Fall 2022

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Engineering Innovation @LehighU

SPARKING SYNERGY

State-of-the-art facility anchors research neighborhoods in biohealth and energy

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LEHIGH UNIVERSITY | P.C. Rossin College of Engineering and Applied Science

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Engineering Innovation @LehighU

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LEHIGH UNIVERSITY

LETTER FROM THE DEAN

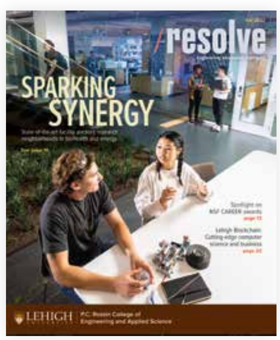
Engagement, belonging, community

Welcome to the Fall 2022 issue of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

What makes Lehigh Engineering, Lehigh Engineering?

It's more than the big-time academic resources and the small-school feel. It's more than the tradition that links each of us back to the very roots of engineering as a profession. It's more than the bed races, Lehigh-Lafayette Weekend, and the view from the look-out point on a crisp fall evening. (But, of course, those certainly don't hurt.)

Lehigh's long-standing commitment to the creation of knowledge through experiential learning and interdisciplinary research serves as the bedrock for our community's many successes—a heritage of achievement that cascades across generations of students and faculty.



The success of an institution with this mindset absolutely depends upon its community's enthusiastic support, its eager participation, and its intellectual openness. Thus, creating the climate for individuals to develop a sense of belonging and community while pursuing new knowledge is the key to continued growth and success—in the physical and digital spaces where we congregate, and in the programs we develop in search of what's next.

The Rossin College's Strategic Plan for Diversity, Equity, and Inclusion (DEI) recognizes this interdependency and sets goals and steps to build a stronger, more engaged community. Weaving DEI into the fabric of our institution at every level fosters the participation that is key to sustained impact—be it a research breakthrough that leads to a new patient-centered medical treatment, or a mentoring program that opens doors and changes the trajectory of countless futures.

HST IS DESIGNED FROM THE GROUND UP TO FOSTER A SENSE OF PURPOSEFUL COMMUNITY.

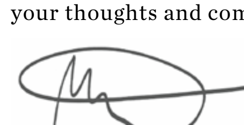
Lehigh's brand-new Health, Science and Technology (HST) Building, featured in this issue's cover article on page 16, is a strong expression of this forward-thinking approach to institutional development. From its architectural layout to the thoughtful composition of the building's faculty and student tenants and their complementary research interests, the HST Building is designed from the ground up to foster a sense of purposeful community. Open spaces and interdisciplinary neighbors facilitate synergies, as the Rossin College partners with Lehigh's College of Health to advance research and education at the intersections of our disciplines.

Our Q&A (page 8) shares the perspective of chemical engineering alumnus Vince Forlenza '75, current chair of the Lehigh Board of Trustees. A former CEO of Becton, Dickinson and Company, Vince led the firm's transformation into a global powerhouse in the medical device, diagnostic, and life sciences sector. A longtime Lehigh and Rossin College supporter, Vince has been generous in his support of the College of Health and the development of intersection points with our engineering community.

This issue's Rising Star (page 24) is Christina Haden, a teaching associate professor in our Department of Mechanical Engineering and Mechanics. Christina has been at the forefront of college diversity and inclusion efforts for years, and her innovative approach to course design and delivery is yet another shining example of the Lehigh interdisciplinary, inquiry-based, impact-focused mindset in action.

As a way for the extended Lehigh Engineering community to take action, we have launched the Rossin College Diversity, Equity, and Inclusion Fund, which will help ensure that students from historically underrepresented groups have the opportunities and means to fully engage in the Lehigh experience. Turn to the inside back cover of this issue to learn more about this effort and our ongoing initiatives supporting experiential learning and interdisciplinary team science.

Thank you as always for your interest in Lehigh Engineering and in the Rossin College. Please drop me a note with your thoughts and comments.



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OPPOSITE PAGE: DOUGLAS BENEDICT/ACADEMIC IMAGE; THIS PAGE: TIM COX

A prize catch

$7.5 million grant buoys research to develop fish-inspired schools of undersea robots

Keith Moored, an associate professor of mechanical engineering and mechanics, and colleagues from the University of Virginia and Harvard and Princeton universities aim to discover and demonstrate the hydrodynamic principles behind high-speed, high-efficiency fish and bio-robotic schooling.

The Lehigh team, led by Moored (left), will also conduct fluid dynamics simulations to better understand the fundamental physics behind fish schooling.

DOUGLAS BENEDICT/ACADEMIC IMAGE

The interdisciplinary team has been awarded $7.5 million from the U.S. Department of Defense—through a five-year Multidisciplinary University Research Initiatives (MURI) award—to help develop fast and efficient schools of bio-inspired underwater vehicles.

"It's important, particularly from the Navy's perspective, in order to build the next generation of underwater vehicles," Moored says. "If you look at how the military operates in the air, we have drones that can do all sorts of things, but we don't have that same kind of equivalent underwater. The Navy has been trying to invest in underwater drone technology that can serve a lot of purposes—where you can keep people out of harm's way and do things like surveillance and reconnaissance, but also underwater mine detection and removal."

Moored says that a deeper understanding of fluid dynamic interactions will enable bio-inspired robots to perform these tasks more effectively and with less energy as a group, just like fish in a school.

"We know that there are some benefits by having fish swim together, from a performance standpoint," he says. "They can actually swim faster when they swim together. They can actually swim more efficiently as a group than they can individually. What we're looking at is, really, understanding this better, so that ultimately we can design a school of bio-inspired robots to swim together in a beneficial way. And when [the bots] are deployed for a mission, they can go do distributed tasks, so that it's not just one bot going to do something, but they can spread out and go map an area, do reconnaissance or surveillance on other underwater vehicles, sweep for mines, or other missions."

The team—which includes Daniel Quinn, Haibo Dong, and Hilary Bart-Smith (UVA); George Lauder (Harvard); and Radhika Nagpal (Princeton)—will address three key, unresolved questions to reveal the hydrodynamic principles behind schooling: What are energy-reducing schooling states? Do the organization and synchronization of fish schools make full use of hydrodynamics? And, how is high-performance schooling achieved through the fusion of hydrodynamic principles and control?

"We're really trying to understand how we derive hydrodynamic benefits and what is the optimal schooling pattern in order to do that," Moored says. "The placement of fish within the school changes what kind of benefits are derived, but also the synchronization of their tail motion matters a lot too. We need to understand that kind of space better, of how the synchronization and placement of fish affects the hydrodynamic benefits."

> "THE **PLACEMENT** OF FISH WITHIN THE SCHOOL CHANGES WHAT KIND OF **BENEFITS** ARE DERIVED."
>
> —Keith Moored

Additionally, Moored says, "There are also forces that push and pull the fish around in the school that are derived completely from the hydrodynamic interactions between the fish. That may be linked to how the fish school is actually arranged in terms of its formation. We're trying to understand these pushing and pulling forces and whether they're sculpting the patterns of formations that we see in real fish schools, and whether that's something we can take advantage of in a robotic system."

Ideally, Moored says, researchers might be able to have the robotic devices swim in a specific formation by taking advantage of the right physics, rather than having to build controllers to affect their positions.

The team will build robotic devices as test beds and scientific demonstrators to prove, or disprove, hypotheses. They are currently working with tuna bots developed by Bart-Smith's team that are about eight to 10 inches in length, and blue bots created by Nagpal that are about five or six inches in length.

At Lehigh, the project will fund one postdoctoral scholar, two graduate students, and several undergraduate researchers each year. All told, some 30 to 40 researchers will be involved in the project.

Lehigh will focus its expertise on the fundamental physics involved.

"We take abstractions of these robots," Moored says. "For instance, we may look just at a model of the tailfin by itself, which is the main propulsive element of the specialized robots, and we will look at having two or more of these tailfins by themselves interacting. That abstraction is useful because it has all of the salient features of these robots. Some of the details are missing, which makes things simpler for us to analyze it with, but it has enough of the physics there that we can understand these kinds of complex interactions much better. We're going to do these more simple experiments with what we call hydrofoils interacting with each other."

The team will push out what it learns about optimal placement and synchronization of the swimming hydrofoils to the other researchers for additional testing, experiments, and demonstrations.

PhD student laser-focused on glass crystallization research

Evan John Musterman, a doctoral student in materials science and engineering, is one of 80 outstanding students to receive a grant through the Office of Science Graduate Student Research (SCGSR) program, a highly competitive award funded by the Department of Energy.

Since June 2022, Musterman has been at Brookhaven National Laboratory, advancing his research at the forefront of laser-fabricated single-crystal architecture in glass. At Lehigh, Musterman works with advisors Himanshu Jain (materials science and engineering) and Volkmar Dierolf (physics), making his work a truly interdisciplinary collaboration.

"I'm thrilled to be in residence at Brookhaven to advance a key area of fundamental importance to crystallization, which is to better understand the structural transformation of the glass phase preceding crystal formation," says Musterman, who will spend a total of nine months at the national lab.

The focus of Musterman's PhD work has been growing single crystals on the surface of glass via laser-generated heat. These crystals, because of their special properties, have the potential to be engineered for all kinds of desirable uses, most notably in optical, photonic, and quantum applications. Before that can happen, scientists need an understanding of just when or where the glass transforms into a crystal.

"It's a stochastic, random process," says Musterman. "At Brookhaven, I will work on a new method of studying how glass transforms just before crystallization."

It's a difficult challenge, he says. Musterman will be utilizing the state-of-the-art synchrotron-based imaging and spectroscopy capability at the National Synchrotron Light Source II within Brookhaven. Adding a laser to a beamline capable of measuring extended X-ray absorption fine structure (EXAFS) with sub-micron resolution, he hopes to be able to characterize local glass structure before crystallization.

"The idea is to be able to locally control where the crystal is going to form and locally probe the structure of the glass and the crystal at the same time," says Musterman.

Speaking to the significance of potential applications, Jain says: "Microelectronic integrated circuits and optical telecom technologies have revolutionized our lives. Imagine the impact if these two are combined into one 'optical chip with photonic integrated circuits.' It's a daunting task and it will require a multidisciplinary effort starting with the fabrication of 3D architecture of active optical waveguides within a glass."

