Vital Collaborations

The interdisciplinary field of biomechanics has found a natural home at Yale

From Waste to Energy

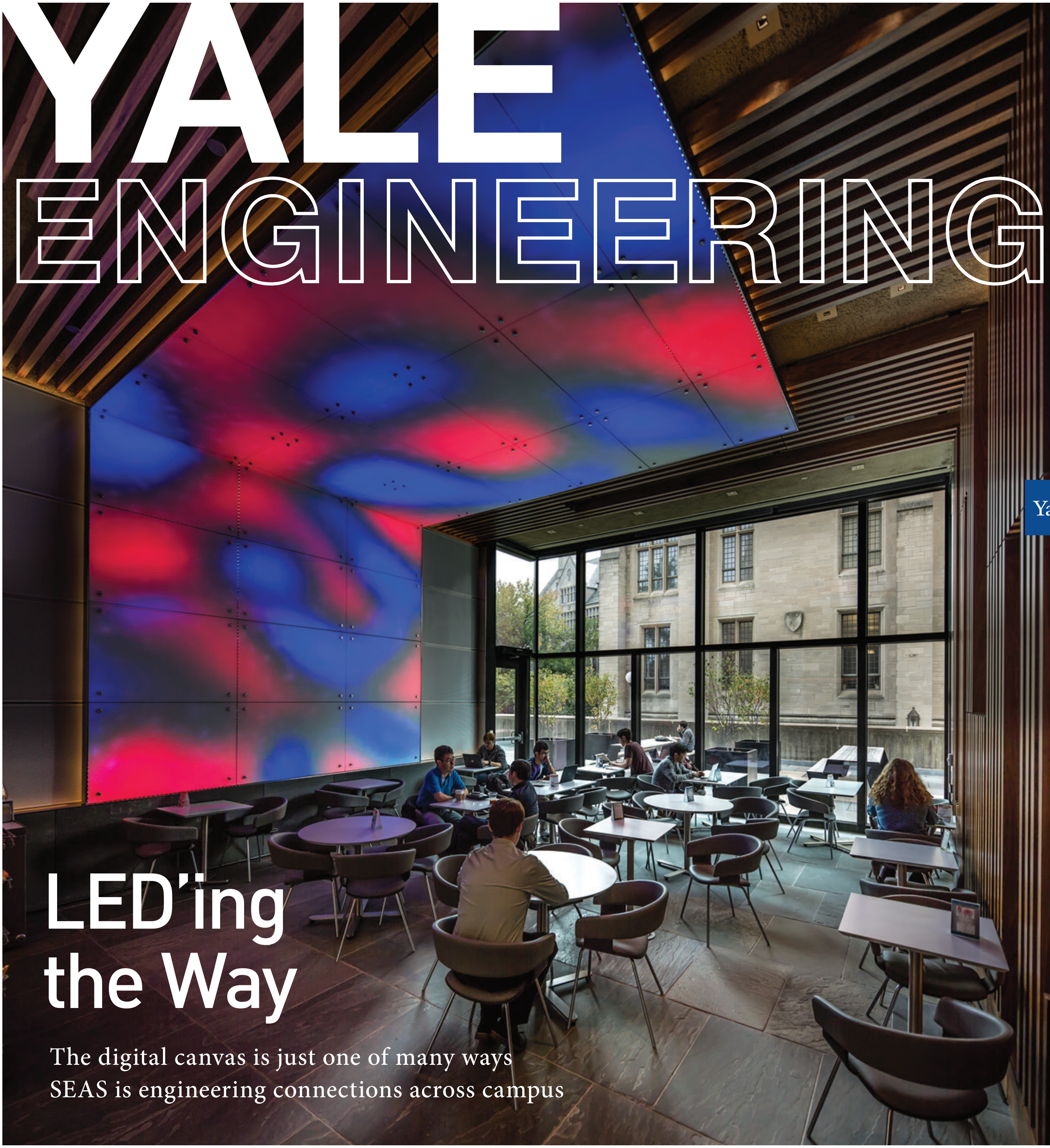
Yale engineers discover real benefits by utilizing a synthetic solution

Expanding the SEAS Network

The new Yale Institute for Network Science connects SEAS to a variety of researchers

2013-2014

YALE ENGINEERING



LED'ing the Way

The digital canvas is just one of many ways SEAS is engineering connections across campus

Yale

The Publication of Yale's School of Engineering & Applied Science

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YALE ENGINEERING 2013-2014

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Message From the Dean

More unified, more accessible, more innovative, more excellent — words to describe the rejuvenation of Yale Engineering?

These words actually come from new University President Peter Salovey's vision for Yale's future as this great University forges ahead in today's technology-driven world — his "design principles," if you will. Not every president has viewed Yale Engineering as central to the mission of the University, the obvious example being when the School of Engineering at Yale was dissolved in the mid-sixties. But as every engineer knows, "failed" experiments and ineffective designs generally offer more lessons than successful ones. Indeed, they often provide the opportunity to create something far better than what might have ever been imagined. Today, Yale's School of Engineering (formally re-established in 2008) has emerged revitalized and reinvented, a destination of choice for today's Yale students, engineers and non-engineers alike.

And what does Yale's 23rd President hold up as emblematic of his vision for Yale? Our new Center for Engineering Innovation and Design! In fact, as exemplified in the stories throughout this issue of Yale Engineering, our unique identity as a School of Engineering and Applied Science is built upon the four "design principles" articulated by President Salovey.

Our School takes special pride in being central to the future of Yale in the eyes of our new President. On this last point, we have complete confidence: President Salovey may have passed up a career in engineering many years ago, but we know that engineering is in his blood — his dad was a chemical engineering professor!

T. Kyle Vanderlick
Dean, School of Engineering & Applied Science

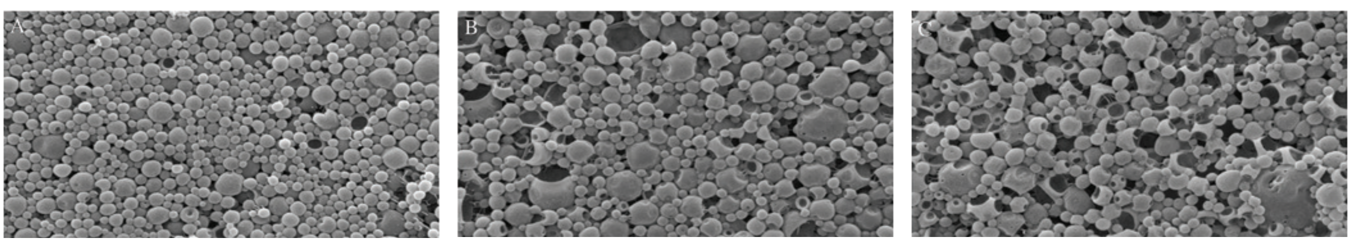
Year in Review

A look back at some of the news stories from the Yale School of Engineering & Applied Science over the last academic year

< 2012 : September

Solving Bat Echolocation

Electrical engineering professor Roman Kuc determined how bats use echolocation to find prey even when the prey isn't moving, like a grasshopper sitting still on a leaf. Kuc found that the flapping of the bat's wings caused its prey's wings to move as well, while the leaf moved much less. The findings have potential applications in improved robotic sensor design.



2012 : October ^

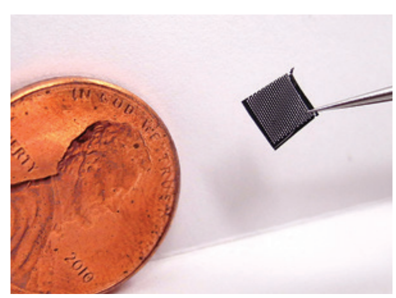
Fighting Viral Infections

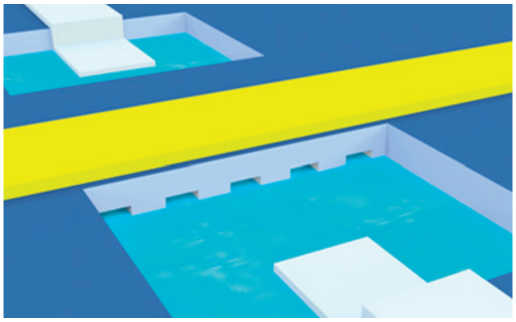
Chair of biomedical engineering W. Mark Saltzman and collaborators developed nanoparticles to prevent infection by a widespread viral STD: herpes simplex virus type 2. The group demonstrated that topical administration of their nanoparticles can improve survival after HSV-2 infection in mice. The nanoparticles carry short interfering RNA (siRNA) molecules that have been shown to interfere with nectin-1, a protein involved in HSV-2 infection and cell-to-cell transmission.

2012 : November

New Breed of Micro Fuel Cells

A team of Yale researchers led by Andre Taylor, associate professor of chemical & environmental engineering, and Jan Schroers, professor of mechanical engineering & materials science, developed a new breed of micro fuel cells that could serve as a long-lasting, low-cost, and eco-friendly power source for portable electronic devices, such as tablet computers, smart phones, and remote sensors. Major components of the new device are made of bulk metallic glasses (BMGs) – extremely pliable metal alloys that are more durable than the metals typically used in micro fuel cells.





2012 : December ^

Mimicking Real Cells

The construction of artificial cells has been a long-sought goal. Electrical engineering graduate student Weihua Guan made great progress towards that goal by creating a microelectronic device that controls the flow of ions through a nanometer channel that mimics the function of real cells. Guan's "nanoionic" device performs the same functions as an ion channel in a cell membrane, creating a "membrane potential" by selectively controlling the ion flow through the device, an abiotic analogue to voltage-gated ion channels in living systems.

2013 : January >

Studying Mating Swarms

Nicholas Ouellette, associate professor of mechanical engineering & materials science, and colleagues conducted the first large-scale quantitative study of an insect mating swarm by using synchronized high-speed cameras and other tools developed for turbulent flow studies. The group measured the three-dimensional positions, velocities, and accelerations of the swarms' individual members, as well as those of whole swarms. The researchers found that the swarms form hierarchal sub-flocks and also that some internal force binds them to their swarm. The study is part of a larger effort to understand how local, spontaneous interaction among living organisms leads to the organization of complex, dynamic, but coherent systems.

2013 : February >

Bendable Glass

Working with colleagues from Yale and elsewhere, Jan Schroers, professor of mechanical engineering & materials science, can now predict whether a given glass will be brittle (making it very easy to break) or ductile (allowing the material to change shape without breaking). The researchers found that any glass could have either quality by identifying a special temperature that ultimately determines its property. The group also stated that the key to forming ductile glass is cooling it fast.

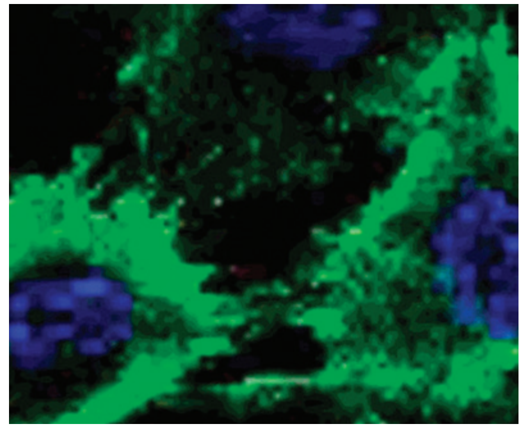
Continued on next page →

Year in Review

2013 : March >

Managing Inflammation

A research group led by assistant professor of biomedical engineering Anjelica Gonzalez found that to properly manage inflammation, control of the white blood cell flow is key. The researchers found that some aspects of blood vessel architecture facilitate white blood cell migration to a greater degree than others, a means of self-regulation. Excessive migration can result in extreme inflammation, turning otherwise helpful white blood cells into agents of disease.



< 2013 : April

Eggcellent

Launching an egg 1,571 feet in the air and returning it safely to the ground earned the Yale Undergraduate Aerospace Association top honors in the "Battle of the Rockets." The contest required students to design and build a rocket that could reach 1,200 feet and land an egg undamaged without the use of parachutes or parafoils and at a descent rate of less than 30 feet per second. Yale was the first team in the competition's history to safely recover an egg.

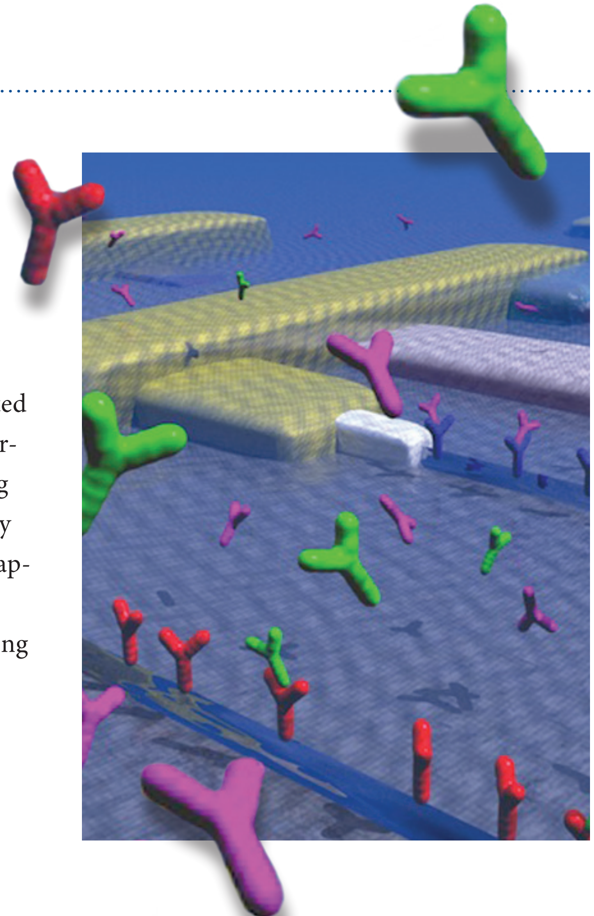
2013 : May >

World Champions

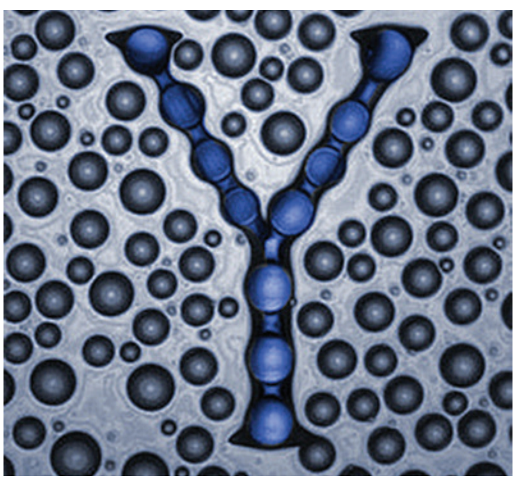
The Bulldogs Racing team became World Champions at the 2013 Formula Hybrid International at New Hampshire Motor Speedway. The competition challenges collegiate teams from around the world to design, build, and race high-performance hybrid and electric vehicles. The team pulled away with first place in the Formula Hybrid International Competition Overall Best Hybrid Award, first place for the Ford Most Efficient Hybrid System Award, first place for the Chrysler Innovation Award, and second place for the GM Best Engineered Hybrid Award.

2013 : June >

Tiny Sensors, Huge Potential



Mark Reed, professor of electrical engineering, and colleagues reported a breakthrough in designing electronic biosensors that can be regenerated and reused repeatedly. The group created the biosensors utilizing silicon nanowires configured as tiny transistors that are exponentially more sensitive than current sensing technology, while also being cheaper and easier to use. In addition to pollution and toxin detection, the group's biosensors have the potential to transform health care, enabling the diagnosis of diseases long before they can be detected by current methods and allowing for much earlier intervention and treatment.



