years of successful feasibility studies, he decided that instead of continuing to adapt the technology to different applications, such as the eye and ear, he was ready to start optimizing it in the context of a startup company. Portal Instruments was incorporated late in 2012 with Dr. Patrick Anquetil (MIT PhD '05, Harvard Business School MBA '09), who Professor Hunter named CEO.

"There are four key philosophical approaches to innovation," says Professor Hunter. "One is to be able to carry a lot of laws and equations around in your head and be able to compute them quickly.

"Two is to surround yourself with great tools so you can implement an idea as soon as possible.

"Three is to surround yourself with people who can criticize what you are doing and keep you on your toes.

"And the last one is to be passionate about what you do. Without that, the other elements are irrelevant."

Professor Yang Shao-Horn: Lithium Air Batteries

It's clear why innovative product design and development are important, but what about innovative fundamental research? Without it, the game-changing discoveries and products you see at the end of the process would never exist.

Take Professor Yang Shao-Horn: Her Electrochemical Energy Lab's (EEL) fundamental research often has a domino effect that leads to a progressive series of discoveries, as is the case with their current research project to develop efficient lithium-air (Li-O2) batteries for electric cars.

Betar Gallant connects a lithium-air battery used for testing by Professor Shao-Horn's EEL lab.

Because Li-O2 batteries utilize oxygen for energy storage instead of the heavier transition metal-based materials in today's batteries, they represent the potential to create a lightweight battery with up to three times the energy density of standard lithium-ion batteries. The inefficient charging process in Li-O2 batteries and the inability to cycle (charge and discharge) more than a few times have posed significant obstacles, but if these challenges can be overcome, electric cars with rechargeable, lightweight batteries could become a consumer-friendly alternative to gasoline-fueled vehicles. With their eyes toward that goal, Shao-Horn and her team – Ethan Crumlin (SB '05, SM '07, PhD '12), now a post-doc at Lawrence Berkeley National Lab; recent graduate Betar Gallant (BS '08, SM '10, PhD '13); and Yi-Chun Lu (PhD '12), now an assistant professor at Chinese University of Hong Kong – made innovative developments that have progressed the fundamental understanding of lithium-air batteries and moved them closer to market.

Shao-Horn's group has pursued a strategy that combines fundamental characterization and electrode materials design to help address the efficiency challenges. In one project, the group developed a vertical carbon-fiber-based electrode, increasing the amount of void space – essential for maximizing the amount of discharge product and energy that can be stored – up to roughly 90% compared with approximately 60% in more conventional electrodes. The electrode structure enabled one of the highest gravimetric energy densities, 2400 Wh/kgelectrode, to be realized to date. The team was pleased to discover that an unintended consequence of this electrode development – where the carbon is arranged in an organized, vertically aligned "carpet" pattern – was the ability to visualize the electrode behavior during charge and discharge and "see" how the discharge product grows and disappears.

In another project, the team was able to watch the electrochemical reactions taking place in real time during discharge and charge using an *in situ* ambient pressure X-ray photoelectron spectroscope (XPS). Their study showed that using an all-solid-state battery with metal oxides as the oxygen electrode is crucial for