Musterman is the embodiment of Lehigh's innovative Pasteur Partners PhD (P3) program, says Jain. P3 is a new track of doctoral training that provides students with experience in problem-solving in real-world environments, such as at a company or national lab.

"I can't wait to learn from his findings," Jain says.

While at Brookhaven (center), Musterman will gain fundamental insight on how atoms transform from the chaotic state of glass to controlled order in novel functional crystals.

ADVANCED MILLING TECHNIQUE PRODUCES NOVEL 'GREEN' FERTILIZER

Researchers from Lehigh University, Deutsches Elektronen-Synchrotron (DESY) in Germany, and the Ruđer Bošković Institute in Croatia have demonstrated that a purely mechanical method can produce a novel, more sustainable fertilizer in a less polluting way.

The synthesis method is an adaptation of an ancient technique: By milling two common ingredients, urea and gypsum, the researchers produce a new solid compound that slowly releases two chemical elements critical to soil fertilization, i.e., nitrogen and calcium. The milling method is rapid, efficient, and clean—as is the fertilizer product, which has the potential to reduce the nitrogen pollution that fouls water systems and contributes to climate change.

The team, which includes Jonas Baltrusaitis, an associate professor of chemical and biomolecular engineering at Lehigh, also found that their process is scalable; therefore, it potentially could be implemented industrially. The new fertilizer still needs to be tested in the field.

The synthesis method was optimized at the PETRA III light source at DESY, one of the few facilities in the world where mechanochemistry can be routinely performed and analyzed using X-rays from a synchrotron.

The results were published online in the journal *ACS Sustainable Chemistry & Engineering*.

"On its own, urea makes for a very weakly bound crystal that falls apart easily and releases its nitrogen too readily," says Baltrusaitis. "But with the calcium sulfate through this mechanochemical process, you get a much more robust cocrystal with a slow-release." The advantage of this cocrystal is that its chemical bonds are weak enough to release nitrogen and calcium but strong enough to keep the two elements from being unleashed all at once.

The milling procedure is fast and very efficient, resulting in a pure fertilizer without any waste byproducts except water. "Not only are we proposing a better functioning fertilizer," says Baltrusaitis, "we also are demonstrating a green method of synthesis."

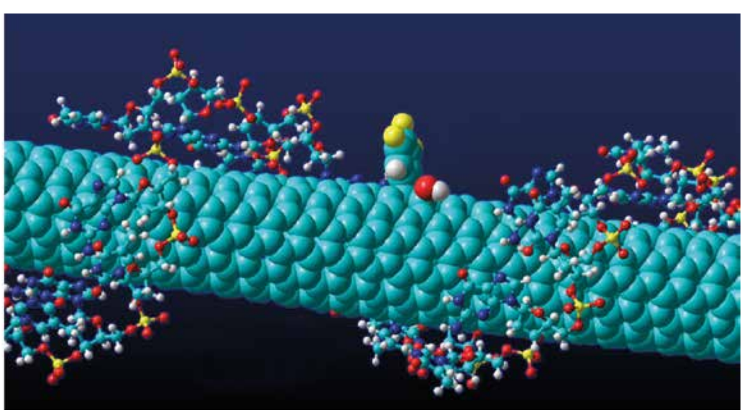
TOP: BROOKHAVEN NATIONAL LABORATORY; BOTTOM: DESY/GESINE BORN

Nanosensor platform could advance detection of ovarian cancer

Ovarian cancer kills 14,000 women in the United States every year. It's the fifth leading cause of cancer death among women, and it's so deadly, in part, because the disease is hard to catch in its early stages. Patients often don't experience symptoms until the cancer has begun to spread, and there aren't any reliable screening tests for early detection.

A team of researchers is working to change that. The group includes investigators from Memorial Sloan Kettering Cancer Center (MSK), Weill Cornell Medicine, the University of Maryland, the National Institutes of Standards and Technology (NIST), and Lehigh.

Two recent papers describe their advancements toward a new detection method for ovarian cancer. The approach uses machine learning techniques to efficiently analyze spectral signatures of carbon nanotubes to detect biomarkers of the disease and to recognize the cancer itself.



By using machine learning to analyze data from carbon nanotubes wrapped in DNA, researchers can detect both ovarian cancer biomarkers and actual cancer cells.

The first paper appeared in *Science Advances* in November 2021.

"We demonstrated that a perception-based nanosensor platform could detect ovarian cancer biomarkers using machine learning," says Yoona Yang, a postdoctoral research associate in Lehigh's Department of Chemical and Biomolecular Engineering and co-first author along with Zvi Yaari, a postdoctoral research fellow at MSK. The authors also included Ming Zheng, a research chemist at NIST; Anand Jagota, a professor of bioengineering and chemical and biomolecular engineering and vice provost for research at Lehigh; and Daniel Heller, associate member and head of the Cancer Nanotechnology Laboratory at MSK.

"Perception-based sensing functions like the human brain," says Yang. "The system consists of a sensing array that captures a certain feature of the analytes in a specific way, and then the ensemble response from the array is analyzed by the computational perceptive model. It can detect various analytes at once, which makes it much more efficient."

For this study, the array consisted of single-wall carbon nanotubes wrapped in strands of DNA. The way in which the DNA was wrapped, and the variety of DNA sequences that were used, created a diversity of surfaces on the nanotubes. The diverse surfaces, in turn, attracted a range of proteins within a uterine lavage sample enriched with varying levels of ovarian cancer biomarkers.

"Carbon nanotubes have interesting electronic properties," says Heller. "If you shoot light at them, they emit a different color of light, and that light's color and intensity can change based on what's sticking to the nanotube. We were able to harness the complexity of so many potential binding interactions by using a range of nanotubes with various wrappings. And that gave us a range of different sensors that could all detect slightly different things, and it turned out they responded differently to different proteins."

The machine learning algorithm was trained using the data from the nanotube emission—the spectral signatures—to recognize the pattern of emission that signaled the presence and concentration of each biomarker.

"The mental breakthrough here is that these nanotubes are nonspecific sensors," says Jagota. "They don't know anything about biomarkers, meaning they aren't programmed to bind to anything specific. All we knew is that they can be exposed to an aqueous medium, and whatever they're exposed to within that medium will produce spectral shifts and changes in magnitude. And using a combination of these sensors, we were able to train the algorithm to mathematically transform these inputs to outputs with high accuracy."

The second paper appeared in March 2022 in *Nature Biomedical Engineering* and comprised the work of many of the same researchers.

"In this paper, we weren't looking at biomarkers any longer, we were looking at the disease itself," says Heller. "We wanted to know, could this technology differentiate a blood sample from a patient with ovarian cancer from a patient without ovarian cancer?"

Those patients without ovarian cancer included both healthy people and people with other diseases.

In this study, the nanotubes were functionalized with quantum defects, which essentially increased the diversity of responses the nanotubes would provide.

"The nanotubes had a certain molecule bound to it that gave it an extra signal in terms of data," says Jagota. "So richer data came from every nanotube-DNA combination. And the model was trained not on the biomarker, but on the disease state."

The model developed a "disease fingerprint" from the spectral emissions of the nanotubes. The results were statistically significant in terms of the model's specificity in detecting ovarian cancer and sensitivity in detecting both known and unknown biomarkers of the disease.

The team has shown their technique can detect ovarian cancer better than the current methods, but it can't yet identify early stages of the disease. In part, says Heller, the issue is finding enough samples to train the algorithm because so few people are diagnosed at those time points.

"We're working on determining how we can actually detect this disease at the earliest possible stages," he says.

Next steps could also include branching out to develop the technique for a range of diseases, and determining if it can be optimized to work in clinical conditions, says Jagota.

ILLUSTRATION: DANIEL HELLER/MSKCC; NATURE BIOMEDICAL ENGINEERING COVER IMAGE: OLGA KHARCHENKO; COVER DESIGN: ALEX WING

CHRISTA NEU

Fulbright award jets doctoral student to Germany

John Kershner will continue work on owl-inspired aero-acoustics overseas

He was surprised. And also not surprised.

Mechanical engineering PhD student John Kershner was in the middle of an internship this past spring when he went online and saw that his application for a Fulbright research award had been accepted. His heart started racing. And his thoughts started colliding.

I'm going to move to Germany. That is so exciting! Oh my gosh. I'm at Penn State right now. I'm not even at Lehigh. And I have to move to Germany in like six months.

"It was a little bit of stress, but mostly excitement," he says.

It was also sort of half expected. Not to toot his own horn, says Kershner, but becoming a Fulbrighter wasn't a total surprise because his application was, well, pretty amazing.

When Lehigh's Office of International Affairs found out that he was applying, they were ready with all the assistance he'd need to make his bid virtually undeniable. And his advisor, Justin Jaworski, an associate professor of mechanical engineering and mechanics, was also eager to help.

"He has been supportive from the start of me getting an international aspect to my education," Kershner says. "So between working with people at Lehigh, and with Professor Jaworski specifically, and my personal experience—it was a really, really good application."

The Fulbright U.S. Student Program offers graduating college seniors, graduate students, and young professionals the opportunity to pursue graduate studies, conduct research, or teach English abroad. Its mission is to expand perspectives and create connections in a complex, changing world.

At Lehigh, Kershner works with Jaworski in researching owl-inspired aero-acoustics with the ultimate aim of making aircraft quieter. In Germany, he'll spend approximately six months of this academic year building on that research at Brandenburg Technical University at Cottbus-Senftenberg in Brandenburg.

"I'm going to work with a researcher at that university, as well as at the DLR, which is the German equivalent of NASA, to experimentally test these owl-inspired designs," he says.

He says one key point the Office of International Affairs stressed during the application process was to develop a strong argument for choosing the country in which to conduct research.

"I ENJOY LEARNING ABOUT OTHER **CULTURES**. THOSE EXPERIENCES **OPEN YOUR MIND** TO DIFFERENT WAYS OF THINKING."

—John Kershner

"Lehigh helps you hone that message," he says. "It was the best advice I got."

For Kershner, the choice was Germany. He grew up in Reading, Pennsylvania, surrounded by the history and culture of the Pennsylvania Dutch, a group formed during the 18th and 19th centuries by German immigrants fleeing religious persecution in Europe. Kershner says his grandmother spoke the language, and he started taking German in middle school. In high school, he did a three-week exchange program in the country, and as an undergraduate at York College of Pennsylvania, he spent a semester working there as part of a co-op program.