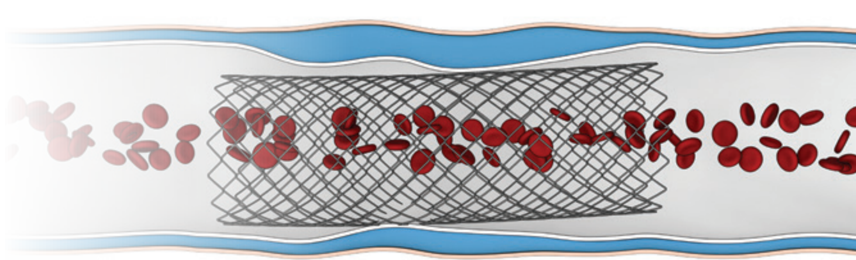
< 2013 : July

Soft Water

Mechanical engineering & materials science professor Eric Dufresne led a group that found a way to drive water droplets along a flat surface without applying heat, chemicals, electricity, or other forces: all that's required is varying the stiffness of the surface in the desired direction. The droplets, the group found, prefer the soft spots. The discovery may reveal more about the behavior of living cells and could also yield advances in microfluidics, micro-scale fabrication, and the development of effective coatings – all of which benefit from the control of liquids.

2013 : August >

New Vascular Stents



Rong Fan, assistant professor of biomedical engineering, and collaborators developed a biodegradable alloy for use in medical implants. The new alloy, called JDBM, combines magnesium, neodymium, zinc, and zirconium. This next generation of vascular stents degrade uniformly in physiological conditions so further surgery to remove the implants is not necessary. The group is now focusing on the surface modification of the alloy to fine tune its degradation rate and improve its biocompatibility.

TECHNOLOGY

Macro Changes for Micro Devices

For nearly 50 years at Yale, T.P. Ma has been trying to make semiconductors disappear – or as close to it as possible

In the four and a half decades since he first arrived at Yale as a Ph.D. student in electrical engineering, T.P. Ma has made major contributions to the advancement of semiconductor technology. He's been named a Fellow of the Institute of Electrical and Electronics Engineers (IEEE), elected to the National Academy of Engineering, received the Connecticut Medal of Technology, and named the Raymond John Wean Professor of Electrical Engineering & Applied Physics. Not bad for someone who struggled to find an advisor with an interesting research project.

"When it came time for me to select a faculty member, I found no professors at Yale who listed 'semiconductors' as their specialty," recalls Ma. "The only one whose portfolio looked somewhat close to semiconductors was the one I initially went to see, but fate had it that he was not in his office – we did not have email service to make an appointment ahead of time," he laughs.

Fortunately, fate already had someone else in mind. Professor Richard Barker told Ma he was starting a research project in semiconductors, and Ma was immediately hooked.

"Richard Barker's enthusiasm toward the new project, his 'hands-off' style of research management, and the fact that I could become a 'pioneer' in Yale's semiconductor research history all were factors that attracted me," says Ma.

From that point on, Ma had his opportunity to work on semiconductors – in particular, developing ultra-thin dielectrics for semiconductor devices. Dielectrics are a critical element of semiconductor chips, and in the 1970s, the prevailing wisdom suggested that semiconductor chips would double in density about every two years – an increase that would be achieved largely by making dielectrics thinner. This prediction, an element of Moore's Law (an observation made by Intel co-founder Gordon Moore) suggested that by the year 2000, the dielectrics used in semiconductor chips would have shrunk to about 20 angstroms, or two billionths of a meter. That put Ma well ahead of the game, as he was already working on ultra-thin devices at this scale in the 70s.

"At the time that I did my Ph.D. thesis, the prevailing thicknesses of the gate dielectric in commercial products were around 200 nanometers (nm), and we were working on dielectrics with 2-4nm in thickness," says Ma. "[But] at that time, the existing tools for measuring the thickness had an error bar of more than a nanometer, and therefore we often did not even know exactly how thin a gate dielectric we were dealing with. The general attitude of the semiconductor industry was 'it's nice for academic study of such ultra-thin gate oxides, but it's never going to be useful for commercial applications.' Fortunately, there were funding agencies at the time that were willing to support 'curiosity driven' research, even in engineering."

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It didn't take long for Ma's colleagues in the field to see the value of ultra-thin dielectrics, which are ubiquitous throughout electronic devices today.

"This has proved to be enormously profitable for the semiconductor industry," says Ma.

He went on to make similar advances in the design of dynamic random access memory, or DRAM – the type of memory that's used in your laptop or desktop computer, as well as in mobile devices. Traditionally, DRAM uses a design with one transistor and one capacitor, where the capacitor stores a single bit of data. A one gigabyte (1GB) RAM chip holds 8 billion transistors and 8 billion capacitors to store 8 billion bits – 1GB – of data.

As with other electronic components and devices, a major long-term goal was to keep shrinking them down. The more capacitors and transistors you can fit on a single RAM chip, the more storage it can have. (This is how we've gone from computers with RAM chips of 128MB each to 4GB each and higher in the span of just a few years.) There's still some room to keep scaling transistors down, but it may soon be impossible to shrink capacitors beyond their current size.

"The storage capacitor in a conventional DRAM structure has to maintain certain minimum capacitance – the ability to store charge – due to two constraints," explains Ma. "These are the ability of the sense amplifier to sense the charge stored on the storage capacitor, and [that] it needs to store enough charge to distinguish from the occasional disturbance.

"Since the capacitance is directly proportional to the area of the capacitor," he continues, "and the per-bit 'ground area' is shrinking for each new generation of DRAM, the storage capacitor will have to be either taller [like building skyscrapers in a city with little open ground space], or in the form of deeper trenches, both of which are approaching their limits."

So Ma and his group took a different approach: if you can't shrink the capacitor, why not eliminate it? Working with then-student Jin-Ping Han, Ma developed a new capacitor-less DRAM design using a ferroelectric dieletric – essentially, the transistor element of the RAM chip has a memory effect without the need for a capacitor.

By now, it may have become apparent that some of the biggest problems in electrical engineering are all about making things smaller. Most recently, Ma has set his sights on new ways to shrink transistors. There are still some decreases in size to be achieved with the current silicon-based designs, but eventually – likely by 2020 or perhaps even earlier – the industry will have to come up with a new approach. Ma thinks he's found one in unipolar logic technology.

Semiconductors are, at their core, materials that have electrical conductivity; electrons are moving around. But in traditional semiconductors, the electrons aren't the only things moving around; there are also mobile holes. These holes are basically the opposite of electrons. For these purposes, you can think of them as positively charged electrons.

What's important to know in this case is that in most semiconductor devices, the effective mass of a hole is much larger than that of an electron, so the holes can't move around as quickly. This can reduce the speed of any device made from the semiconductor, even if the electrons still move relatively fast.

Silicon-based devices are typically an exception to this problem; in these, the electrons and holes both move around fairly well. But we already know that silicon-based transistor designs can't be scaled down much further. When they hit their limit, other materials will have to be used – and while semiconductors made with other materials have much better electron mobility, there's a serious drawback: the holes move much, much slower. Any overall gain in the movement of electrons is wiped out by the very limited mobility of the holes.

If you were paying attention during the DRAM discussion, you may have guessed what's coming next. Can't make the capacitor smaller? Get rid of it. Can't speed up the holes? Then build a semiconductor that doesn't need them.

Ma's new unipolar logic approach eliminates the need to worry about the speed of holes by creating CMOS (complementary metal-oxide-semiconductor) logic gates that don't need holes to work.

The building block of conventional CMOS logic circuits, the CMOS inverter, requires a combination of an N-channel transistor (where electrons are the conduction carriers) and a P-channel transistor (where holes are the conduction carriers). Due to the nature of the transistor operation, the N-channel transistor has a positive "threshold voltage" while the P-channel transistor has a negative one. If you apply a positive gate voltage, the N-channel transistor will turn on and conduct current, while the P-channel transistor will turn off. Conversely, applying a negative gate voltage will turn on the P-channel transistor and turn off the N-channel transistor. As a result, whether a positive or negative voltage is applied, one of the transistors in the inverter is turned off. This is the key in minimizing the power consumption of CMOS circuits.

A unipolar CMOS inverter approach takes advantage of the "double-gate" feature of a 3-D transistor structure, where the "left channel" can be turned on or off by the left gate, and the "right channel" can be turned on or off by the right gate. For an N-channel transistor with a double-gate structure, both the left and right channels use electrons as the conduction carriers. But the channels have complementary threshold voltages relative to each other, which achieves functionality similar to the typical design: one is always turned off, no matter what voltage is applied.

"In this way we can achieve CMOS logic functions even without needing a P-channel, so holes are eliminated from the design," explains Ma. "With only N-channel transistors, materials that limit hole mobility can be used without slowing down the overall device, because the only thing that matters is how quickly electrons can move within the material."

Ma has patented the technology and recently received funding from Sandia National Laboratories for a one-year feasibility study. And of course, he will continue to explore the possibilities for improvement in other areas of semiconductor research – making more big advancements in ever smaller spaces.

MEDICAL INNOVATION

The Translator

Converting biological discoveries into clinical devices is where Rong Fan finds success

The human body is made up of trillions of cells. No one knows the exact number, but estimates range from five to 100 trillion.

Rong Fan can tell you quite a bit given just one.

Fan, an assistant professor of biomedical engineering, sees the future of medicine in systems biology. Paths to quick diagnoses and personalized treatments and therapies will likely be key tools of 21st century medicine, but getting from foundational biology research to workable technology ready for the clinic or the doctor's office takes a significant leap. That's where Fan's work comes in.

Translational research – so-called because it helps to "translate" results from basic scientific research into practical health applications – isn't often found in an engineering environment. Engineering as it's typically thought of tends to deal with practical applications from the beginning; there's nothing to translate when you start with the applied side of things. So translational research doesn't fit the typical engineering profile. Then again, neither does Fan, who started out with a Chemistry Ph.D. at Berkeley.

Fan initially focused on the chemistry of nanomaterials – specifically on how to make one-dimensional nanostructures like nanowires and nanotubes, prized for the unique physical characteristics that are available in materials on the scale of a billionth of a meter in size. But after attending a seminar that dealt with the structures of a cell's scaffolding – the so-called cytoskeleton – he was blown away by the elegant nanomaterials that nature creates on its own. Though he hadn't taken a biology course since high school, he quickly began attending more biology-focused talks, finding them both fascinating and frustrating.

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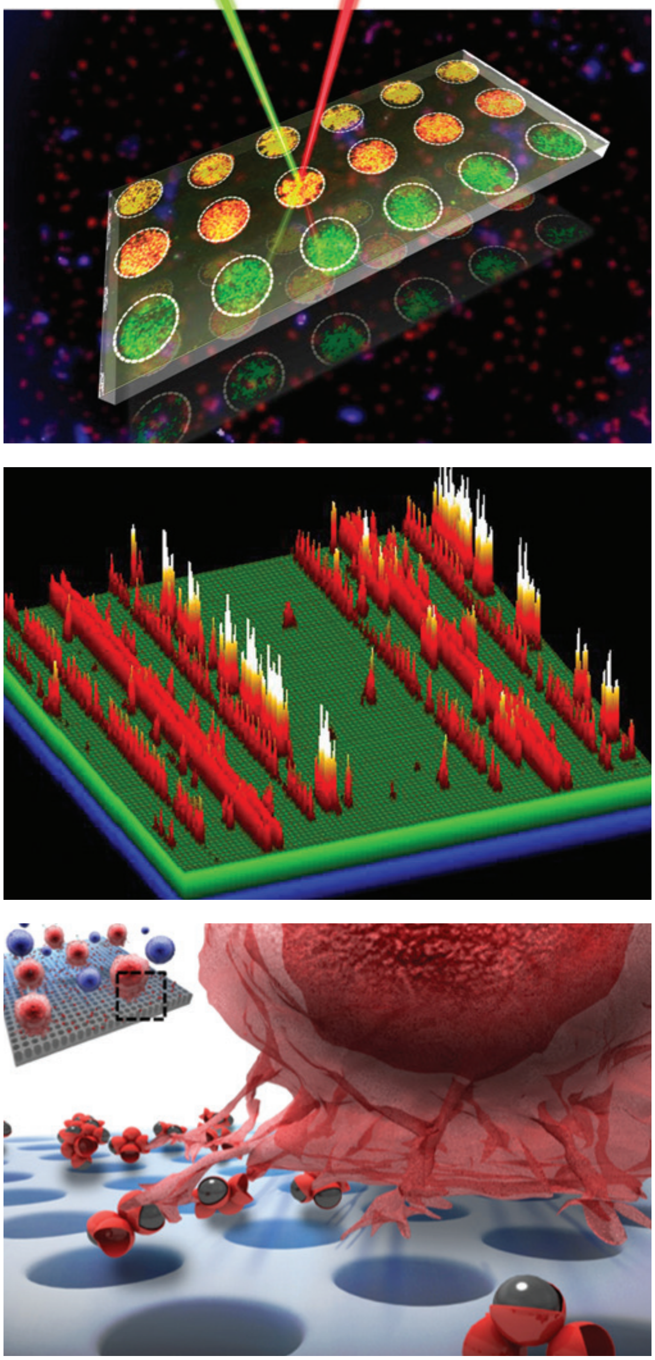


Left: *(top) Laser scanning imaging cytometry; (middle) Fluorescence intensity map of a single-cell, protein assay microarray; (bottom) Nanostructured surface allows for capture of rare circulating tumor cells*
Right: *Fan inspecting his protein microchip*

"I noticed that many of the talks often concluded with a sentence saying, 'This discovery has important implications in human disease and can help with early diagnosis and design new therapies,'" says Fan. But despite the lofty wording, no one was talking about how that would work. How do you get from these biological discoveries to actual improvements in diagnosis and treatment?

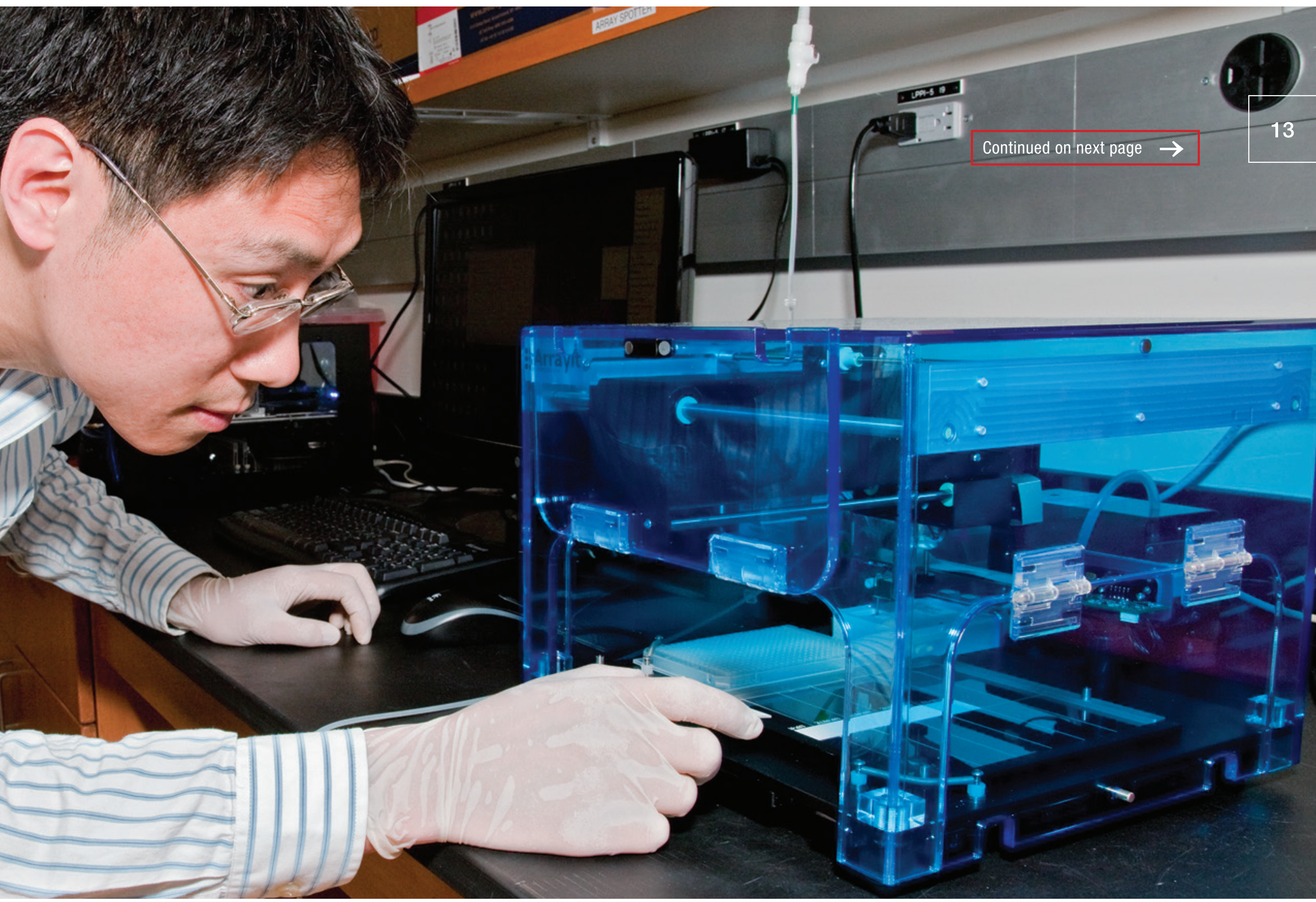
"This missing link in my mind turns out to be exactly what biomedical engineering is doing," says Fan. "So basically I became interested in translational biomedicine. The adoption of systems biology is a complex story, but that is what I believe will truly transform medicine in the future. But how to make it into reality requires translational research – in particular, biomedical engineering."