When it came time to defend his chosen country for the Fulbright, those rich experiences made it easy. And attaining the award puts him a step closer to one of his goals.

"I'd like to work internationally after graduating with my PhD," he says. "I enjoy learning about other cultures, and I think those kinds of experiences open your mind to different ways of thinking and communicating, and make you a better person overall."

RESEARCH RECOGNITION

» **Arindam Banerjee**, **John Coulter**, and **Carlos Romero** have been named as Fellows of the American Society of Mechanical Engineers (ASME).

» **John Coulter**, Rossin College senior associate dean for research, is the new chair-elect of the Engineering Research Council (ERC) of the American Society for Engineering Education (ASEE).

» **Dan M. Frangopol** (CEE) has been elected into the Canadian Academy of Engineering (CAE) as an International Fellow for "the creation, development, and application of life-cycle engineering under uncertainty."

» **Elsa Reichmanis** (ChBE) is the 2022 recipient of the John M. Prausnitz AIChE Institute Lecturer Award, which recognizes her long-term accomplishments as a senior chemical engineering faculty member.

» **Arup K. SenGupta** (CEE/ChBE) was honored for his wide-ranging contributions to water science and technology and expanding access to safe drinking water through a three-day symposium on "Ion Exchange, Sustainable Separations & Humanitarian Engineering" at the Spring 2022 meeting of the American Chemical Society (ACS).

Image-based simulations improve accuracy in assessing healing progress of fractures

When you first break a bone, the body sends out an inflammatory response, and cells begin to form a hematoma around the injured area. Within a week or two, that blood clot is replaced with a soft material called callus that forms a bridge of sorts that holds the fragments together. Over months, the callus hardens into bone, and the healing process is complete.

Dailey discusses her lab's efforts to help surgeons improve patient care on the Rossin Connection Podcast.

Listen at **engineering.lehigh.edu.**

But sometimes, that bridge between the bones fails to form, creating a nonunion. In patients with long-bone fractures (of the tibia or femur, for example), nonunions can be particularly debilitating, severely affecting their quality of life and ability to work.

For surgeons, nonunions can be difficult to diagnose as they require subjective assessments of X-rays taken over a period of six to nine months. The difficulty lies in that the bone *could* be healing, just very slowly, in which case additional intervention may not be necessary. But if it's not healing, the patient has endured months of pain and limited activity, only to face additional surgery.

In a perfect world, surgeons would have a tool that could identify nonunions earlier.

"The end goal is to save patients time, money, and frustration," says Brendan Inglis '19 '22G, who recently finished his master's degree in mechanical engineering. "Because if the surgeon comes back to you and says you have a clinically diagnosed nonunion, and you need further interventions, that's going to further delay your ability to get back to your life."

Inglis is the lead author of a paper published in *Scientific Reports* that shows how the dual nature of the healing zone, as both a soft and hard material, determines the mechanical rigidity of the whole bone. The work builds on research in the lab of Hannah Dailey, an associate professor of mechanical engineering and mechanics. Previously, the team has shown the viability of using a noninvasive, imaging-based virtual biomechanical test to assess the progress of fracture healing. Additionally, the team has developed and validated a material properties assignment method for intact ovine bones using virtual biomechanical testing.

The problem, says Inglis, was that the virtual tests overpredicted the mechanical properties of the bone early in the healing process because parts of the callus are still too soft to be modeled as bone.

"When we applied that model to fractured ovine tibia, essentially a sheep's lower leg, the mechanical properties didn't match," he says. "Our hypothesis was that all the soft tissue and cartilage involved in the healing of a fractured limb was being overpredicted, meaning the callus was being assigned properties that were too stiff."

"UNDERSTANDING WHY THE **HEALING PROCESS** FAILS BETTERS OUR CHANCES OF CREATING A TOOL THAT COULD **INFORM SURGEONS**."

—Brendan Inglis

In other words, the previous model didn't accurately differentiate between bone and callus. If callus was treated as being stiffer than it actually was, it could imply that the bone was further along in the healing process than it actually was.

"Callus is a highly heterogeneous tissue, meaning it contains more than one density and stiffness value," says Inglis. "So if you're going to model an operated limb, you can't treat everything as dense bone. You need to come up with some way to treat callus differently. But the mechanical properties of callus still aren't well understood, and there wasn't anything in the literature that set the cutoff point between where you start treating the healing zone as soft tissue, and where you start treating it as bone."

To determine that cutoff, Inglis and his team worked with collaborators at the Musculoskeletal Research Unit (MSRU) at the University of Zurich. The Swiss researchers used a torsion tester to measure torsional rigidity in excised sheep tibia, and the Lehigh team used the corresponding CT scans and data to replicate those biomechanical tests virtually.

Inglis explains that the brightness of the pixels within the CT bone scans correlates to density. The brighter the pixel, the stiffer that area of bone.

"You can imagine that from a black pixel to the brightest white pixel, there's a whole spectrum of values. So essentially what we did was find the cutoff below which the pixels are getting darker and should be treated as very soft. We postulated that prior to this study, those darker pixels were being calibrated too high, and assumed to be too stiff in the model."

Utilizing a piecewise material model, they optimized a cutoff point that separates soft tissue from bone.

"When you get that density cutoff right, the virtual models can accurately replicate the rigidity you get from a bench biomechanical test of that same bone," he says. "Once you have a model that's validated to what was done on a bench test, you can start to predict different things about the behavior of healing bones. And the more we understand about why the healing process fails, the better our chances of creating a tool that could one day inform surgeons. So this model gives us a foothold into one day translating this work into the clinic."

CHRISTA NEU

Accelerating the pace of machine learning

Electrical and computer engineering professor Rick Blum seeks to remove the bottleneck in wireless, distributed learning applications

Machine learning happens a lot like erosion. Data is hurled at a mathematical model like grains of sand skittering across a rocky landscape. Some of those grains simply sail along with little or no impact. But some of them make their mark: testing, hardening, and ultimately reshaping the landscape according to inherent patterns and fluctuations that emerge over time.

Effective? Yes. Efficient? Not so much.

Rick Blum, Lehigh's Robert W. Wieseman Professor of Electrical and Computer Engineering, seeks to bring efficiency to distributed learning techniques emerging as crucial to modern artificial intelligence (AI) and machine learning (ML). In essence, his goal is to hurl far fewer grains of data without degrading the overall impact.

In a paper published in a special ML-focused issue of the *IEEE Journal of Selected Topics in Signal Processing*, Blum and collaborators propose the use of a "Gradient Descent method with Sparsification and Error Correction," or GD-SEC, to improve the communications efficiency of machine learning conducted in a "worker-server" wireless architecture.

"Problems in distributed optimization appear in various scenarios that typically rely on wireless communications," he says. "Latency, scalability, and privacy are fundamental challenges."

Various distributed optimization algorithms have been developed to solve this problem, he says, "and one primary method is to employ classical GD in a worker-server architecture. In this environment, the central server updates the model's parameters after aggregating data received from all workers, and then broadcasts the updated parameters back to the workers. But the overall performance is limited by the fact that each worker must transmit all of its data all of the time. When training a deep neural network, this can be on the order of 200 MB from each worker device at each iteration. This communication step can easily become a significant bottleneck on overall performance, especially in federated learning and edge AI systems."

Through the use of GD-SEC, Blum explains, communication requirements are significantly reduced. The technique employs a data compression approach where each worker sets small magnitude gradient components to zero—the signal-processing equivalent of not sweating the small stuff. The worker then only transmits to the server the remaining non-zero components. In other words, meaningful, usable data are the only packets launched at the model.

"Current methods create a situation where each worker has expensive computational cost; GD-SEC is relatively cheap where only one GD step is needed at each round," says Blum.

Professor Blum's collaborators on this project include his former student Yicheng Chen '19G '21 PhD, now a software engineer with LinkedIn; Martin Takáč, an associate professor at the Mohamed bin Zayed University of Artificial Intelligence; and Brian M. Sadler, U.S. Army Senior Scientist for Intelligent Systems at the Army Research Laboratory.

TOP: MARCO CALDERON PHOTOGRAPHY; BOTTOM: ISTOCK

KEYSIGHT TECHNOLOGIES OUTFITS NEW LABORATORY

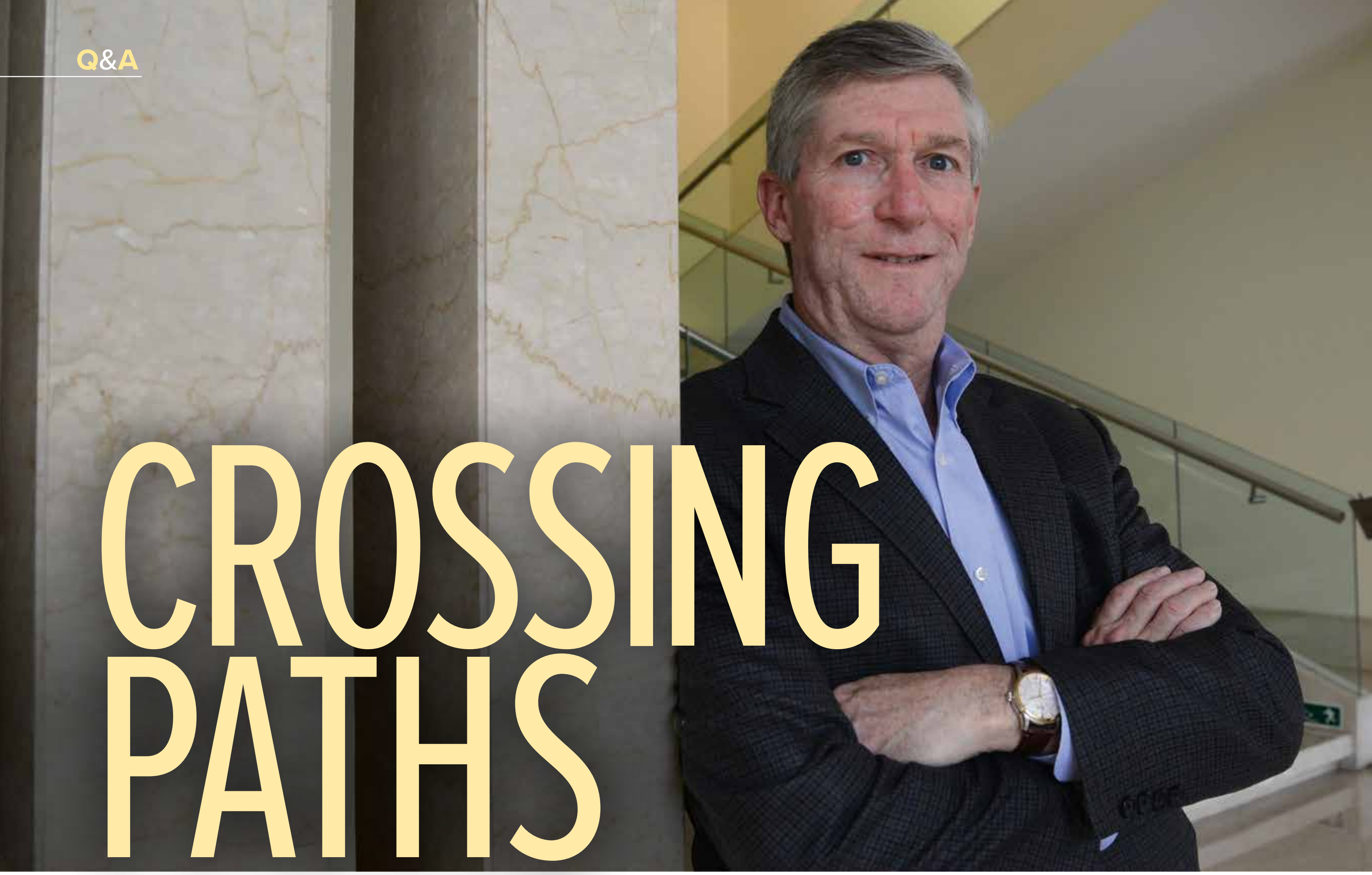
The new Keysight Technologies Lab in Packard Laboratory features 20 stations of high-tech testing and measuring equipment that allow electrical engineering and computer engineering students to perform state-of-the-art industry-ready experiments, conduct innovative design projects, and engage in experiential learning.

The space was made possible by a gift from Keysight Technologies Inc., a California-based company and global provider of electronics test and measurement solutions. The firm's executive chairman (and former CEO) is Ron Nersesian '82, a Lehigh electrical engineering alumnus (pictured above, left).

At a dedication ceremony held in March, Nersesian said: "Lehigh Engineering students are widely regarded as among the most innovative and industrious in the world. We're very glad to provide this support to Lehigh's Department of Electrical and Computer Engineering. With this new lab at their disposal, its students will graduate and be ready to contribute on job day one."

Professor Chengshan Xiao, chair of the Department of Electrical and Computer Engineering (ECE), collaborated with Keysight's corporate director of education, Dr. Doug Baney, on the two-year effort.

"Our ECE faculty have already designed new and advanced courses to fully utilize the Keysight equipment such as vector signal generators, signal analyzers, multi-channel oscilloscopes, Internet of Things systems, etc.," said Xiao, "and our students love them."



CROSSING PATHS

Vince Forlenza ’75 on integrating health and engineering for the greater good

As CEO of Becton, Dickinson and Company, chemical engineering alumnus Vincent Forlenza ’75 led BD’s transformation from a medical supply manufacturer to a global powerhouse in the medical device, diagnostic, and life sciences sector. In that role, he also orchestrated numerous public-private partnerships—increasing access to low-cost diagnostics and expanding vaccination programs, for example—aimed at improving health care in developing countries. A steadfast supporter of Lehigh’s academic and research mission and a university Trustee, Forlenza was a central figure in the development of the College of Health and the new Health, Science and Technology Building, providing strategic insight drawn from his nearly 40-year career at the intersection of health, technology, business, and corporate social responsibility. Following his retirement as BD’s executive chairman, Forlenza was tapped to chair Lehigh’s Board of Trustees. From that post, he continues to champion the integration of engineering and health-focused research as a path toward greater innovation and equity.

Q: Surmounting challenges in global health care has been your career focus. What do you find most compelling about this work?

A: The most compelling aspect is the ability to have a large and rapid impact on people’s lives. For example, working with countries around the globe to build basic diagnostic testing capabilities made a difference to individuals and societies as they battled HIV and other infectious diseases. In addition, it gave me the opportunity to partner and work with outstanding people from organizations such as the U.S. President’s Emergency Plan for AIDS Relief (PEPFAR), the Gates Foundation, the Clinton Global Health Initiative, and others.

Q: How has your engineering background guided you in managing complex organizations and finding the right approach to issues related to human health?

A: My engineering education taught me how to solve multivariable problems, or in other words, how to deal with complexity and uncertainty. Engineering was a great foundation to then broaden my knowledge in other fields, such as finance, management, and social issues, as I built my career. Solving global health issues requires understanding not only the basic technologies but all the other dimensions of the problems as well. Running large organizations requires aligning people to solve multidimensional problems effectively, usually in multifunctional teams. I believe it is easier as a leader in a technology-driven organization to start with the knowledge of the science and technology than with the nontechnical aspects. The ability to integrate both is key in leadership positions. Consequently, I am a big supporter of the integrated learning approach that Lehigh President Joe Helble is advocating.

Q: What do you see as the biggest challenges facing health and health care?

RAMESH PATHANIA/MINT/GETTY IMAGES

"There are many health-related activities at Lehigh, but there has never been a strategy to scale these efforts," says new Lehigh Board of Trustees Chair Vince Forlenza. "We have that opportunity now."

A: Globally, it continues to be access and cost, which, I think, will remain as major challenges in the future. Climate change, politics, lack of basic health knowledge, misinformation, and pandemics are also making the challenge more difficult. At the same time, new scientific knowledge and technologies are exploding rapidly and making cures for many diseases potentially possible. CRISPR, the gene-editing technology, is but one example. Society's challenge will be to organize health systems in a way that integrates the social determinants of health with technology, cost, and access to reach broad populations. This is why the new College of Health is focused on population health and the improvement of the delivery of health care to all segments of society. Think health technologies for health equity.

Q: You emphasized the importance of an integrated approach. How will your role as Board of Trustees chair enable you to nurture a cross-campus integration around health and health care?

A: The Board strongly supports an integrated approach to learning, including expanding Lehigh's cross-college programs to enable our graduates to solve problems and create opportunities in health as well as in other domains. One sees that issues in information-technology-driven businesses, such as social media, require a deep understanding of not just the technology but also social and political issues. The intersection of technology and the understanding of human behavior is key in all these areas. As chair, it will be my role to make sure the Board is aligned with the work President Helble is leading on strategic planning that will set priorities for Lehigh, including integrated and experiential learning.

Q: What role has Lehigh's existing strength in engineering played in launching the College of Health?

A: Successful strategies often start with leveraging core capabilities and applying them in new areas. Capabilities in engineering are one of the fundamental strengths that Lehigh brings to this new endeavor. There are many health-related activities at Lehigh, but there has never been a strategy to scale these efforts. We have that opportunity now.

The College of Health and the Rossin College are working closely together as we build capability and strategy. Twenty members of the engineering faculty are already affiliated with the College of Health. Members of the engineering faculty participated in the College of Health's research strategy session, which resulted in the hiring of two epidemiologists who will work closely with the engineering faculty. In addition, the colleges have made two joint appointments, Professor Bilal Khan (community and population health and computer science and engineering) and Assistant Professor Gabrielle String (community and population health and civil and environmental engineering). The colleges are also working on a joint undergraduate degree where students will work on real-world health problems requiring engineering solutions to provide health equity and improve health.

LEFT: MICHAEL NAGLE/BLOOMBERG/GETTY IMAGES; RIGHT: CONTRIBUTED PHOTO

Q: Programs in bioengineering, healthcare systems, the Mountaintop Initiative, and Lehigh Business are also aligned with public health. Why is Lehigh's culture so attuned to the needs in this space?

A: I think the pragmatic nature of the Lehigh faculty, administration, and students drives them to areas where they believe they can make a real difference. Most everyone has a family member or friend who has benefited from advances in health or been frustrated by the inefficiencies in the current U.S. healthcare system. I have also interacted with members of the Lehigh community whose experiences bring a global perspective of the needs for better health in the less developed countries. The pandemic certainly intensified this desire to improve global health.

Q: What areas of intersection between the College of Health and the Rossin College hold significant promise for innovation?