Fan got to work developing technologies to study interactions between cancer and the human immune system. His first, an integrated microchip designed to analyze blood from a single finger-prick, measured the levels of proteins in the sample – specifically, proteins that indicated the presence of cancerous cells as well as proteins associated with the immune system's response to cancer. This allows for a unique look at the interaction between the immune system and cancerous cells, while also providing a unique picture of protein levels – a so-called proteomic signature – that can be used to determine which treatments might best work for the patient whose blood is being examined.

From there, Fan moved on to proteomic profiling of single cells, building a prototype device he used to demonstrate that – unexpectedly – some of the immune cells that respond to tumors in the body are extremely different within their specific cell type. This discovery provided a more complete picture than had been available to examine the way patients respond to a particular type of cancer treatment.

This was the path of the work that brought Fan to Yale as a tenure-track professor in 2010, the result of a somewhat unusual job hunt.

"My heart is in engineering. All the departments I applied to for faculty jobs were in engineering – mostly biomedical engineering," says Fan. "However, it was not easy because my degrees were not in engineering at all.



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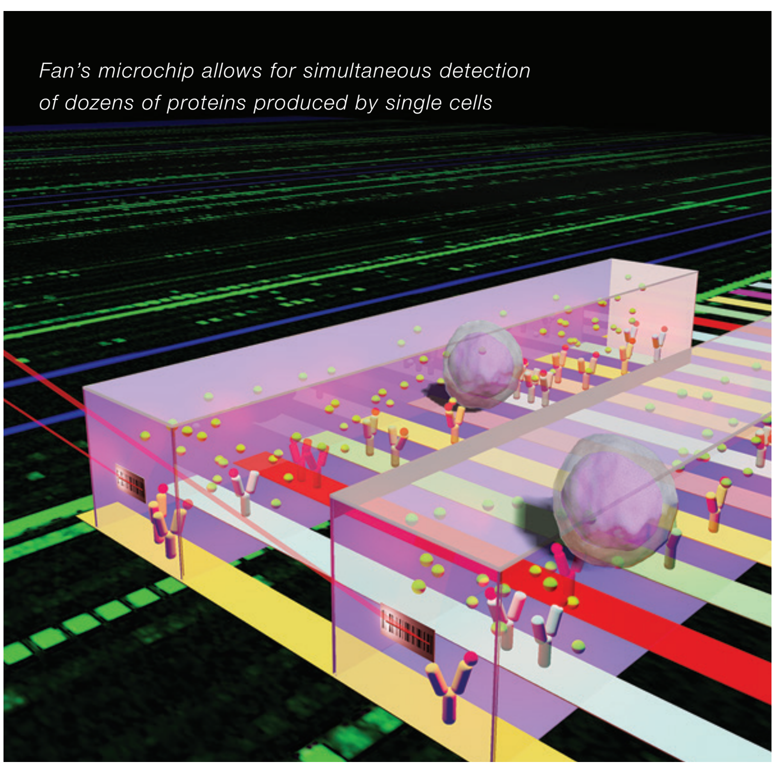
"I found Yale BME was truly great and all the research programs at Yale were interesting to me – cancer therapy, drug delivery, tissue engineering, molecular imaging, and so on. However, there was no one working on microfluidics technology or systems biology. I thought my expertise might fit well in this department."

BME Chair Mark Saltzman agreed and invited Fan to interview.

"Rong is an exceptionally creative person, which was clear to all of us when we first met him," said Saltzman. "I am delighted that he accepted our offer to join the faculty at Yale, as his work brings together several aspects of our overall biomedical engineering effort: Rong is an expert in medical devices, applied mathematics, and systems biology that is relevant for human medicine."

It quickly proved to be a mutually good decision.

"After I arrived at Yale, it was even more clear this department is indeed a perfect fit," says Fan. "All of the faculty here have provided enormous support to help me grow and develop my own research program at Yale."



Fan's microchip allows for simultaneous detection of dozens of proteins produced by single cells

That research program has flourished, with work being featured as a cover story in *Nanoscale*, Fan being awarded the prestigious early-career Packard Fellowship, and the successful launch of a start-up company focused on immune system analysis (see sidebar, page 15).

Fan credits Yale's unique and encouraging approach to cross-University collaboration with his successes to date.

"Yale BME is perfectly positioned to conduct translational research as it is primarily a SEAS department, but also affiliated with Yale's School of Medicine," he explains. "There are several cross-department centers/programs such as the Yale Cancer Center, the Yale Stem Cell Center, and the Human & Translational Immunology program that provide a lot of opportunities to promote collaboration."

Fan laughs at the second reason he believes he's had such successful collaborations throughout the University – the proof that he really is an engineer at heart.

"I develop technologies based on the needs for biological or clinical research rather than how sexy this tool is," he laughs. "I sort of start from identifying problems and needs, and then design tools to tackle them. So the technologies from my lab organically fit to the interest of many medical research laboratories at Yale."

He's continuing such collaborations today.

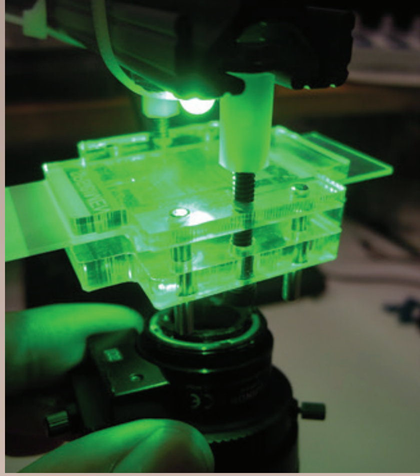
"My current focus is to develop single-cell analysis technology and marry it with systems biology principles to better understand complex human diseases," Fan explains. "We developed a single-cell proteomic profiling microchip and it recently showed that brain or prostate tumor cells from the very close vicinity could be phenotypically distinct according to their protein signature."

Findings like these, which provide evidence that cells of the same "type" may in fact be dramati-

Yale

MEDICAL INNOVATION

IsoPlexis: Profiling Proteins

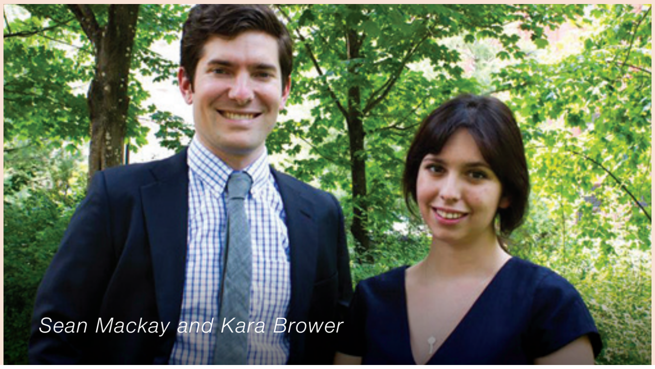


Continuing in the recent tradition of successful start-up launches from SEAS, IsoPlexis is the brainchild of Rong Fan, School of Management student Sean Mackay, and Yale SEAS undergraduate alumna Kara Brower.

"I developed a single-cell protein profiling technology and truly believe it is a superior tool to understand cellular functions in a much clearer and complete picture," says Fan. "This technology can detect a large panel of relevant proteins while the state-of-the-art technologies can detect only a few, seeing just a small piece of the full story."

Fan hoped to see his technology disseminated to the larger research community, where it could help others with their biology research or clinical studies. Yale's Office of Cooperative Research was confident the technology offered venture opportunity, but Fan was concerned he might not have enough time to spearhead such an endeavor.

"I asked a student who took my class two years ago – Kara, who did most of the work and led the creation of this startup," says Fan. "I think they are doing just terrific."



Sean Mackay and Kara Brower

The company, which incorporated in March, received a fellowship through the Yale Entrepreneurial Institute and has been meeting with potential investors. Their goal is to make Fan's device, which offers microchip-based single-cell analysis, available for less than $10,000. It could prove incredibly valuable as a tool for academic research and, perhaps down the road, in a clinical setting.

"Our technology uniquely identifies the most active subsets of individual cancer and immune cells," says Chief Executive Officer Sean Mackay. "By doing this, we have potentially disruptive value to drug developers. We enable them to target activation or destruction of these specific cells, which may lead to more effective cancer and immune-mediated therapies."

Brower, who serves as Chief Technology Officer, credits support from Fan and the University as a whole for their success to date.

"Working with Dr. Fan for the past year to develop IsoPlexis has been tremendously rewarding and exciting, especially in regard to our recent technological developments to bring the product to market," says Brower. "With a team of Yale students and alumni, we created a fully automated beta version of Dr. Fan's Immuno-Chip, established an important business network, and began six company collaborations in the Yale community and general New Haven and Boston areas that have begun to show promising results. We now are continuing to apply for federal grants, and are excited to keep moving forward."

cally different, have major implications for disease diagnosis and treatment. Cells from the same tumor, for example, could be different enough to respond to treatment in a totally different way – referred to as intratumor heterogeneity.

"This presents a significant challenge to accurately diagnose the disease and is also responsible for recurrence and drug resistance," says Fan. Better diagnosis and treatment, based on a full picture of the cell population rather than just treating all the cells as being the same, requires the new approach of single-cell analysis. But there is still much work to be done.

"Single-cell analysis is the new forefront of biomedical research, but the major challenge is the lack of breakthrough technologies to handle and process single cells such that the genetic, epigenetic, or proteomic information can be obtained at the single cell level with high coverage and accuracy," says Fan. "So it is a field where engineering can make major contributions."

Today's Wasted Heat, Tomorrow's Energy Source

Yale engineers discover real benefits in a synthetic solution

Last year's "OPEN 2012" program from the U.S. Department of Energy and its Advanced Research Projects Agency for Energy (ARPA-E) awarded $130 million to 66 "transformational, breakthrough technologies that show fundamental technical promise" for developing a broad array of energy sources, from conventional fossil fuels to solar, wind, and geothermal power. Menachem Elimelech, the Roberto C. Goizueta Professor of Chemical & Environmental Engineering, and Chinedum Osuji, associate professor of chemical & environmental engineering, received $2.6 million of that ARPA-E funding to develop a low-cost power generation system that can operate sustainably on a large (industrial) scale.

The researchers' approach utilizes energy derived from the difference in salt concentrations between two water sources, known as salinity gradients. "For obtaining fresh water from a salty solution, we need energy – the 'energy of separation' – so we eventually get a fresh water stream and a more salty, or concentrated, stream," explains Elimelech. "Now, if you mix these streams, we can harness the 'energy of mixing,' which is equal to the energy of separation but with a minus sign."

Two well-known processes used to do this separation – pressure-retarded osmosis (PRO) and reverse electrodialysis (RED) – both use membranes in the mixing of streams.

"PRO [uses] a semi-permeable membrane that converts the osmotic pressure (or concentration) difference between the two streams to mechanical work via a semi-permeable membrane that allows water to pass through but retains salt. The mechanical work is then converted to electricity by a hydro-turbine," says Elimelech. "In RED, the energy of mixing is converted directly to electricity with the aid of specialized selective membranes that allow ions to go through but retain water."

Though both processes are viable sources of energy, improvements are needed before either can be used on a large scale; the PRO membrane needs technological improvements, while the RED membrane is cost-prohibitive. A larger challenge, however, is with the source of the salinity gradient.

To date, large-scale implementations of these systems have used continuous flows of natural fresh and saltwater sources. This is obviously ideal from a sustainability perspective: the sources are essentially free and completely renewable. But the natural water used in these so-called open-loop systems presents technical challenges.

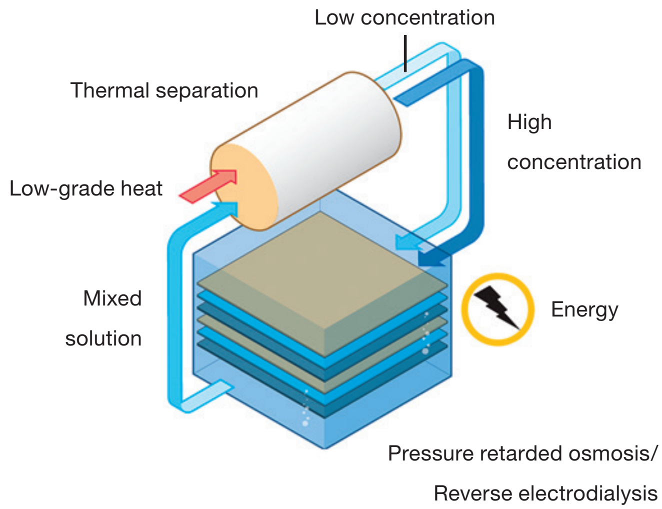
First, these water sources require costly, extensive pretreatment, in addition to other measures to prevent fouling of the system. More critically, while salinity concentrations between natural water sources are different enough to harvest energy when mixed, the differences are *not* large enough to make the technology profitable on a large scale.

Elimelech and Osuji propose to adapt such technology for "closed-loop" use: instead of continuous natural water flows, their system uses synthetic solutions, first blending them together to harvest energy, then using heat to separate them into low- and high-salinity streams for continuous reuse. In this approach, sustainability comes not just from the water sources, but from the heat source used in separation – a technology referred to as the "osmotic heat engine."

"Our process is particularly adept at utilizing low-grade heat sources, where the modest temperatures available do not typically allow for economical energy generation using conventional heat engines," says Osuji. "Examples of such heat sources include industrial waste heat and geothermal energy. In that sense, we are capturing valuable and useful energy instead of just letting it escape into the atmosphere."

By recent estimates, the industrial sector, the largest power user, discharges approximately one-third of the energy consumed as heat loss – heat that can instead drive the researchers' closed-loop system.

Of course, the efficiency and sustainability of the system also depends on the solution. "In an open-loop system, you



Power generation from waste heat with a closed-loop membrane-based system

need continuous inputs of river water and seawater, and they are wasted once used – we get a mixed brine that is discharged to the ocean," says Elimelech. "In the closed-loop system, we use a synthetic solution and because the solution is reused and always in the closed-loop, we need only the initial solution. So, we need very little, as opposed to with natural water sources, where we need a lot.

"We can create the necessary solutions by simply mixing simple salts that are highly soluble and inexpensive with distilled water," he continues. "In our project, we are using sodium chloride, but we can also use other high-solubility salts."

Elimelech and Osuji's work, undertaken in collaboration with Tzahi Cath and Michael Heeley of the Colorado School of Mines, spans the breadth of the engineering challenges associated with the closed-loop approach: developing robust and high-performance membranes to use in the solution mixing; testing their setups on the laboratory scale, bench scale, and pilot scale; and finally, developing a mathematical model for the entire process that demonstrate the system's efficiency and allows for further design optimization.

The ARPA-E award was announced late last year, and work began early in 2013. To date, Elimelech and Osuji have already modeled the hybrid system and begun developing the membranes needed for use. They remain on schedule to complete a full-scale pilot system test by mid-2016.

A Hive of Creativity and Innovation

In its first year, Yale's Center for Engineering Innovation & Design has quickly become the nucleus of campus creativity

EDUCATION

It’s hard to keep the street-level picture windows clean at the Center for Engineering Innovation & Design (CEID). Curious pedestrians keep smudging the panes with handprints and even nose prints while trying to get a better look at the eye-catching stuff going on just beyond the glass. They might see someone making puppets at a sewing machine or fashioning electronic jewelry from LEDs or generating human organs or bat ears on one of the 3-D printers. The glass in front of the 3-D printers, in fact, is a window-washer’s nightmare. Sometimes the curious passersby can’t resist walking into the CEID to ask questions or to touch what they’ve been observing. Once they enter the center’s wonderland, many of them become members.

That’s exactly what the School of Engineering & Applied Science envisioned when the CEID opened in August 2012. “We wanted the space to speak to the outside world about engineering, and to demystify technology,” says Dr. Joseph Zinter, the center’s assistant director. “We wanted people walking by to say, ‘That’s cool. And if that’s engineering, I want to be part of it.’”

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Yale

EDUCATION

In just one year, more than 1,200 people from the Yale community joined the center after completing an entertaining 45-minute orientation and a brief quiz. The meteoric rate of growth surprised everyone.

"It suggests that a space like this really needed to exist," says Ellen Su, one of the center's two full-time design fellows. She graduated from Yale last spring with a degree in art. How did she end up in an engineering center? In exactly the way that the CEID's leadership envisioned. She got interested in the power of design to solve practical problems, but couldn't find much at Yale to help her explore this interest, so she started a Design for America club to promote design thinking and education. Then the CEID opened. "I joined and started using so many resources here," she says, becoming the sort of student Zinter calls "a super-user." Before long she was one of the center's Undergraduate Design Aides, and after graduation she stayed to become an employee.

Her story exemplifies a couple of the CEID's aims: to be a bridge to the broader Yale community and a catalyst for interdisciplinary creativity. It's working splendidly. The CEID's leadership is pleased not only by the unexpectedly high number of members, but by the range of their affiliations at Yale: they come from over 50 undergrad majors and every professional school, including Drama, Medicine, Public Health, and Divinity. Fewer than half – 45 percent – are so-called STEM majors (science, technology, engineering, math). Thirty percent are majoring in social sciences and humanities, and the largest single contingent of members comes from the School of Management (SOM).

"Before the CEID," says Zinter, "SOM wasn't exactly banging on engineering's door." Now there's a space that allows these disciplines to collaborate and investigate mutual interests in innovation and practical solutions. Last spring, for instance, students from SOM, anthropology, graphic arts, and other majors took Zinter's engineering class, Appropriate Technology for the Developing World, at the center. All contributed their skills and perspectives to the class project: to devise practical ways to turn cassava, a staple food for a billion people, from a simple survival crop into products that could generate income for the poor farmers who grow it.

One of Zinter's favorite examples of how the center can be what he calls "a discipline-agnostic space" was last year's

Tree House project. An architecture student named Griffin Collier had long wanted to build a super-duper tree house. Supporters on Kickstarter pledged $10,500, which took care of material expenses, but an undertaking this complicated required many sorts of expertise, an array of machinery and design software, and a place to brainstorm and store materials.

The CEID became the perfect headquarters for more than 50 students, faculty, and staff, including architects, forest managers, and engineers with varying skills (design, prototyping, machining, structure, software, safety). The building materials – including thousands of pounds of aluminum – were stored on the center's floor before being cut, drilled, milled, and finished in the center's various shops. Then came the construction. The tree house now perches in a big oak near campus. The castle in the air imagined by Collier became reality because a space now exists where it could be discussed, designed, and fabricated.

Some people, like Collier, come to the center with a firm idea in mind. Others arrive with vague notions or conceptual fragments, hoping to explore possibilities or find expert guidance on the next steps. "Linking people up is probably the most powerful thing we do," says Zinter.

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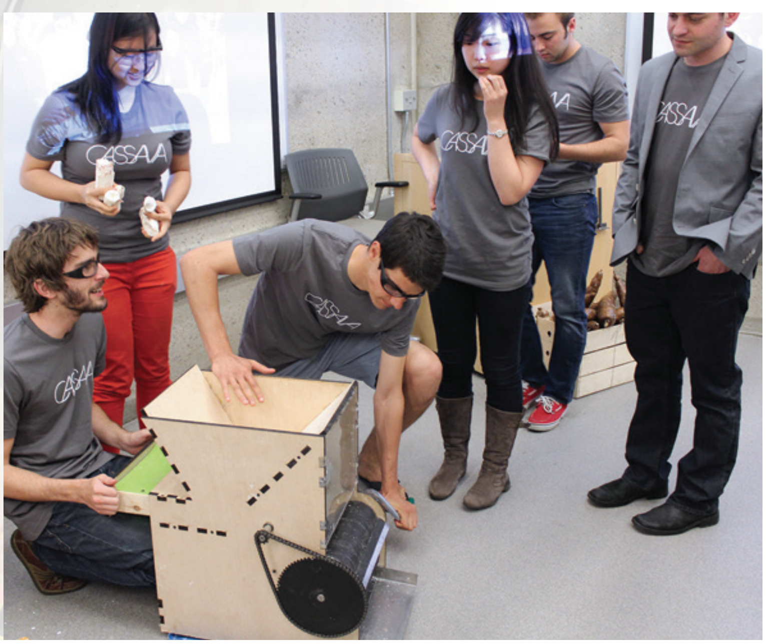
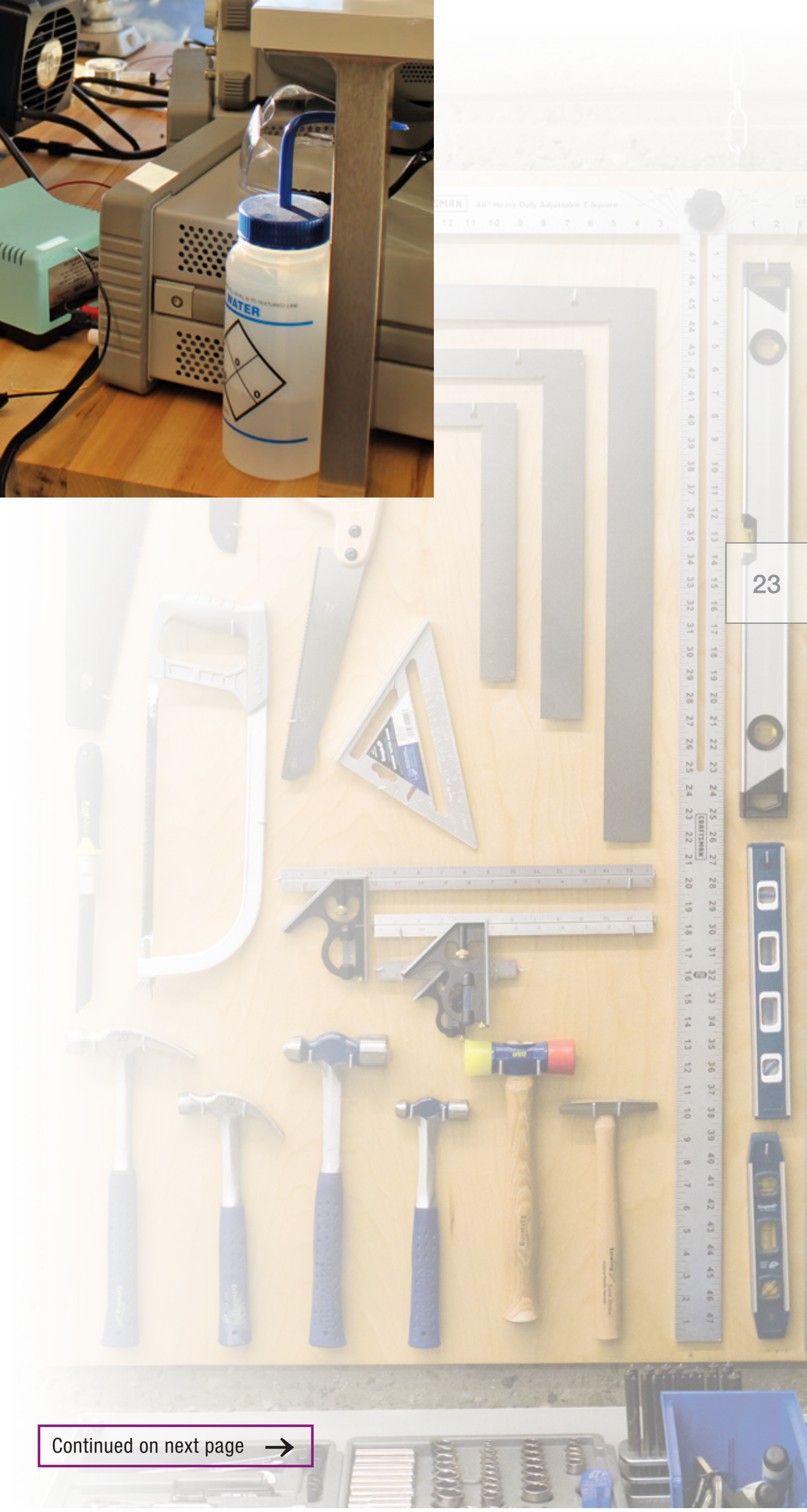


In the past year, for instance, the CEID has functioned as a new bridge between engineering and medicine. The center held an event with the medical school at which physicians pitched ideas and problems to engineers. Some of the ideas, says Yusuf Chauhan, the other full-time design fellow at the CEID, violated the laws of physics, but others led to collaborations with engineers – for instance, a cardiac impeller pump that provides continuous flow of blood to a patient waiting for a new heart. Su and several others are working on a scoliosis brace fitted with sensors that will give parents and doctors better data about how a child is using, or not using, the brace.

Dan Rathbone, a mechanical engineer who will graduate in 2014, was intrigued by the problem presented by Kurt Eric Roberts, an associate professor of surgery. Roberts wanted a noninvasive way to suture hernias. Current practice requires punching four holes through the skin, a painful procedure. Roberts and Rathbone, working at the CEID, developed a way to patch from the inside, using laparoscopy and a new fastening device designed by Rathbone. Roberts is now talking to potential investors. "It wouldn't have happened without the CEID," says Rathbone, another super-user.

One day not long after the CEID opened, Zinter noticed someone with a Yale hospital badge working at a 3-D printer station. Zinter asked him the center's most popular question: What are you working on? "I'm printing some pulmonary vasculature," said the man. "Cool," said Zinter, sensing an opportunity for new links. "Let's talk."

His name was Mark Michalski, a fourth-year radiology resident. Michalski's idea was to use the center's 3-D printers to turn sectional images from patients' MRIs into exact physical models that could help surgeons plan their procedures. He tested his theory this past summer with help from Zinter, Chauhan, and Dr. Dieter Lindskog, an orthopedic surgeon at Yale. Lindskog needed to remove a large tumor from a patient's knee. It was a complicated operation because of all the knee's parts – tibia, fibula, femur, tendon, patella, plus the tumor. Michalski did an MRI and gave the images to Zinter and Chauhan, who used software to turn them into instructions for a 3-D printer. After studying an exact three-dimensional copy of his patient's condition, Lindskog was able to plan his surgical approach more precisely. A 3-D model made at the CEID has also been used to plan prostate surgery.



The models may be helpful for educating patients as well. A surgeon can use one to show a patient exactly what's wrong and what the procedure will be. Similarly, consider the cancer patients who quit chemotherapy because the accompanying nausea seems worse than the disease; showing such patients 3-D models that illustrate how treatment is shrinking their tumors might encourage them to stay the course.

"Who knows where the medical applications for 3-D printing could go?" says Zinter. The center's printers and other high-tech engineering equipment give doctors the means to explore ideas by making them physical.

Another bridge to the medical school is "Medical Device Design & Innovation," an engineering course taught at the center by Zinter and Richard Fan, a Ph.D. in biomedical engineering and a postdoctoral associate in Yale's Department of Urology. The class goal is to design solutions to real medical problems. Zinter and Fan reviewed over 20 physician proposals. Four projects were chosen for development: a novel transport system for harvested organs; a tool that can accurately detect and count a patient's epileptic seizures; a small semi-robot to do surgeries on the base of the

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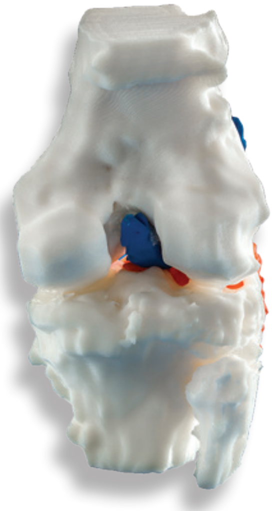
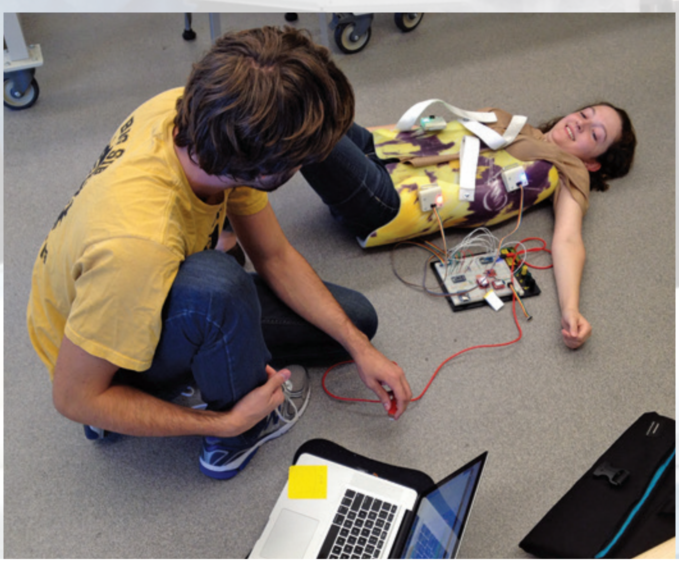
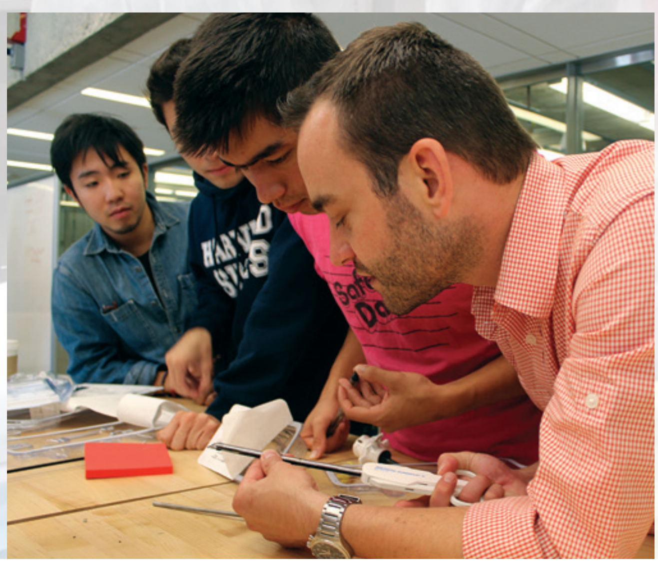


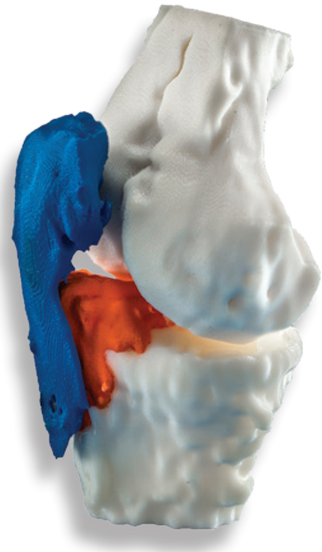
tongue; and a low-cost, subcutaneous drug delivery system. The students and physicians will collaborate throughout the design process, linking engineering and medicine through the common denominator of innovation.