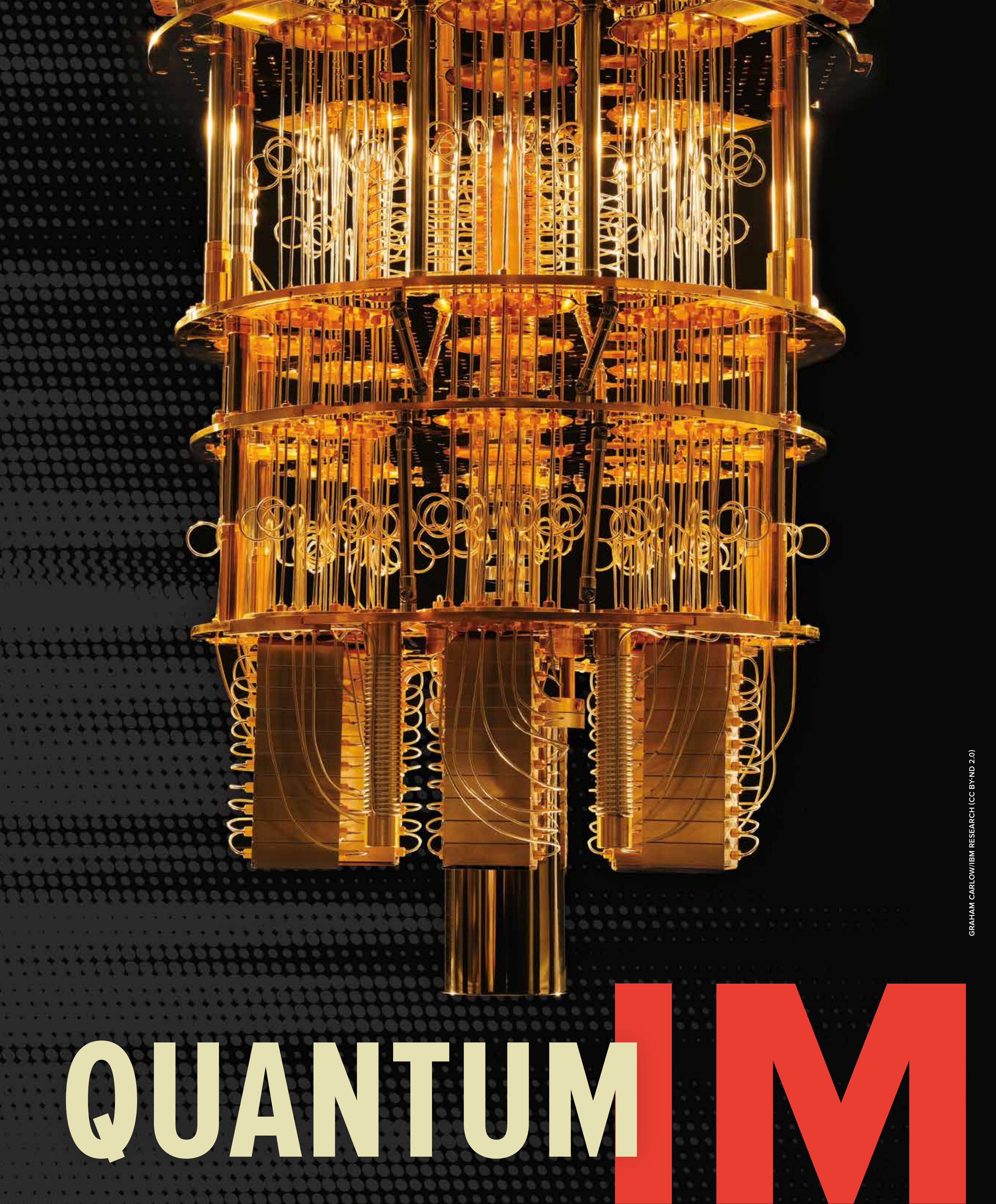
A: These discussions are just beginning and will be influenced by the areas of research of the new faculty in the College of Health as they join Lehigh. The use of artificial intelligence and machine learning combined with new technologies and devices, including wearable monitors and diagnostics to enable further decentralization of quality care to the home and other settings, is one potential opportunity for collaboration. The bioengineering faculty is already expanding its strength in these areas. Faculty growth in the Rossin College has been primarily in data/computation and bioengineering. Health will be an application area for these foundational engineering capabilities in partnership with the College of Health.

Q: You and your wife, Ellen, (above) made a $5 million gift to fund a faculty chair in the College of Health. Why is this kind of support critical to a new academic enterprise?

A: Ellen and I believe that the endowed chair is a strong sign to the academic community that Lehigh is serious and highly supportive of the College of Health. The chair will enable the college to bring in unique talent that we can build on and should increase our capabilities for both research and partnerships.

Q: How does the College of Health present a growth opportunity for the Rossin College?

A: Partnering with the College of Health will enable Lehigh engineers to access a new set of capabilities, broaden their areas of impact, and tap into new funding. It will also be a wonderful way to expose students to interdisciplinary learning to broaden their perspective and career opportunities.



QUANTUM IM

BY KATIE KACKENMEISTER

At the dawn of new era, Lehigh's Quantum Computing and Optimization Lab harnesses emerging technology to solve optimization problems beyond the reach of classical computers

To the casual observer, a quantum computer—with its tiered, "upside-down wedding cake" design, strands of precisely strung wires, and shiny, metallic finish—could be mistaken for a funky chandelier or a work of modern art.

Yet, despite the machine's futuristic look, the computing technology, as it exists today, is somewhat clunky.

"Quantum computers are in their early stage of development," says Tamás Terlaky, George N. and Soteria Kledaras '87 Endowed Chair Professor in the Department of Industrial and Systems Engineering (ISE). "They have limited capacity. They are not reliable. They are 'noisy,' meaning error-prone. You could relate them to the early vacuum-tube, first-generation computers that existed before the silicon transistor was discovered."

It's the benefit of hindsight, having witnessed the wide-ranging impact of the "silicon revolution" and the invention and growth of the internet, that has Terlaky and fellow members of Lehigh's Quantum Computing and Optimization Lab (QCOL) excited to play a leading role in what they see as the dawn of a new technological age.

QCOL was formed in 2019 with major support from the Defense Advanced Research Projects Agency (DARPA) and Lehigh's ISE department. The group is led by Terlaky and includes ISE faculty members Luis F. Zuluaga and Xiu Yang (a 2022 recipient of the NSF CAREER award; see page 13), computer science and engineering assistant professor Arielle Carr, graduate students, and outside collaborators from industry, national labs, and academia.

"Young researchers are curious and open-minded. Being among the first in the world to work in this area will bring strategic advantages for their careers." —Tamás Terlaky

The interdisciplinary lab, a research group within Lehigh's Institute for Data and Intelligent Systems (I-DISC), is working on optimization algorithms in quantum computing (QC) that could hold the key to "solving problems in economics, transportation and supply chains, telecommunications, and other areas that are unsolvable today," says Terlaky.

"Quantum computing is a revolutionary new computing paradigm," he says. "We cannot fully assess its long-term potential and impact."

Seizing a subatomic edge

"Quantum computing uses subatomic particles to represent and operate abstract mathematical concepts; like using nature to compute for us," says ISE doctoral student Muging Zheng. "It inspires people to use an entirely new perspective to describe things that they have been working on for years, and eventually make improvements in both the classical and quantum world."

In very basic terms, QC harnesses the unusual properties of subatomic particles to gain a computational edge. Where traditional computers process binary bits (electrical or optical pulses that translate to zeros and ones), the "qubits" (electrons or photons) used by quantum computers can exist in multiple states at one time (a property called superposition), which has the potential to exponentially increase the systems' number-crunching power.

PACT

PhD student Brandon R. Augustino agrees: “It’s not very often that one is able to get in on the ground floor of such an exciting and likely impactful line of research, so I jumped at the opportunity.”

An artist’s depiction of the circuitry of a quantum computer.

One of QCOL’s main goals is to evidence that quantum computers can outperform classical computers in solving sophisticated optimization problems—that is, to show that there is quantum supremacy, says Zuluaga.

As an example, Zuluaga points to the quadratic assignment problem, which aims to allocate a set of facilities to a set of locations, while minimizing costs associated with distance, commodity flow, and other factors. “This type of problem, which cannot be solved with current classical computing resources, arises, for instance, when designing the placement of interconnected electronic components onto a printed circuit board or on a microchip.”

The field has already produced major theoretical advances in the solution of unstructured search problems, such as the factorization of large numbers (the backbone behind cryptography and security keys technology), says Terlaky, but that’s only scratching the surface of its potential to supercharge optimization.

“This type of problem, which cannot be solved with current classical computing resources, arises, for example, when designing the placement of electronic components on a microchip.”

—Luis F. Zuluaga

Starting at square one

The ability to solve such complex optimization problems could drive progress, not just in the next generation of electronics but also in drug development, data encryption, and a myriad of other areas of profound social impact.

That potential is a big draw for graduate students, who, Terlaky says, are among the very few pioneering researchers coming from ISE, operations research, and algorithmics areas to explore the emerging power of quantum computing in solving difficult optimization problems.

“Young researchers are curious and open-minded,” he says. “To work on something that is completely new, a lot of time and effort must be invested. At the same time, they realize that being among the first in the world to work in this area will bring strategic advantages for their careers.”

Joining the quantum community

To strengthen its footing in the field, Lehigh recently became a member of the IBM Quantum Hub at NC State University. The partnership primarily gives Lehigh researchers access to cutting-edge quantum computing systems for testing algorithms, conducting experiments, and engaging in industrial collaborations.

Lehigh is also among the founding academic members of the Quantum Economic Development Consortium, a federal initiative to stimulate economic developments that are made possible by the emergence of quantum computing. QED-C also includes established companies and startups, as well as other research and academic institutions.

“We participate in workforce development activities, discussing educational programs and learning about industry case studies,” Terlaky says. “The QED-C membership showcases Lehigh as a major player in the rapidly developing area of quantum computing, and at the same time, it provides QCOL access to invaluable information about hardware and software developments, industry pilot projects, and potential internship opportunities for our students.”

And while the number of QC-related jobs is growing exponentially, he adds, the supply of highly skilled quantum optimization researchers remains limited.

“By graduation, our students will be uniquely positioned to choose an excellent job in the area of their choice.” ®

DAVID PARKER/SCIENCE SOURCE

BY CHRISTINE FENNESSY

GREAT EXPECTATIONS

The NSF CAREER award recognizes promising early-career researchers poised to become academic role models and leaders in their fields. In 2022, three Rossin College professors joined the distinguished group of Lehigh faculty who hold this prestigious national distinction.

Fixing the noise problem in quantum computing

The promise of quantum computing is a big one.

The ability to solve—in days—problems in areas such as mathematics, finance, and biological systems that are so complex it would take a classical computer hundreds of years to calculate.

But that ability is a long way off, and a big reason why is noise.

"The key barrier for quantum computing is noise in the device, which is a hardware issue that causes errors in computing," says Xiu Yang, an assistant professor of industrial and systems engineering. "My research is on the algorithm level. And my goal is, given that noise in the device, what can we do about it when implementing quantum algorithms?"

Yang recently won support from the National Science Foundation's Faculty Early Career Development (CAREER) program for his proposal to develop methods to model the error propagation in quantum computing algorithms and filter the resulting noise in the outcomes.

Yang will use cutting-edge statistical and mathematical methods to quantify the uncertainty induced by the device noise in quantum computing algorithms. His work could help quantum computing move toward real-world adoption in a wide range of fields, such as drug development, portfolio optimization, and data encryption, where the technology is seen as a potential game-changer.

"My first goal is to model noise accumulation," he says. "So for example, if I run a so-called iterative algorithm, the noise or the error from the device will accumulate through each iteration. It's possible that for some algorithms, the error will be so large that the outcome of the algorithm is useless. But in other cases, it may not be that significant."

XIU YANG
Industrial and Systems Engineering

RYAN HULVAT/MERIS

In those cases, the noise that's contaminating the outcome could be filtered out.

"So I first need to see how the error propagates, and then, if I know how much it contaminated the outcome, I can determine if the results are useless, or if the noise can be filtered out to get the desired outcome," he says.