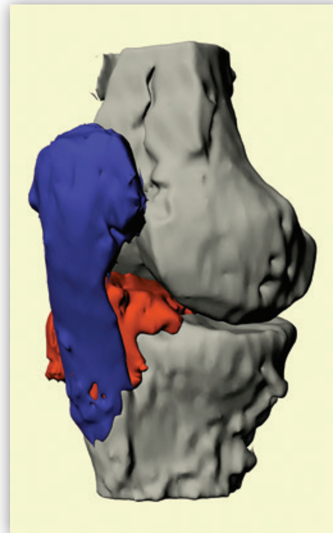
The CEID's space itself was carefully designed to foster exploration and innovation. "If you build it, they might come," says Zinter, "but if you *design* it well, they'll come back." It's no accident, he explains, that the center's most eye-catching equipment, such as the 3-D printers, are located near the windows. Nor is it accidental that when newcomers walk into the center, the first creation-station they encounter is stocked with user-friendly supplies such as glue guns, Styrofoam balls, and pipe cleaners. The tool nook, like all the others, is laid out to be aesthetically pleasing and easy to "read." Most of the supplies and equipment are free for members to use, 24/7, though some of it requires training.

The idea behind all this is to lower the barriers, including fear of technology, for people who want to create things. Before the CEID, the barriers were high. "Our science and technology students are Yale's greatest untapped resource," says Eric Dufresne, associate professor of mechanical engineering & materials science, physics, and cell biology, and director of the CEID, "but there weren't many places for them to pursue their own creative agendas. They usually were confined to the research agendas of the faculty."

Rathbone, the mechanical engineering student, remembers arriving at Yale several years ago eager to "build stuff." But he couldn't find a place where that was easy





Renderings and 3-D printed lightweight, plastic 1:1 scale model of the knee – including the femur, fibula, tibia, ACL, patella (blue), tendon, and the tumor (orange)

to do. A couple of labs and workshops were scattered around campus, mostly in basements, mostly reserved for engineering classes. Tinkering, experimenting, "building stuff," creativity – these basics of engineering were essentially frustrated. "Now we have this gorgeous building," says Rathbone.

Jan Kolmas, another mechanical engineering student who will graduate in 2014, tells a similar story. He came to Yale hoping to become an aerospace engineer, but since Yale didn't offer that major, he took matters into his own hands by starting the Yale Aerospace Club. They began building high-altitude balloons. "But it was very difficult," he says, "because it was hard to get into the machine shop and use the tools. We couldn't do more complicated projects."

The CEID changed all that. "Everything we need is here," says Kolmas. "The tools, the machine shop, the electronics, the meeting rooms." The club has graduated to making unmanned aerial vehicles and is also attracting new members.

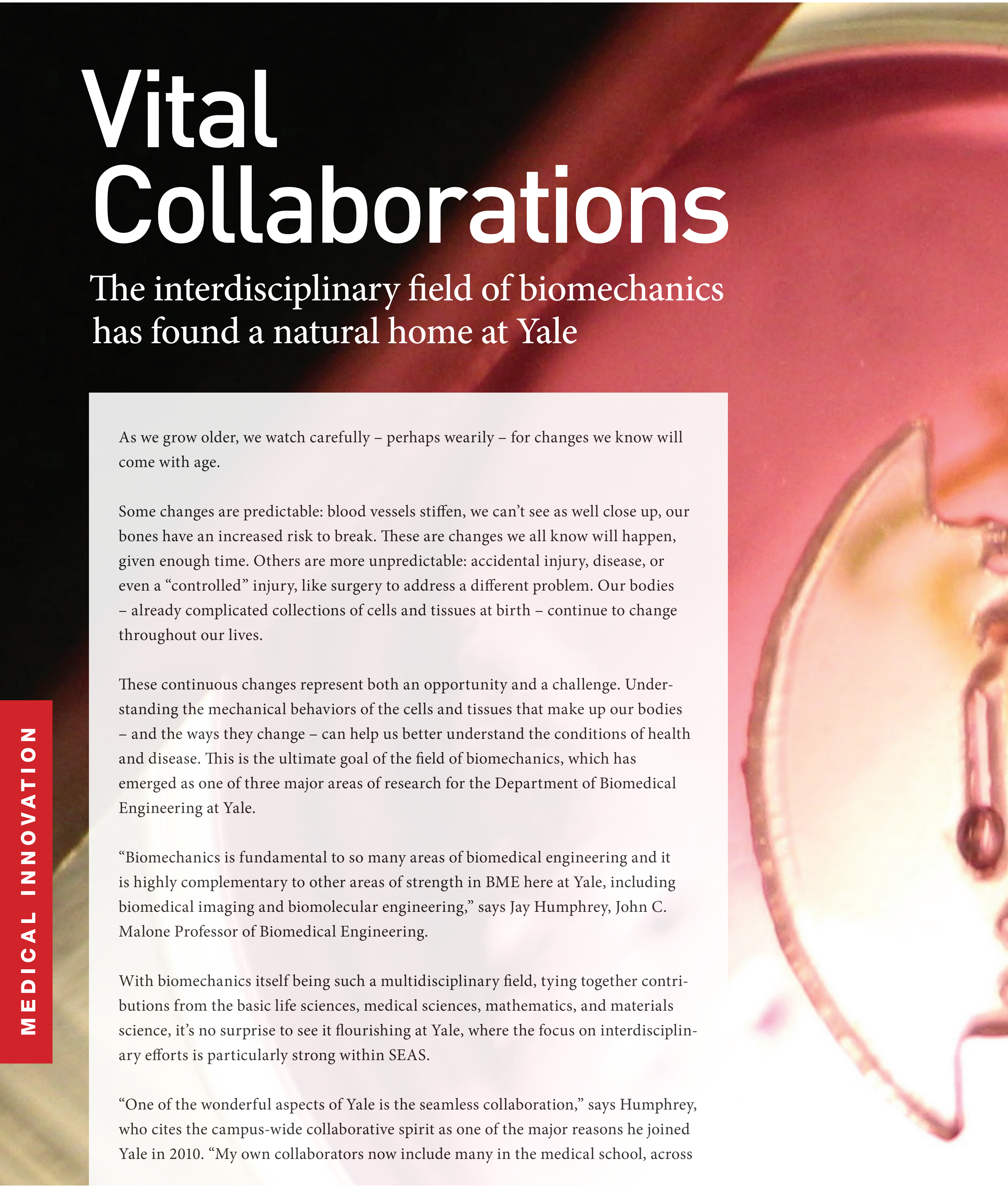
Multiplicity of uses was also part of the plan for the CEID. "You can study, socialize, take classes, design projects, or hold meetings here," says Dufresne. "Most of the activity is conceived by students. It's a community built around science and technology." The CEID's schedule brims with club meetings, career talks, tech talks, and student-run workshops on a wide range of topics: software design, chocolate molds, 3-D printing, engine tear-downs, the physics of bubbles.

When smart curious people gather in an engaging space where everyone's work is visible, and where the inevitable question is "What are you working on?" the prospects for creativity and innovation go way up. "That happens all the time," says Kolmas, "with my projects and other people's projects. It has broadened my horizons."

"That happens especially with things totally unconnected to my own work," says Rathbone. "I have no interest in microfluidics, but when the device is dismantled and lying there on the table, it suddenly seems a lot more interesting." A mechanical engineer who knows something about microfluidics has a better chance of envisioning something new that draws from both, especially if there's a space that makes it easy to explore and test ideas through iteration after iteration.

"Yale is doing something really special with the CEID," says Zinter. "It represents a change in pedagogy, with cross-disciplinary learning and design thinking that extend far beyond engineering into how to view problem-solving in the real world, not just problems in the back of a textbook. Because of the CEID, Yale engineers will be different from engineers coming out of other places, with more depth, breadth, and purpose."

*Steve Kemper wrote **Code Name Ginger**, about Dean Kamen and the invention of the Segway. His most recent book is **A Labyrinth of Kingdoms: 10,000 Miles Through Islamic Africa**.*



Vital Collaborations

The interdisciplinary field of biomechanics has found a natural home at Yale

As we grow older, we watch carefully – perhaps wearily – for changes we know will come with age.

Some changes are predictable: blood vessels stiffen, we can't see as well close up, our bones have an increased risk to break. These are changes we all know will happen, given enough time. Others are more unpredictable: accidental injury, disease, or even a "controlled" injury, like surgery to address a different problem. Our bodies – already complicated collections of cells and tissues at birth – continue to change throughout our lives.

These continuous changes represent both an opportunity and a challenge. Understanding the mechanical behaviors of the cells and tissues that make up our bodies – and the ways they change – can help us better understand the conditions of health and disease. This is the ultimate goal of the field of biomechanics, which has emerged as one of three major areas of research for the Department of Biomedical Engineering at Yale.

"Biomechanics is fundamental to so many areas of biomedical engineering and it is highly complementary to other areas of strength in BME here at Yale, including biomedical imaging and biomolecular engineering," says Jay Humphrey, John C. Malone Professor of Biomedical Engineering.

With biomechanics itself being such a multidisciplinary field, tying together contributions from the basic life sciences, medical sciences, mathematics, and materials science, it's no surprise to see it flourishing at Yale, where the focus on interdisciplinary efforts is particularly strong within SEAS.

"One of the wonderful aspects of Yale is the seamless collaboration," says Humphrey, who cites the campus-wide collaborative spirit as one of the major reasons he joined Yale in 2010. "My own collaborators now include many in the medical school, across many departments. Simply put, collaboration is critical to advancing both basic science and translation to the clinic, and this is one of Yale's strengths – both in the physical proximity between engineering and the medical school and in the attitudes of the investigators. There is a real desire on both sides to work together and to learn from one another."

Stuart Campbell, who joined SEAS in 2012 as assistant professor of biomedical engineering, agrees.

"My work is very interdisciplinary, and it was obvious to me from the start that the environment at Yale was a great match," says Campbell. "The research resources, like imaging facilities in the medical school, are outstanding. Perhaps more important is the large number of collaborators I was able to identify, literally from one end of campus to the other. I am working with other Yale faculty members who are experts in biophysics, cell biology, and cardiology to form unique and powerful collaborations."

One of Campbell's collaborations, with Drs. Daniel Jacoby and Yibing Qyang, focuses on cardiomyopathies, the leading cause of sudden cardiac death in young athletes. Cardiomyopathies are a class of inherited heart diseases where an unnatural remodeling of the heart muscle leads to life-threatening symptoms like irregular heart rates or even heart failure.

In recent years, as genetic testing has become more common, researchers have shown that cardiomyopathies are often caused by genetic mutations. This knowledge gave clinicians the opportunity to screen relatives of patients with known cardiomyopathies to identify others at risk for the disease, just as relatives of some cancer patients may be screened for cancer. But even if someone is found to carry mutations that are associated with cardiomyopathy risk, obstacles remain.

"Now the critical challenge is to determine how to treat this growing group of individuals who carry disease

Background: *Clipped engineered cardiac tissue construct*

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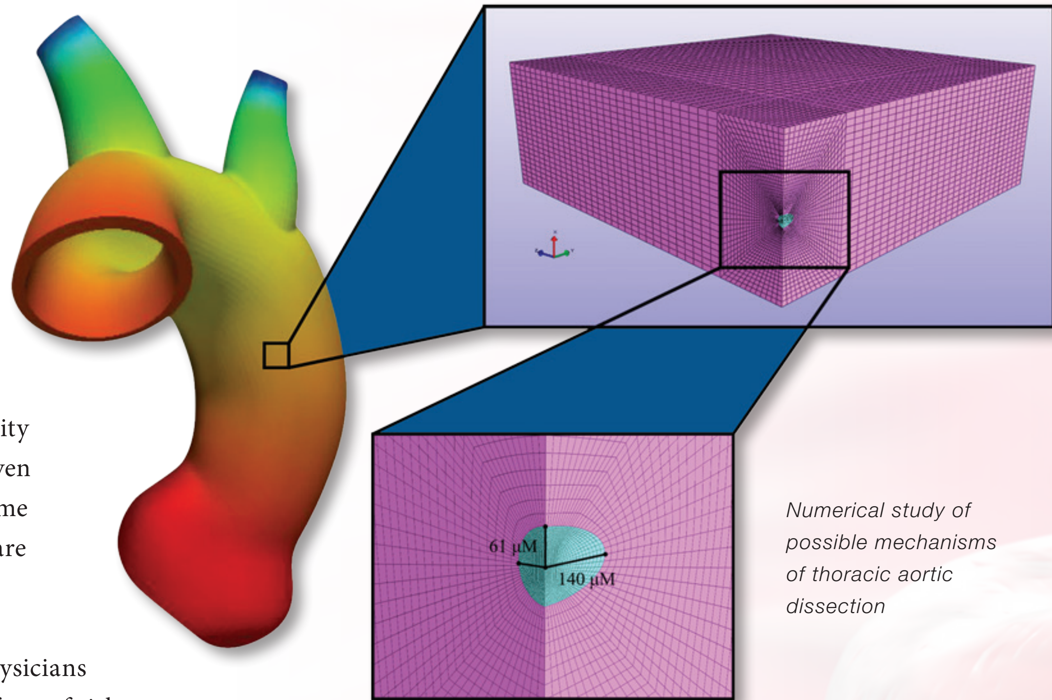


Numerical study of possible mechanisms of thoracic aortic dissection

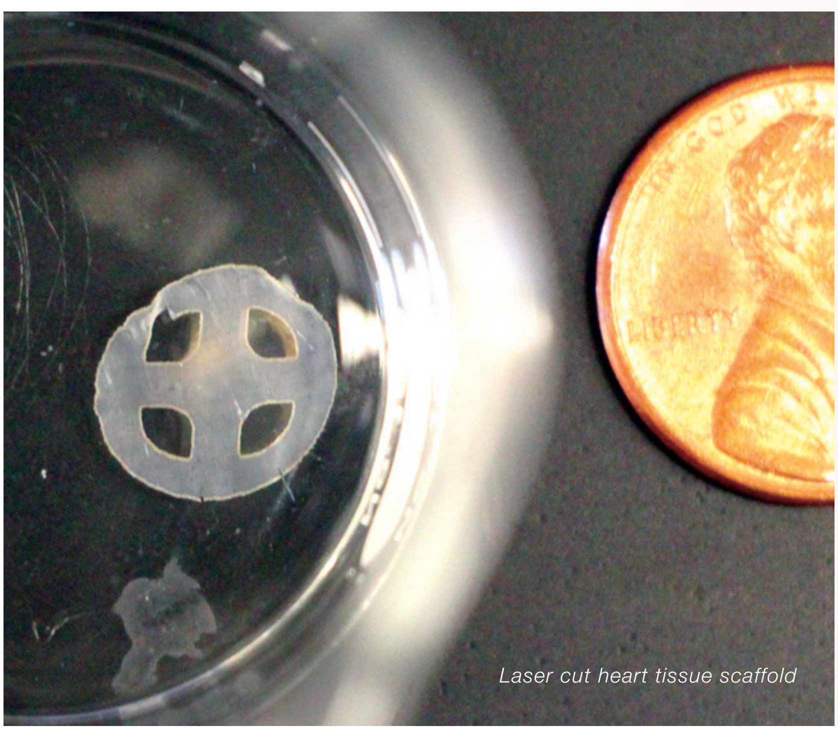
genes, but currently do not have obvious symptoms," explains Campbell. "This is difficult to do because the age at which symptoms appear and the severity of disease varies widely, even among members of the same immediate family who share the same gene mutation.

"The dilemma faced by physicians involves balancing side effects of risky treatments with the benefits of early intervention, and this can be agonizing for physicians and families alike, particularly when deciding how to treat children," Campbell says.

Along with Drs. Jacoby and Qyang, Campbell's group is working to accurately assess the risks for individual cardiomyopathy patients using an engineering-based approach. One effort involves obtaining cells from a patient via a simple blood sample and transforming them into functioning cardiac tissue – working heart tissue for analysis.

"This approach, which utilizes stem cell technology, effectively lets us recreate the patient's diseased heart tissue in a laboratory setting," explains Campbell. "The biomechanical function – for example, strength of muscle contraction – of these samples can then be studied in great detail and compared with samples derived from healthy individuals."

The group theorizes that larger differences in tissue function will indicate a greater risk of dangerous clinical symptoms. If proven correct, this concept and the technology the group has developed could help clinicians assess patients' risks on an individual level and tailor treatments appropriately.



Laser cut heart tissue scaffold

Campbell emphasizes that the value of the engineering approach hinges on the close working ties with researchers from other areas.