To that end, Yang will investigate various types of algorithms to determine how they are affected, and whether or not they need to be redesigned or if he can develop a filter instead.

"Basically, I'm analyzing the suitability of quantum algorithms on quantum computers," he says. "So this is a quantum numerical analysis from a probabilistic perspective."

The ultimate goal is to enable quantum computing to achieve its promise of unparalleled speed when it comes to solving highly complex problems like those physical and chemical systems involving interactions between millions of molecules.

"Let's say a pharmaceutical company wants to design a new drug or vaccine," he says. "They need to understand the interaction between all those particles. If I were to use a classical computer, that process would be very slow. But with a quantum computer, it would be very, very fast."

Yang says the award not only helps his field get a step closer to that reality but also reflects a recognition outside his community of researchers that quantum computing's potential is worth the investment.

"This award is from both the NSF's Division of Computing and Communication Foundations and its Division of Mathematical Sciences," he says. "Which means that people in the math and statistics community are now getting interested in quantum computing. They realize this is a very important area, and we can make a contribution."

A simpler path to supercharge robotic systems

Robotic arms are typically composed of joints, which help the arm move and perform a task. Each of those joints is capable of either rotating or extending—and the number of such possible independent movements is referred to as the robotic system's degree of freedom. The more joints in the arm, the higher the degree of freedom.

"In general, robotic systems are very high-degree-of-freedom systems," says Subhrajit Bhattacharya, an assistant professor in the Department of Mechanical Engineering and Mechanics. A robotic arm, for example, "might have 10 different joints. So if you're trying to make the arm move and grab something, this high degree of freedom—these 10 different joints—present 10 different variables for making that motion. The more variables you have, the more computationally expensive it is to operate that system."

Bhattacharya is a member of Lehigh's Autonomous and Intelligent Robotics (AIR) Lab and he researches ways to reduce this complexity. He received the NSF CAREER award for his proposal to use topological abstraction for robot path planning.

Topology is the mathematical study of properties preserved through the twisting, stretching, and deformation—but not the tearing—of an object.

IN THE PAST 5 YEARS, ROSSIN COLLEGE FACULTY HAVE RECEIVED

17 NSF CAREER AWARDS

SUBHRAJIT BHATTACHARYA
Mechanical Engineering and Mechanics

Bhattacharya uses topology to abstract the complexities (basically, removing the details) presented by all these variables within a robotic system to make operating the systems simpler. So if, for example, you're using a robotic manipulator with 10 joints and you want it to grab something, topology would reduce the number of variables involved in that motion, and provide the robot with an algorithm that allows it to efficiently and accurately achieve its final destination.

"The output of the algorithm is the sequence of motions," he says.

Bhattacharya says abstraction is currently being done by others in the field, but in an ad hoc manner. "They're often very randomized searches. What I'm proposing is a more formal approach of doing abstraction that guarantees optimality and algorithmic completeness, which is a guarantee that we'll find a solution if a solution exists."

Robotic systems have become increasingly important in industries such as transportation, manufacturing, and health care, and this formalized approach can make those systems even more reliable, says Bhattacharya. In addition, his approach can be broadly applied and used in systems such as those that employ multiple robots or one or more flexible cables, robotics manipulators, and soft robotic arms.

"The ultimate goal is the design of systematic algorithms that can achieve these topological abstractions in an efficient manner, and in a way that is not specific to a particular system," he says.

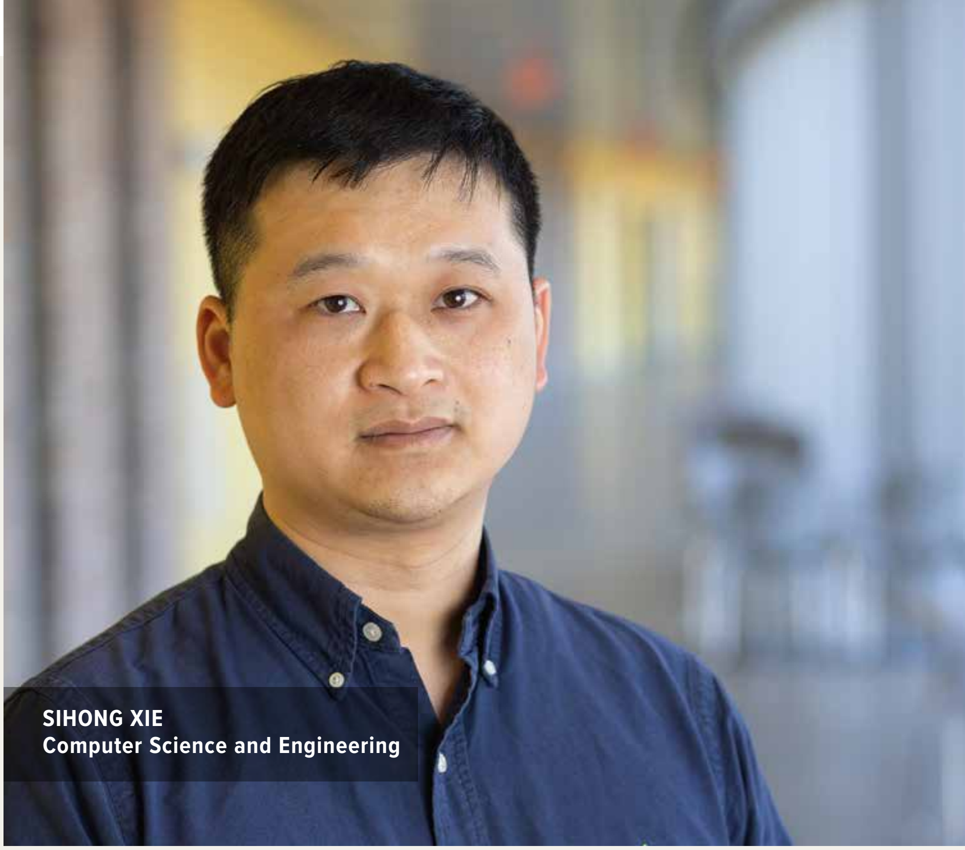
Pulling back the curtain on the intelligence behind AI

Machine learning models are capable of solving complex problems by analyzing an enormous amount of data. But how they computationally solve the problem is a mystery. "It's difficult for humans to make sense of the reasoning process of the program," says Sihong Xie, an assistant professor of computer science and engineering who won the NSF CAREER award for his proposal to make machine learning models more transparent, more robust, and more fair.

"Creating accountable machine learning is the ultimate goal of our research," he says.

Explainability of machine learning algorithms will generate greater confidence and trust of the human users in the models. To establish that explainability, Xie will work with domain experts to combine human knowledge with machine learning programs. He'll incorporate the constraints that guide these professionals in their decision-making into the development of algorithms that more closely reflect human domain knowledge and reasoning patterns.

Ultimately, few human experts will be able to dedicate the time necessary to fully compile the constraints around any one question. To that end, Xie intends to automate the creation of such checklists by collecting relevant data from the experts instead. He and his team will design another



SIHONG XIE
Computer Science and Engineering

LEFT: CHRISTA NEU; RIGHT: DOUGLAS BENEDICT/ACADEMIC IMAGE

algorithm to find what he calls the sweet spot in this checklist creation. One that is sensitive enough to detect subtle but useful positives, but not so sensitive it generates too many false positives.

"Real-world data are dirty," he says. "We want the machine program to be robust enough so that if it is dealing with reasonably dirty data, it will still generate reliable output."

Along with questions about accountability come concerns about algorithmic fairness: If machine learning algorithms now influence what we read in our social feeds, which job postings we see, and how our loan applications are processed, how can we be sure that choices are made ethically?

To address those concerns, Xie will utilize multiple objective optimization to find the most efficient solutions to competing perspectives on what's considered fair.

"Different people, different organizations, different countries, they all have their own definition of fairness," he says. "So we have to explore all the possible trade-offs between these different definitions, and that's the technical challenge, because there are so many different ways to trade off. The computer has to actually search for how much each of these fairness standards has to be respected."

He will provide algorithmic solutions that can efficiently search such trade-offs.

The implications of this research could be profound. Xie says that, eventually, experts could have much more confidence in artificial intelligence, and algorithms could become more responsive to social norms.

"The biggest motivation for me in conducting this research is that it has the potential to make a real social impact," he says. "And because we always have humans in the loop, we're going to ensure that these models inspire more confidence and treat people fairly."

BY CHRISTINE FENNESSY

NO BOUNDARIES

A state-of-the-art facility designed to foster collaboration and innovation, Lehigh's new Health, Science and Technology Building presents a clear vision for advancing interdisciplinary research

PhD students (from left) Zeyuan Sun and Myeongyeon Lee walk through the Reichmanis Lab in HST. The building's design makes it easy to initiate conversations, says Sun.

THE FUTURE OF RESEARCH IS BRIGHT. QUITE LITERALLY. That fact is clear to anyone who walks through Lehigh's new Health, Science and Technology Building. With its open floor plan dotted with islands of live plants and ringed by giant windows illuminating all its laboratory and public spaces, it's the university's boldest statement yet of its commitment to investing in both cutting-edge research and human potential.

"The HST Building is unlike any other building on campus, and its difference reflects what we believe the future of research will look like," says Steven McIntosh, professor and chair of the Department of Chemical and Biomolecular Engineering. "And by that I mean, it's a building that is designed from the start to encourage people to interact."