"I really needed strong support from a clinical cardiologist [Dr. Jacoby], and an expert in stem cell technology [Dr. Qyang]," says Campbell. "The combination of clinical cardiology, stem cell biology, and the tissue engineering and biomechanical testing side is not only rare but should also be very powerful in terms of making headway on diagnosing these patients."

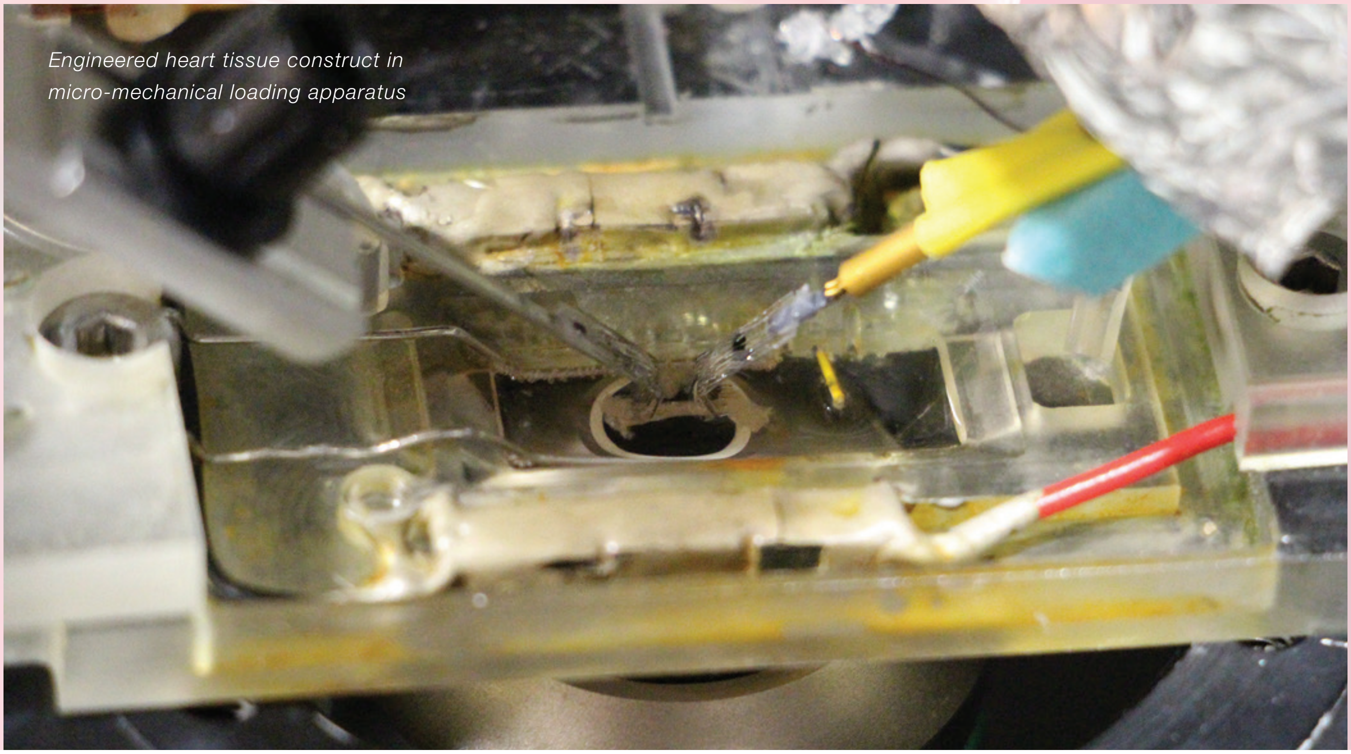
The department's efforts in biomechanics don't stop there. In addition to the vascular research by Humphrey and the cardiac research by Campbell, other faculty members, such as Steven Tommasini, are focusing on bone. Tommasini, assistant professor of orthopaedics & rehabilitation and biomedical engineering, works to understand the biological processes that coordinate bone size, shape, and composition – particularly how changes in metabolism lead to changes in bone cells.

"Osteocytes, bone cells embedded in a mineral matrix, serve many functions," explains Tommasini, including mechanosensors – they respond to changes in mechanical force. As a result, changes to these bone cells, whether as a consequence of diet, age, drug treatments, or other factors, can change the way a bone responds to exercise, for example.

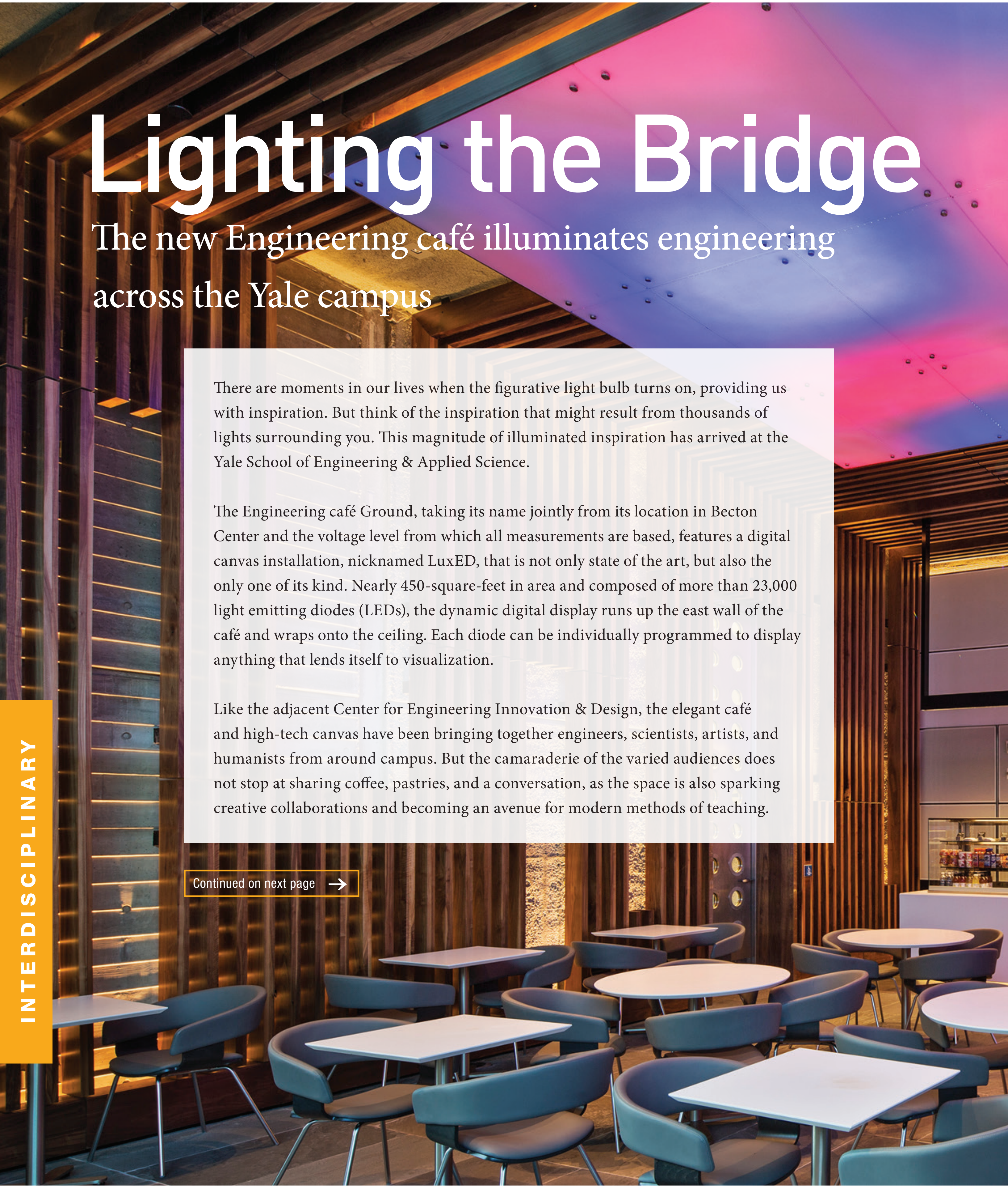
Tommasini is currently exploring the hypothesis that mechanical and biochemical stimuli may cause these osteocytes to remodel their surrounding environment – directly affecting bone quality and quantity. Separately, in a project with associate professor of diagnostic radiology & biomedical engineering Xenophon Papademetris, Tommasini is also developing an approach to determine bone strength in patients with mineral metabolism disorders like Rickets, which can cause weakening of bones.

As experimental technology across the many involved disciplines improves, the contributions that biomechanics can make to human health can only grow. Similarly, Humphrey expects that the biomechanics research and teaching within SEAS will only continue to expand in the coming years.

"We began our program in biomechanics in 2010 and only a few undergraduate students shopped the first class," says Humphrey. "Now, just three years later, our Introduction to Biomechanics class has over 50 students. Yale College students are very astute and they, like many within the biomedical engineering profession, recognize the fundamental role that biomechanics has in promoting many aspects of health and treating many different diseases. Yale provides a truly outstanding environment for students and faculty alike to study and contribute to this fascinating field."



Engineered heart tissue construct in micro-mechanical loading apparatus



INTERDISCIPLINARY

Lighting the Bridge

The new Engineering café illuminates engineering across the Yale campus

There are moments in our lives when the figurative light bulb turns on, providing us with inspiration. But think of the inspiration that might result from thousands of lights surrounding you. This magnitude of illuminated inspiration has arrived at the Yale School of Engineering & Applied Science.

The Engineering café Ground, taking its name jointly from its location in Becton Center and the voltage level from which all measurements are based, features a digital canvas installation, nicknamed LuxED, that is not only state of the art, but also the only one of its kind. Nearly 450-square-feet in area and composed of more than 23,000 light emitting diodes (LEDs), the dynamic digital display runs up the east wall of the café and wraps onto the ceiling. Each diode can be individually programmed to display anything that lends itself to visualization.

Like the adjacent Center for Engineering Innovation & Design, the elegant café and high-tech canvas have been bringing together engineers, scientists, artists, and humanists from around campus. But the camaraderie of the varied audiences does not stop at sharing coffee, pastries, and a conversation, as the space is also sparking creative collaborations and becoming an avenue for modern methods of teaching.

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Engineering Interactivity

While the digital canvas provides an impressive medium, displaying everything from the research images of the School of Engineering & Applied Science's faculty to the renowned Vincent Van Gogh piece Starry Night, a group of four students chose to further enhance the content displayed on the canvas by providing another element: interactivity.

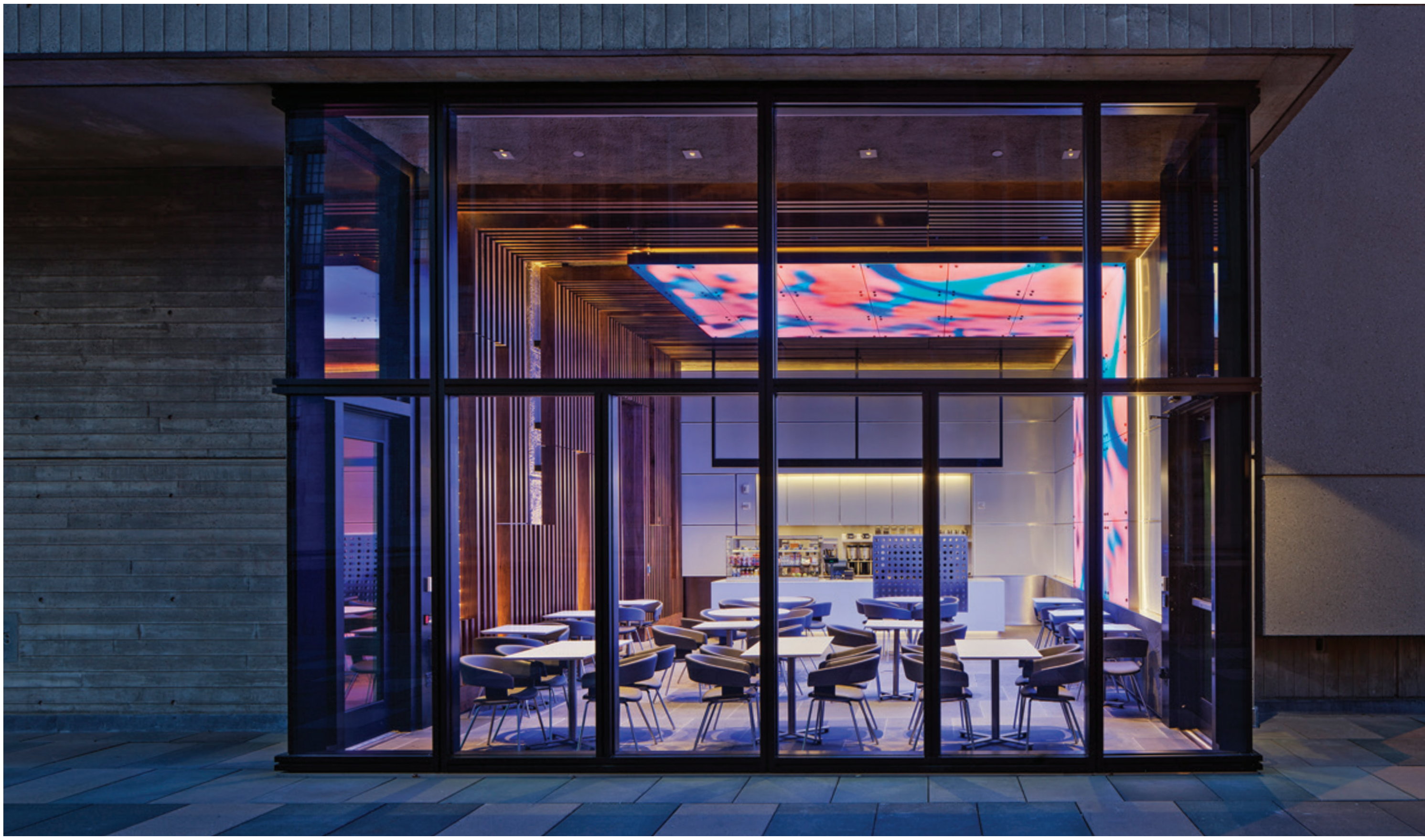
A new freshman course, entitled "Introduction to Engineering Innovation and Design," was created to showcase the role of creative problem solving in the five undergraduate engineering disciplines. A term project challenged student teams to apply their newfound engineering skills to solve problems for clients from across campus. Two student teams elected to work in the new café on projects that allowed café patrons to interact with the LED digital canvas.

Aptly titled "Team Bubbles," one group developed a system that displayed bubbles to signify customers and reflect real-time human movement in and out of café. By placing an infrared sensor on the café's entryway to detect motion, a bubble would form on the canvas each time a customer entered the space. The bubble would then float throughout the wall and ceiling space, joining the other bubbles that were created by earlier customers. When the customer exited the café, the bubble would pop and disappear.

"The project was a great example of the limitless possibilities of the LED technology," said Vincent Wilczynski, Deputy Dean of the School of Engineering & Applied Science. "It shows that not only can the canvas be used for stunning imagery, but also unbounded creative interactivity."

Providing a Culture of Engineering

The creation of the Engineering café Ground was one component of Yale School of Engineering & Applied Science Dean Kyle Vanderlick's continuing effort to foster a culture of engineering on the Yale campus.



“Engineering is the bridge between the sciences and the humanities,” says Vanderlick. “This installation is a symbol of that.”

From a location perspective, the café truly is a link. It sits at the figurative and literal bridge between the two entities. Located between Yale’s central campus, which primarily houses the humanities, and Science Hill and envisioned as a way to encourage students and faculty from different disciplines to mingle, the café is fulfilling the metaphor.

“We wanted to provide a space for the broader community to gather, to chat informally, to have a sense of a ‘home,’” says Vanderlick.

Bentel & Bentel, the architecture firm well known for its work on fashionable restaurants, including New York City’s Gramercy Tavern, Le Bernardin, and the Modern, the restaurant at the Museum of Modern Art, was hired to design the space. Bentel & Bentel suggested that the School incorporate the LED canvas as a key aspect in the new café. This idea was eagerly received, both for its potential to attract non-engineers and because a digital canvas would be a physical manifestation of the intersection of science and art. The canvas was designed to be visible to passersby on Prospect Street, thereby using light to draw attention to engineering.