For instance, the main stairwells aren't continuous. So getting from the basement to the second floor, for example, requires taking one set of stairs, and walking the length of the

FAR LEFT & RIGHT: RYAN HULVAT/MERIS; CENTER LEFT & RIGHT: DOUGLAS BENEDICT/ACADEMIC IMAGE

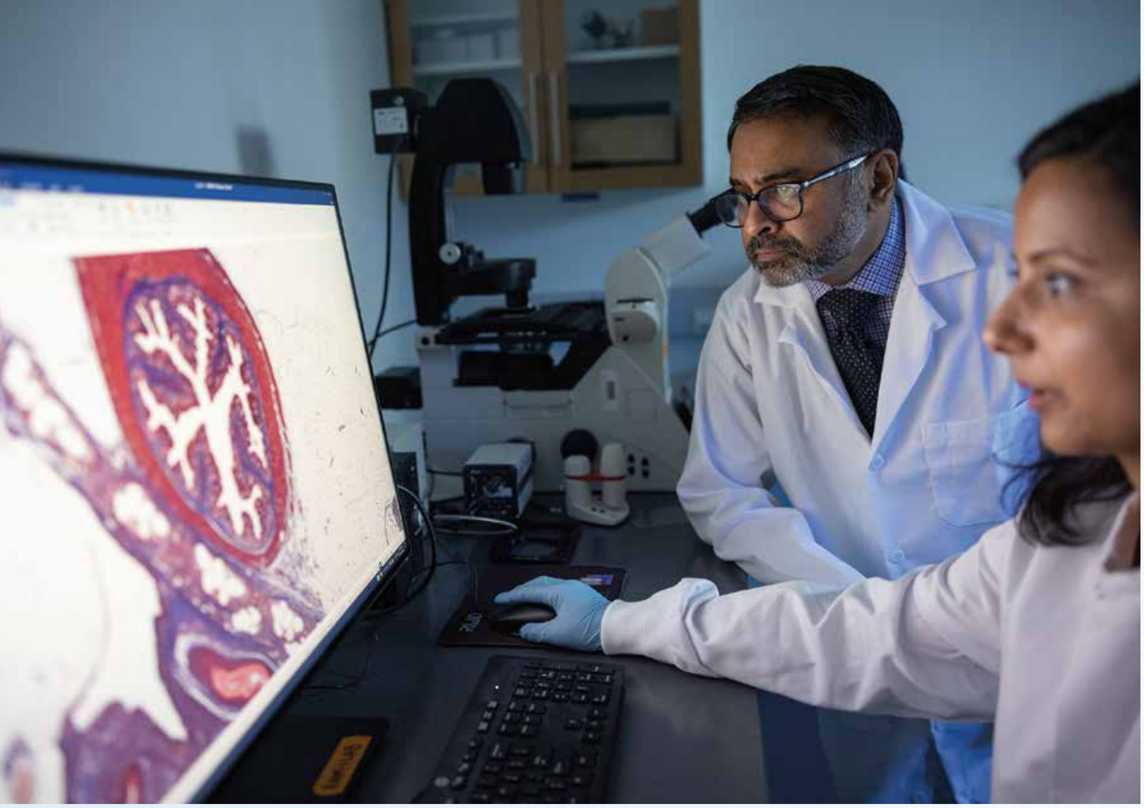
The new facility anchors interdisciplinary research neighborhoods focused on biohealth and materials for energy, says McIntosh (above).

next floor to the second set of stairs, a design feature meant to encourage interaction among faculty, staff, and students.

The labs that line nearly the entire length of the first and second floors seamlessly flow from one space to the next without division by walls or doors. The glass-lined conference rooms allow users to see out and passersby to view what's happening inside.

With the exception of the suite occupied by the College of Health, all the faculty offices are clustered—without regard to departmental affiliation—in the center of the building, within steps of the labs and graduate students. The graduate students themselves are seated amongst their peers from other programs and departments, and work in cubicles surrounded by greenery, cast in natural light, and enticingly placed around cozy common areas.

"We've removed all boundaries within the building," says McIntosh, who served on the facility's design committee. "So if I open my office door, I immediately walk into a common student area, and there are people eating lunch, or having coffee, or talking about their research. This barrier-free space reflects the idea that research now is both interdisciplinary and highly collaborative."



Expanded research infrastructure and new spaces for faculty and student collaboration increase the potential for innovation, says Ramamurthi (top left).

Lehigh has long embraced the interdisciplinary approach to research. Now, with the purpose-built design of HST, there is a physical manifestation of that "better together" ethos, and the implications of it could be significant, says Elsa Reichmanis, professor and Carl Robert Anderson Chair in Chemical Engineering.

"The facility demonstrates Lehigh's interest in promoting collaboration and opening new areas of research and investigations that could have real impact, not only on the immediate area and on Pennsylvania, but nationally and globally as well," she says.

> "The facility demonstrates Lehigh's interest in promoting collaboration and opening new areas of research and investigations that could have real impact." —Elsa Reichmanis

Building 'research neighborhoods'

While the university is known for its exceptional research and cutting-edge facilities, HST will enhance ongoing investigations by combining access to equipment with human capital.

"There are so many resources and facilities spread across our campuses," says Anand Ramamurthi, professor and chair of the Department of Bioengineering. "In the past, it's been difficult trying to consolidate them and provide them sufficient visibility so that faculty and students are aware these resources exist. Because HST is meant to create a community of researchers who work together, it has brought all these resources, facilities, and equipment under one roof."

Ramamurthi's research team creates nanotherapeutics for vascular tissue repair, and also develops stem-cell-inspired approaches for the treatment of proteolytic diseases—disorders like aortic aneurysms and chronic obstructive pulmonary disease (COPD) that are characterized by the breakdown of proteins. Within HST, he'll have access to the complete research infrastructure he needs for his own investigations as well as facilities like a data visualization lab (see page 21) and high-speed computational resources that will enable him to expand his research footprint.

And while individual research teams have their own designated lab space, the open concept of the laboratories gives all researchers immediate access to those with expertise outside their own.

"Students and investigators can walk through each other's labs," he says. "You can see what others are doing, what equipment they have, and vice versa. By putting me and my team in a space adjacent to people outside our research area, who knows what will come out of it?"

For example, he says, he and his team are interested in using machine learning techniques to predict adverse blood vessel rupture outcomes. "While we are novices in these techniques," he says, "within HST, we'll be near the people who are experts in these areas, and that will allow me to identify who I might talk to next, and who I might collaborate with to move my research forward."

Though he's been in the building only since January, Ramamurthi says he's already fielded numerous requests from students and faculty interested in getting trained on his own research equipment.

"And guess what? That opens up new opportunities to talk, because now I can say to them, 'Hey, you have this microscope. We'd like to try something new. Can you work with us on this?' So it goes both ways," he says.

New additions to the Rossin College faculty, including bioengineering professors Tomas Gonzalez-Fernandez

CENTER: RYAN HULVAT/MERIS

(who works on novel cell-instructive 3D printable biomaterials) and Niels Holten-Andersen (who is also on the materials science and engineering faculty and studies bio-inspired synthetic materials with applications in energy, the environment, and health) have also set up their labs in the facility.

Also in residence are the first of a growing contingent of faculty with joint appointments in both the College of Health and the Rossin College: data and computer scientist Bilal Khan, who directs Lehigh's Population Health Data Warehouse, and Gabrielle String, an environmental health researcher who studies water sanitation and drinking-water program implementations and technologies.

While not every piece of equipment within HST will be shared, much of it will be, says McIntosh. Already, big items such as the X-ray photoelectron spectroscopy instrument and the low-energy ion scattering instrument have been set up in the building's basement.

"The idea is that the student makes a sample in the lab upstairs," he says, "then they can go downstairs and, in a single day, do numerous measurements on this sample—and so it's all done in one spot."

McIntosh says that one of the driving principles of the building's design and location and the selection of its occupants sprung from the concept of creating "research neighborhoods" guided by two research themes, materials for energy and biohealth. Researchers in those areas—from the departments of bioengineering and chemical and biomolecular engineering—were moved from the Mountaintop campus to the neighborhood comprising HST, Whitaker Laboratory, Sinclair Laboratory, and the Seeley G. Mudd Building.

"Now we have materials-, bio-, and health-related faculty in HST right next to Whitaker, which has most of the materials researchers, which is right next to Sinclair with its clean rooms, which is right next to Mudd with its chemistry facilities," says McIntosh. "So we have this neighborhood of people who might not do the same research, but speak a similar language, and provide complementary expertise, to benefit the whole group."

Those research thrusts are also present in all HST's lab spaces, he says. "The themes exist vertically in the building and cross-pollinate horizontally across the floors."

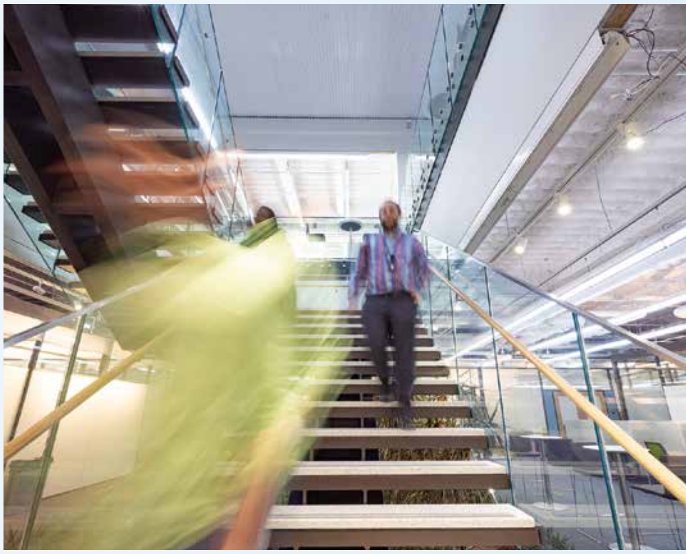
Seeing the bigger picture

The building's layout and concentration of expertise may perhaps most benefit graduate students.

"My office is basically 10 steps from one lab, 20 steps from another, and 15 steps from where my students are sitting," says bioengineering and chemical and biomolecular engineering professor Anand Jagota, who was recently named Lehigh's vice provost for research. The arrangement creates new opportunities for interaction, he says, and those interactions "are much more natural."

Jagota, the bioengineering department's founding chair and the associate dean of research in Lehigh's College of Health, leads a variety of projects including virus adhesion to cells, how virus-laden droplets get resuspended from surfaces, and improving wound adhesives. While his team has always had access to the equipment they need, Jagota says the spatial organization within the HST Building will allow for greater interaction and collaboration, particularly among graduate students.

"For example, if a student wants to do something but doesn't know the technique for it, the open, shared lab allows them to reach out to students and faculty from other research groups for help," he says. "They no longer have to default to asking their advisor. And this enables them to build important relationships that can benefit their own research."



Staggered staircases have a modern feel and a purposeful design—encouraging movement and interaction.

Building those relationships and exploring new opportunities is key to preparing Lehigh students for the working world, says Reichmanis, whose research includes designing advanced materials for energy storage applications and controlling the organization of polymers for electronic transport.