“I believe the installation will develop as a new cultural, visual icon on campus, and Prospect Street is going to change, because of the light, the energy, the activity,” said Wilczynski, who discussed the LED project during its design with Leo Villareal, a Yale alumnus and one of the world’s foremost LED artists. Villareal’s largest installation, The Bay Lights, is currently displayed on San Francisco’s Bay Bridge. “Engineering will make its way out into the street. And engineering makes it all work.”

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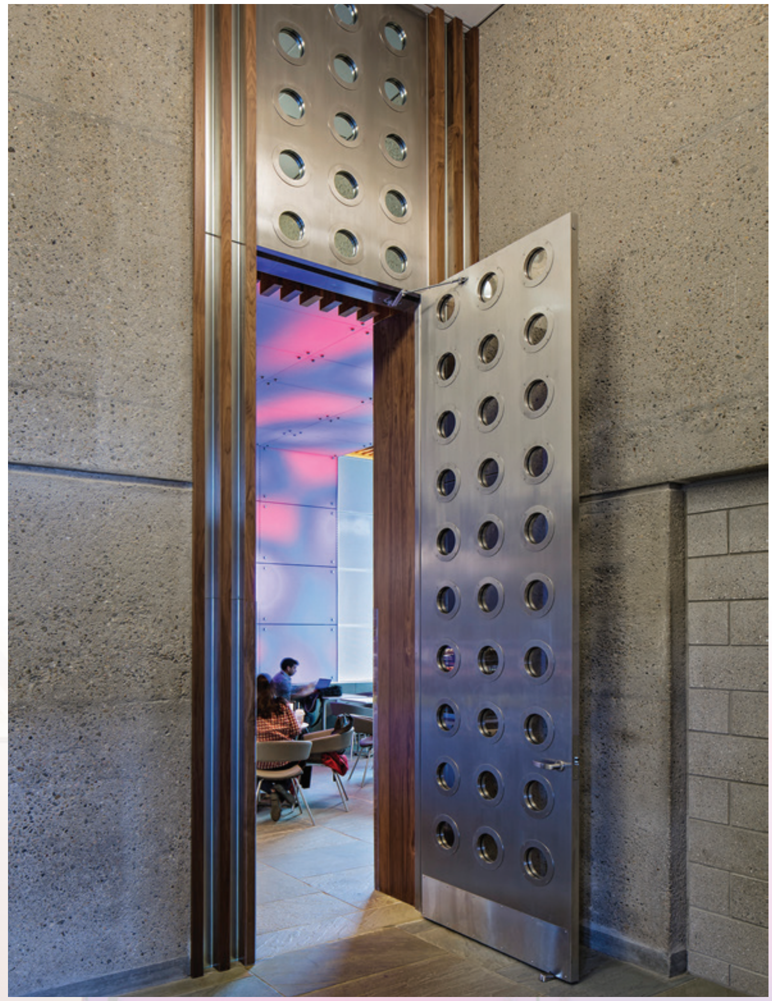
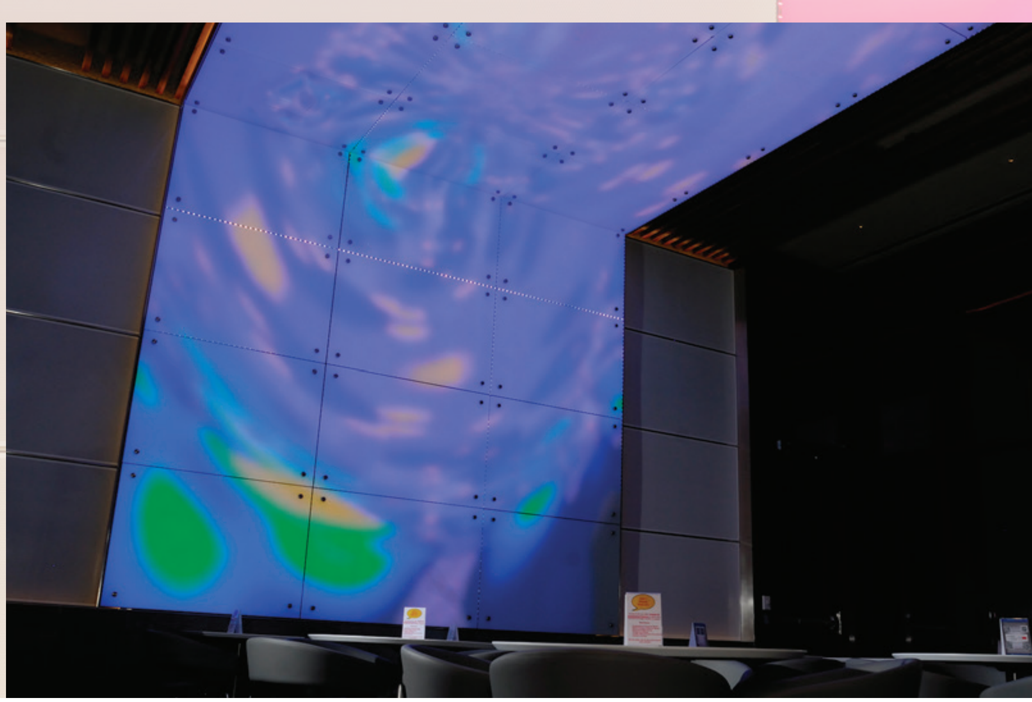


The Yale-affiliated aspect of the project extends well beyond Villareal and helps make this installation uniquely Yale, with the team of contributors including Philips/Color Kinetics (CEO Jeff Cassis is a Yale Environmental Engineering MS alum), Charney Architects (brothers Rich and Rob Charney are Yale School of Architecture alums), and installation guide Ted Pearlman (parent of a Yale undergrad) who is commonly known in the business as the "NYC King of LED." This Yale-associated team collaborated over a period of eight months to design, create, and install the digital architecture that is unlike any other in the world.

Sharing the Vision – and the Space

Besides Engineering, other disciplines such as Drama and Art have already begun to tap the space for their projects.

Elise Morrison, an English Department postdoctoral associate, has used the digital canvas both for her teaching and for showcasing her own work. She taught students in her theater studies class "Digital Media in Performance" how to use the display and then staged her students' work in the café. Morrison, whose work often incorporates elements of surveillance footage, said she plans to hold two or three of her own performance pieces in the café using the LED panel to display the video.

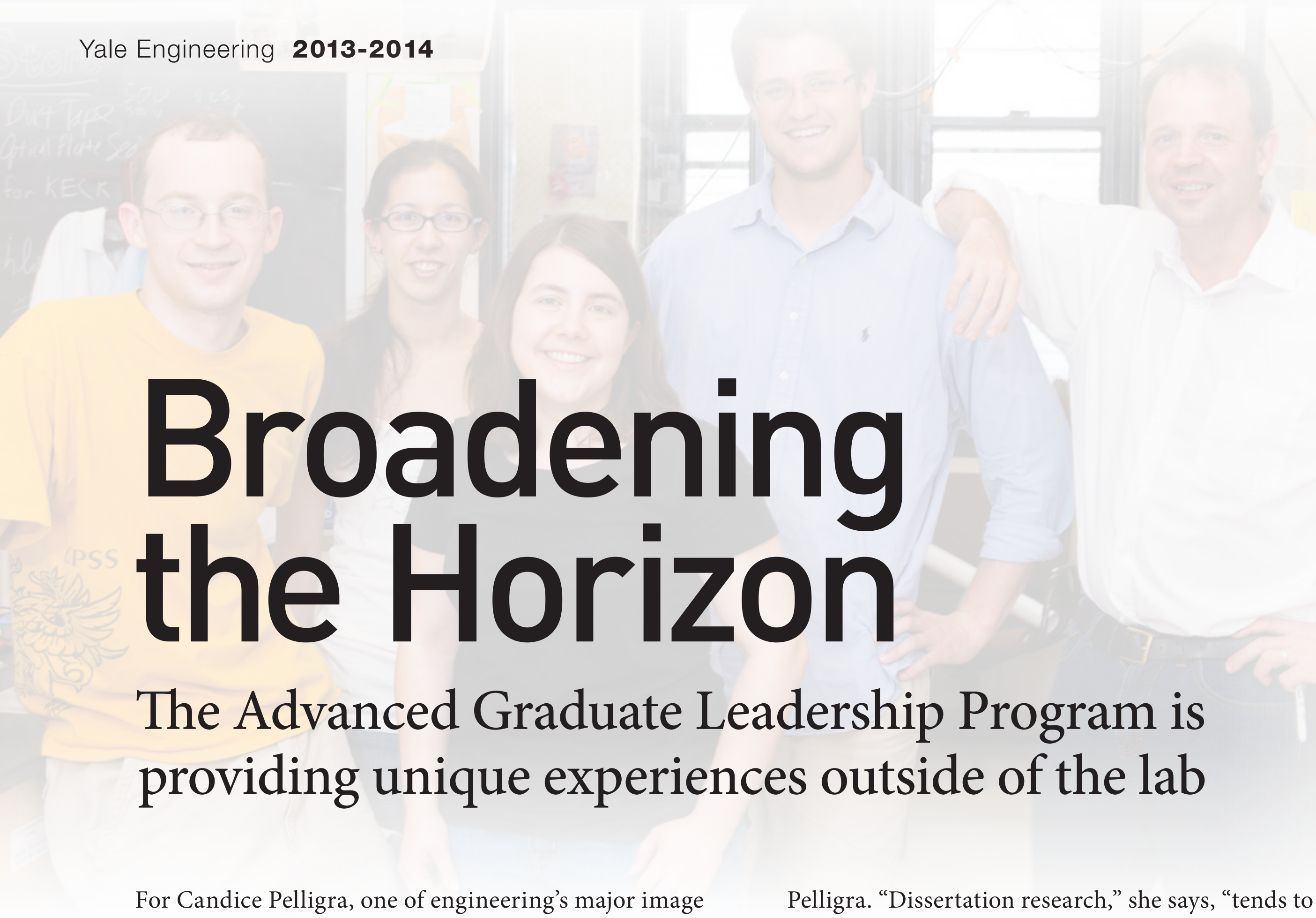


Johannes DeYoung, a critic in Yale's School of Art, teaches digital video and animation and is as thrilled by the possibilities of the digital canvas as anyone. His swirling, evocative, and powerful video visions are an obvious match for the space, and he has already had Yale art students create pieces that were displayed on the café's digital canvas. This past summer he had a chance to see how it all works when he led outreach workshops in digital animation for local high schools, using the café as the classroom.

"It was the first time the students actually programmed some interactive works for the walls, and I was really excited about this," DeYoung said. He is currently thinking about pursuing more in-depth digital video projects.

"It's a social, communal space and a completely immersive environment in that the wall wraps around you, so its potential uses are pretty widely varied. I see this as a way to engage with something that's encompassing – a wall of light that really inundates your senses."

The Engineering café Ground is located at 15 Prospect Street. For more information on the digital canvas and to see recent projects – including photos and videos – visit http://seas.yale.edu/cafe



Broadening the Horizon

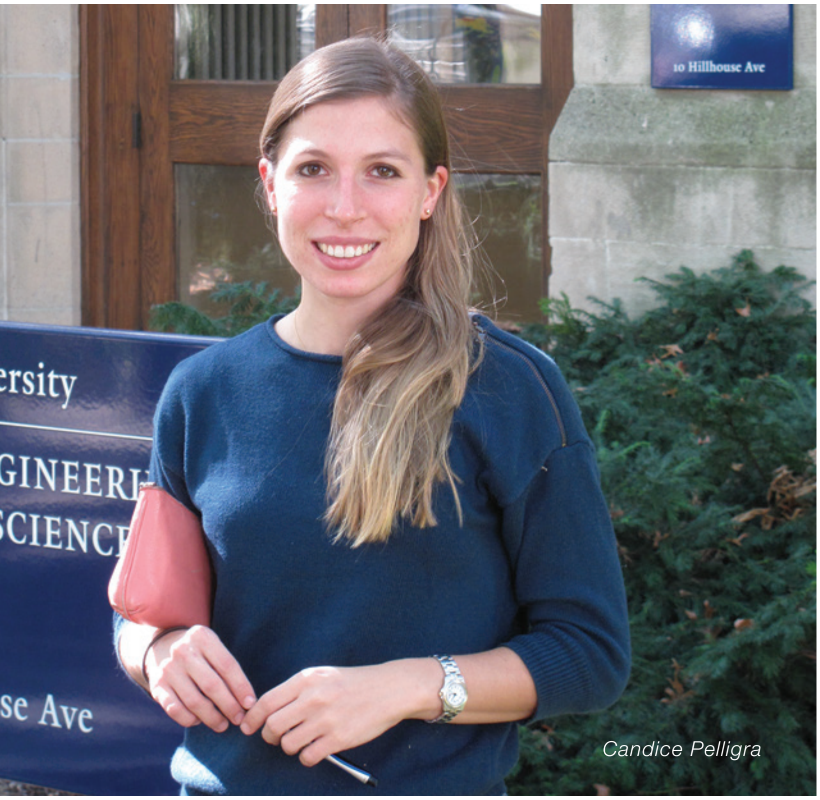
The Advanced Graduate Leadership Program is providing unique experiences outside of the lab

For Candice Pelligra, one of engineering's major image problems most directly affects, well, would-be engineers. "Engineering undergraduates find it hard to imagine actually working as engineers," she says, "as opposed to working in finance, or continuing on to graduate school. Which is a shame because we have a lot of talented undergrads who would do great things as engineers." But Pelligra, a chemical engineering doctoral student, is working to change that. While interning last spring with Undergraduate Career Services, she increased the on-campus presence of area technology companies, connected undergraduates with graduate student mentors, and helped develop Engineering Networking Nights on Yale's campus. "I hoped to give undergraduates a more complete view of their options," she says.

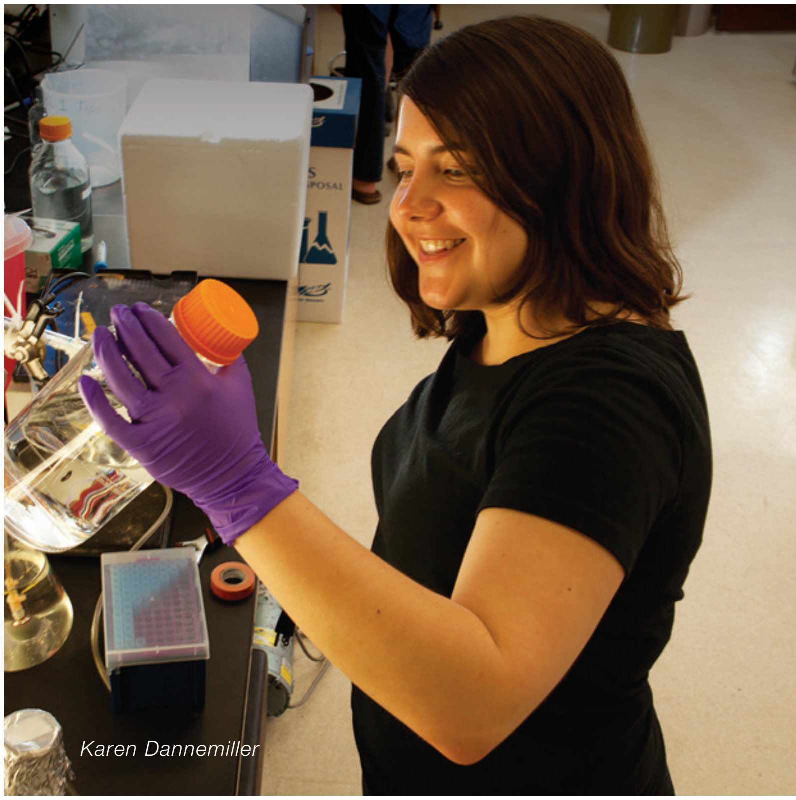
Her fellowship in the Advanced Graduate Leadership Program, of which her internship is one facet, has provided Pelligra a more complete view of her own career options. Since the launch of AGLP in 2009, forty-one fellows have benefitted from the program's beyond-the-lab professional development, including internships in communications, public affairs, policy and government relations, educational outreach, and technology ventures with the Yale Office of Cooperative Research and Yale Entrepreneurial Institute. This broad spectrum of offerings appealed to Pelligra. "Dissertation research," she says, "tends to be all-consuming and very individual. It was important for me to have an opportunity outside the lab where I could give back to Yale while also developing the networking and organizational skills that will be important to my future professional career."

Which isn't to say that internships are incompatible with lab work. Karen Dannemiller took full advantage of her research skills while working on the intersection of airborne particle science and public policy with the California Department of Public Health, a mentorship area that wasn't available to her on campus. "I was already familiar with making mold allergen measurements," Dannemiller says, "but my AGLP internship allowed me to go a step further to find associations between exposure to fungi in house dust and childhood asthma development." Dannemiller, an environmental engineering doctoral student, is working towards a career in academia, especially, she notes, if she can "tie my engineering skills into public health research."

AGLP, however, is not only an internship. The program also offers business courses at the Yale School of Management, individual career coaching, leadership workshops, and meetings with entrepreneurs. "The program serves as a forum for conversations about non-academic life,"



Candice Pelligra


Karen Dannemiller

Pelligra says. "Through AGLP, I've learned so much about my options after graduation, and I feel more prepared to enter the job market, particularly after conversations with AGLP graduates about their career paths."

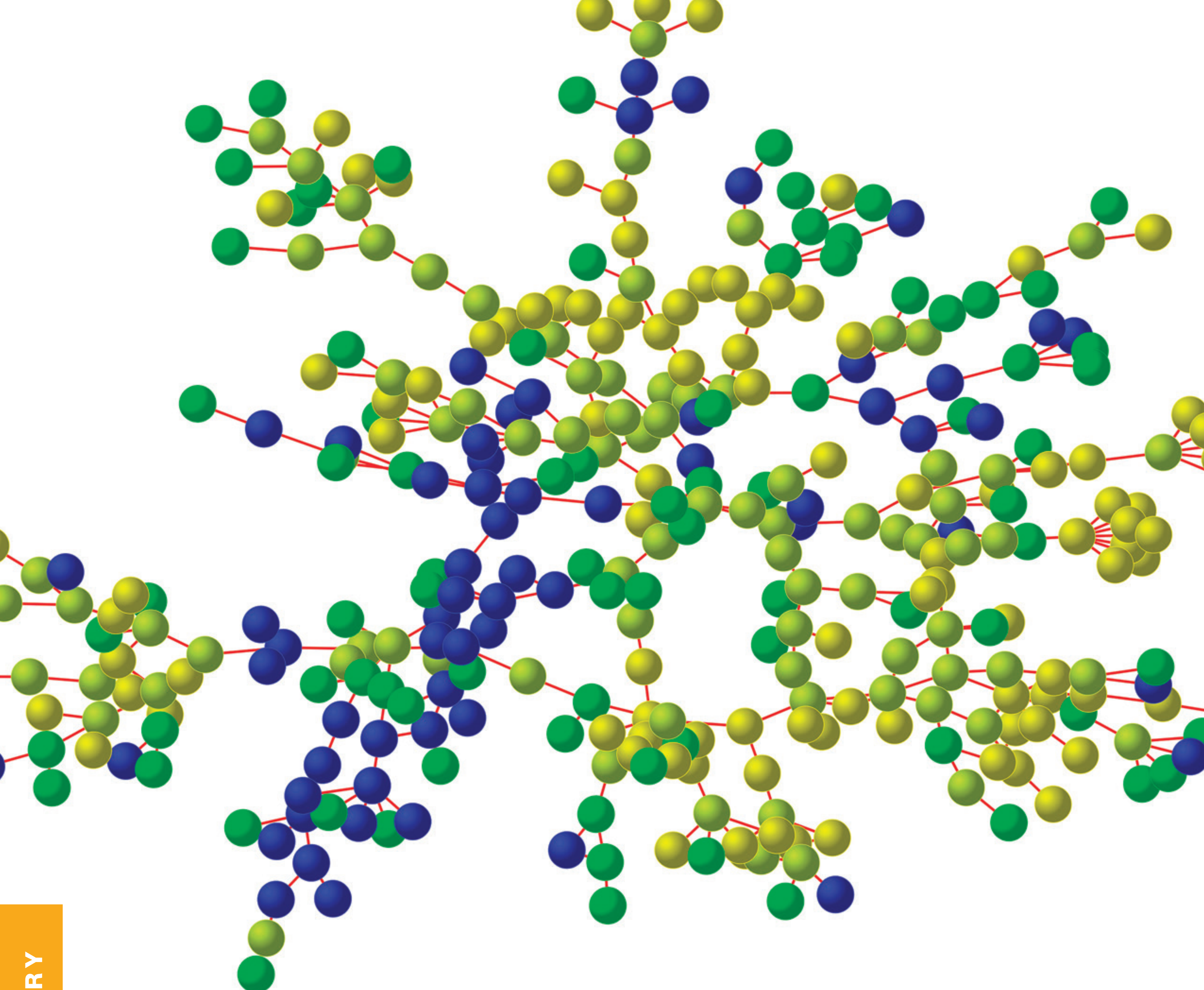
And AGLP alumni couldn't agree more. Sarah Miller, a 2011 environmental engineering doctoral graduate, currently works as a AAAS Fellow at the National Science Foundation's Directorate for Computer & Information Science & Engineering. There she helps broaden participation in computer science and engineering through the CS 10K initiative, which aims to recruit and train 10,000 new high school computer science teachers by 2016. However, it's a job she may not have gotten if her AGLP career coach hadn't helped her combine her interests in education and engineering.

"Graduate students often feel like only research and publications are valued," she says. "AGLP powerfully communicates that service and leadership outside the lab are important aspects of engineering graduate study. Participating in AGLP taught me that my work in public education is not antithetical to my engineering work, but related and valued."

AGLP's career guidance was just as helpful to Jason Park. After graduation, Park, a 2011 biomedical engineering graduate, accepted a position at the prestigious Boston Consulting Group. Park credits AGLP with preparing him for his current position, saying that "while we knew who to ask or where to get the resources to develop as scientists or engineers, there really wasn't a good platform to build on our other interests – whether it was how to launch a start-up, or how big companies approach science, or how public policy can be shaped. That's the role I see AGLP playing."

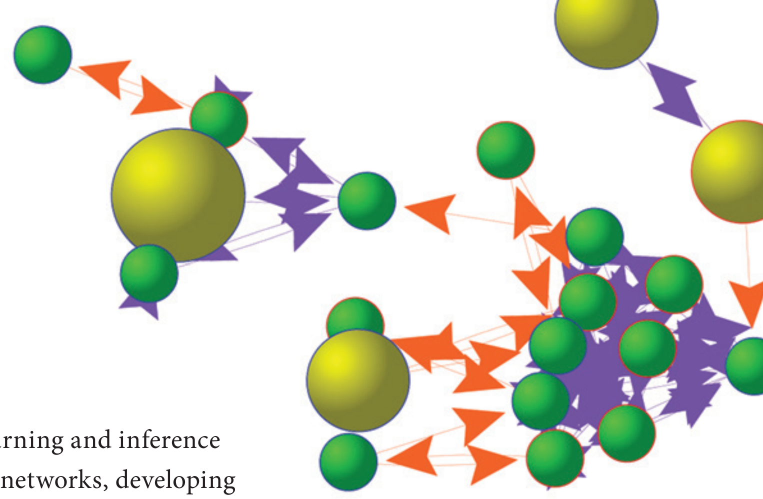
At BCG, Park works with the world's top biopharma companies and non-profit organizations. There he uses daily the analysis and quantitative reasoning skills he developed during his engineering studies, though he's also found that "solving even the most science-oriented R&D problems requires deep understanding of people and organizations, sound business judgment, and the ability to pull together great teams." It's these skills, Park asserts, that are hard for Ph.D. students to develop: "In the lab, you're taught (and incentivized) to do as much of the work yourself as possible, but in the real world, the most important, big, challenging questions are tackled by teams. Collaboration turned out to be way more important than I had ever anticipated."

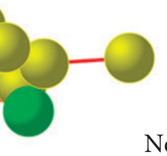
Such collaboration is just as likely to pay off in the future as it has in the past, at least for Yale Engineering's AGLP fellows.

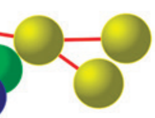


Expanding the SEAS Network

The new Yale Institute for Network Science connects SEAS to a variety of researchers







"The sum is greater than the parts" is a statement researchers at the new Yale Institute for Network Science (YINS) use often. Established in July, YINS is actively bringing together researchers from numerous disciplines across campus to further the study of complex networks.

Networks are ubiquitous in today's world, from the grids that supply electricity, to the communications systems we use throughout the day, to the social networks of friends, relatives, and acquaintances we all maintain. Network science – the study of interactions between different units – is becoming an important research area in the social, physical, and engineering sciences.

A network can be seen as a summary of the patterns of possible communications and interactions between different nodes, whether those nodes are computers, people, or power plants. Networks are useful for understanding and organizing social activities, natural phenomena, and engineered systems. But networks also impose limitations through different forms of network effects. As one considers larger groups of nodes, the limitations imposed by networks become more pronounced. On this, all disciplines agree. But different disciplines often use different terminology and conduct different measurements to describe both the structures and the effects of networks. One of the goals of YINS is to foster a collaborative culture of researchers from these diverse perspectives, an innovative approach that seeks to revolutionize the study of networks.

"The study of networks is dramatically transforming many academic fields and practices," says Yale University President Peter Salovey. "YINS will be a novel collaboration of faculty from the sciences that explores and contributes to this exciting new interdisciplinary field of knowledge."

All of the fields that study interactions in networks share common technical and scientific challenges. These include the development of statistical and computational tools for processing massive amounts of data, developing new models for complex networks, understanding how networks dynamically change in time, developing techniques for learning and inference in networks, developing methodologies for the design of networks, and understanding how local interactions can lead to emergent global behavior. YINS will expose researchers to the phenomena, measurements, methodologies, and challenges of those from different disciplines.

"We believe that researchers will benefit greatly from better understanding the approaches taken in other disciplines," says Daniel A. Spielman, the Henry Ford II Professor of Computer Science and Mathematics and co-director of the institute. "YINS will achieve synergy by gathering faculty who analyze networks with those who use networks to make predictions and those who attempt to design and control network processes."

To appreciate the scope and prevalence of network phenomena, consider the following fields where networks naturally appear: in economics, where the properties of information exchange within different networks determine the outcomes of diverse markets; in sociology, where the development and use of social networks are used to study the diffusion of individual behaviors and forms of collective social action; in computer science, where networks are the preferred abstraction and where algorithms for analyzing networks are developed; in biology, where much of systems biology involves understanding network effects, and the new understanding of gene regulation networks is revolutionizing our understanding of genetics; in physics, where networks are used to understand phase transitions in spin glasses and complex systems; in medicine, where epidemiological studies are increasingly taking social networks into account; and in statistics, where foundational theory and methods are being developed to handle the new technical challenges brought forth by the quantity of big data.

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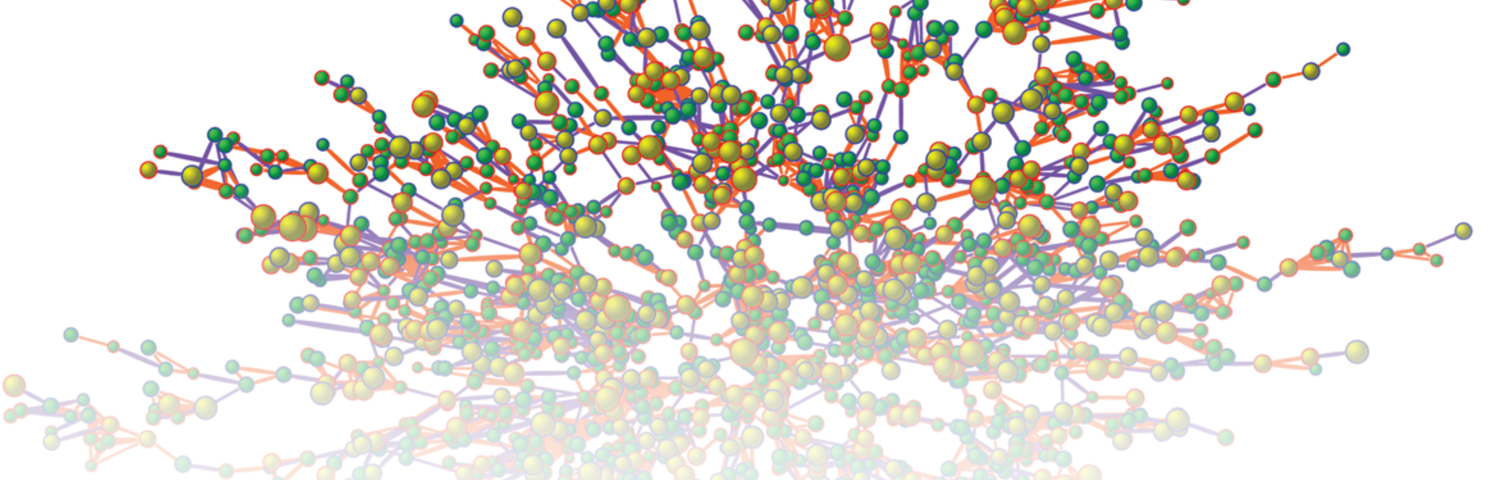
Images by N.A. Christakis and J.H. Fowler



It should come as no surprise that the Yale School of Engineering & Applied Science provides the largest faculty population of YINS, as networks abound within the engineering disciplines. The institute will be housed in the newly renovated building located at 17 Hillhouse, a further extension of the SEAS network on campus.

SEAS is represented at YINS by Sekhar Tatikonda, associate professor of electrical engineering and statistics and an expert in communication and networking theory, as well as through two new faculty scheduled to join next year: Wenjun Hu, arriving from Microsoft China, and Amin Karbasi, arriving from ETH-Zurich.

"By bringing researchers from different backgrounds, I believe YINS will provide a unique environment that stimulates innovative approaches to think about networks and fosters interdisciplinary research," says Karbasi. "With excellent faculty members and strong programs in these diverse disciplines at Yale, YINS is on a great course to produce exciting inter-disciplinary work," adds Hu.

These SEAS representatives bring their varied network expertise to the institute in areas such as robotic networks, where teams of autonomous robots must make local decisions and communicate among themselves to achieve given global tasks; communication networks, the backbone of our information age, where new forms of content must be transmitted over heterogeneous networks that are dynamically changing; power grids, including renewable generation in the form of wind and solar, new economic models and demand pricing, and overall variability in power generation and consumption; sensor networks, where scores of sensors are put in place to monitor everything from farm soil conditions to building structures to the health of the elderly; cloud computing and distributed storage, where there are issues of distributed communication and computation and the location of server farms; and peer-to-peer networks, where content shared between users makes up a large percentage of Internet traffic.

Kyle Vanderlick, Dean of Yale's School of Engineering & Applied Science, is excited by the representation of faculty from all parts of the Yale campus. "This new institute is exactly the type of interdisciplinary initiative that Yale's School of Engineering & Applied Science thrives on," says Vanderlick.

Dr. Nicholas Christakis, sociologist, physician, and co-director of the institute, shares Vanderlick's excitement about the interdisciplinary collaboration that YINS encourages. "Understanding the structure and function of social, biological, and communication networks will allow us to address important epidemics – of germs, of misinformation, of financial panic, of behaviors as diverse as smoking and violence," says Christakis. "We can use network science to intervene in the world to make people's lives better."

In addition to its goal of distinguishing itself by fostering collaborative research among engineering and the social, physical, and life sciences, YINS plans to promote undergraduate and graduate education in network science and disseminate new discoveries about network science through outreach activities such as publications, seminars, and workshops. The institute will provide a crucial point of contact for the many scholars at Yale who are on the network frontier and who need to better understand many forms of network interaction, and perhaps design, improve, or otherwise intervene in networks. "This is truly an exciting time to be at Yale. YINS is the kind of unique collaborative activity that Yale is particularly suited for," beams Tatikonda.

For the associated faculty at YINS, the sum is greater than the parts.

WE'RE NOT DONE!

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