"I think HST gives students an opportunity to more easily build their networks, because the layout makes it easier to talk with faculty and other students," she says. "Students will be more engaged, they'll learn more, and I think the environment here will also help them develop leadership skills in

LEFT & RIGHT: DOUGLAS BENEDICT/ACADEMIC IMAGE terms of how they start or get involved in new projects and feel empowered to explore new areas."

McIntosh sees that sense of empowerment developing already. One of his grad students had a recent random encounter in HST with new bioengineering and materials science faculty member Holten-Andersen. The ensuing conversation spawned an idea for that student's research.

"I think HST changes their sense of belonging and community and being part of the bigger research picture," he says. "The great hope is that your graduate student comes to you and says, 'I was talking to this person from this lab and we tried this new experiment,' and it's something that you as an advisor hadn't even considered. We want students to really own things, because in the real world, they're going to be expected to find the people they need to work with to solve problems."

"If a student doesn't know a technique, the open, shared lab allows them to reach out to students and faculty from other research groups for help. This enables them to build important relationships." —Anand Jagota

Open labs foster camaraderie among graduate students in bioengineering, chemical engineering, materials science, and related fields.

Creating community across disciplines

That sense of belonging is real for Simran Dayal, a PhD student in bioengineering. Dayal is advised by Ramamurthi and researches minimally invasive treatments for abdominal aortic aneurysm, a condition in which the aorta, the main blood vessel that delivers blood to the body, enlarges over time. As it grows, it can cause painful symptoms and potentially become life threatening.

"It's a common disease, especially in older male patients," says Dayal. "The available treatment options are limited to surgery, which is very risky. So we're looking at drug delivery nanotherapeutics that we can inject and prevent growth of the aneurysm."

As a fourth-year student, Dayal is used to the more traditional layout, where halls, walls, and doors separate research teams. It made it hard for someone like her—"a bit of a shy person"—to meet her peers and learn who did what.

"The labs in HST aren't separated by walls, so if I'm walking around and I see someone, I can just start talking to them," she says. "I've gotten to know a lot more people."

Since moving to the building in January, she's helped train students on her lab's equipment, and shared microscopes, plate readers, and freeze-drying systems.

"It's a very collaborative environment," she says. "And with HST investing in bigger pieces of equipment, like a 3D bioprinter, it's exciting to know I'll be so close to machines like that, as well as to the people who know how to use them."

John Sakizadeh '22 PhD also points to the open-concept design of HST as a major factor in enhancing communication between grad students. Sakizadeh, who was advised by McIntosh and graduated in the spring, researched how to synthesize functional nanocrystals for use in converting solar energy into chemical energy.

"It's interesting being next to a group in the lab that we don't normally interact with," he says. "It definitely changes your everyday level of collaboration. If someone needs a chemical, or a fitting for a valve, or training on an instrument, it's so easy to ask for it."

For Zeyuan Sun, being embedded in the "research neighborhood" will have a direct impact on his work. A third-year PhD student in chemical engineering who is advised by Reichmanis, Sun studies the characteristics and properties of conjugated polymer semiconductors in organic transistor applications.

"This is a very multidisciplinary field," he says. "It includes optics, electronics, and solid-state physics, so it requires me to utilize many different resources. HST is right in the middle of all those resources, and that makes it a lot easier."

He definitely appreciates the beauty of the building, all the natural light filtering through giant floor-to-ceiling windows, the abundance of über comfortable common areas to eat, chat, and rest, and the literal transparency of the lab space. But the thing he likes best? His desk.

"It's located between my PI's office and the lab," he says. "So it's easy to initiate conversations with her, and whenever I have an idea for an experiment, I can walk into the lab and conduct it immediately. So yeah, that's my favorite spot."

LEFT: DOUGLAS BENEDICT/ACADEMIC IMAGE; RIGHT: CHRISTA NEU

NEXT-GEN TECH ENABLES NEXT-LEVEL COLLABORATION IN MATERIALS RESEARCH

Lehigh's cutting-edge Nano | Human Interfaces (NHI) Visualization and Data Analysis Lab, housed in the HST Building, will serve as the main control center for immersive remote collaborations among Lehigh researchers and collaborators at Ohio State University (OSU) working on the development of two novel metallic alloys.

In February, Lehigh University entered into a Cooperative Agreement—providing up to $25 million over five years—with the U.S. Army Research Lab (ARL), with OSU as a subcontracted collaborator, to develop novel structural materials for high-strength applications. The first installment of $3 million has been authorized by Congress.

Lehigh's NHI Presidential Engineering Research Initiative is led by Martin Harmer, Alcoa Foundation Professor of Materials Science and Engineering. Also integrally involved is Chris Marvel '12 '16 PhD, a former research scientist in the MSE department who is now an assistant professor in the Mechanical and Industrial Engineering Department at Louisiana State University. Marvel will continue to play a leading role in the Cooperative Agreement.

The Lehigh–Ohio State team's proposal, "Lightweight High Entropy Metallic Alloy Discovery (LHEAD)," includes three basic science projects that seek to address the critical need for longer-lasting and more resilient alternative structural materials for use in advanced material systems such as hypersonic missiles.

The first two projects aim to develop new generations of superalloys (high-strength materials that can function at extreme temperatures) and leverage recent advancements in solid-state materials processing to develop next-generation high-entropy metallic alloys for improved performance. In addition to alloy design, the team will also explore powder-based material processing, phase transformation pathways, atomic-resolution characterization, *in situ* high-throughput mechanical testing, and additive manufacturing.

The third project, rooted in Lehigh's NHI initiative, will support the first two by providing participating researchers with unique resources to improve their communication, problem-solving, and collaborative use of research instrumentation.

Additional Rossin College collaborators include professors Helen Chan and Masashi Watanabe (MSE) and Brian Chen (computer science and engineering). Kate Arrington, a professor of psychology in Lehigh's College of Arts and Sciences, and Andrea Harmer, NHI director of education innovation, are also members of the team.

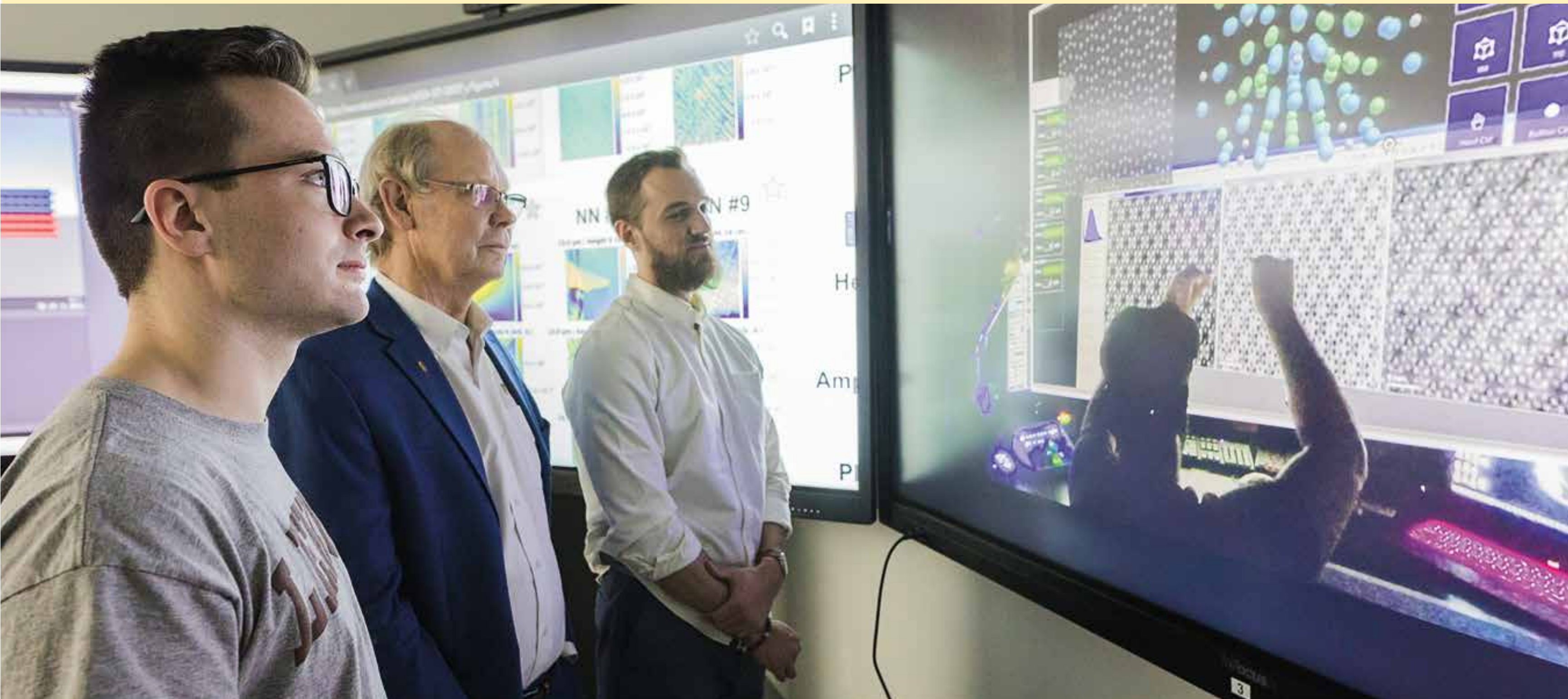
"We are thrilled to be partnering with ARL on this important work," says Harmer. "The LHEAD project has the potential to lead to tremendous advancements in both materials development and in how scientists conduct research together."

The Nano | Human Interfaces Visualization and Data Analysis Lab in the basement of the HST Building features six 98-inch touchscreens, virtual and augmented reality interfaces, and controls that allow secure remote access to electron microscopes located at Lehigh and in Ohio State's Center for Electron Microscopy and Analysis (CEMAS). Ohio State's laboratory will have similar controls to allow researchers there to access Lehigh's microscopes.

Remote characterization and simulation capabilities will allow researchers to interact as they would if they were collecting and analyzing data in the same location. The team plans to extend this technology to other types of instrumentation, such as equipment used for mechanical testing, 3D printing, and simulations, and to enrich these remote experiences with augmented reality.

The new Lehigh facility also includes a human observation lab in which cognitive scientists can track, using a system of cameras and software for observation of eye gaze and human behavior, how researchers work as a team and how they interact with scientific instruments.

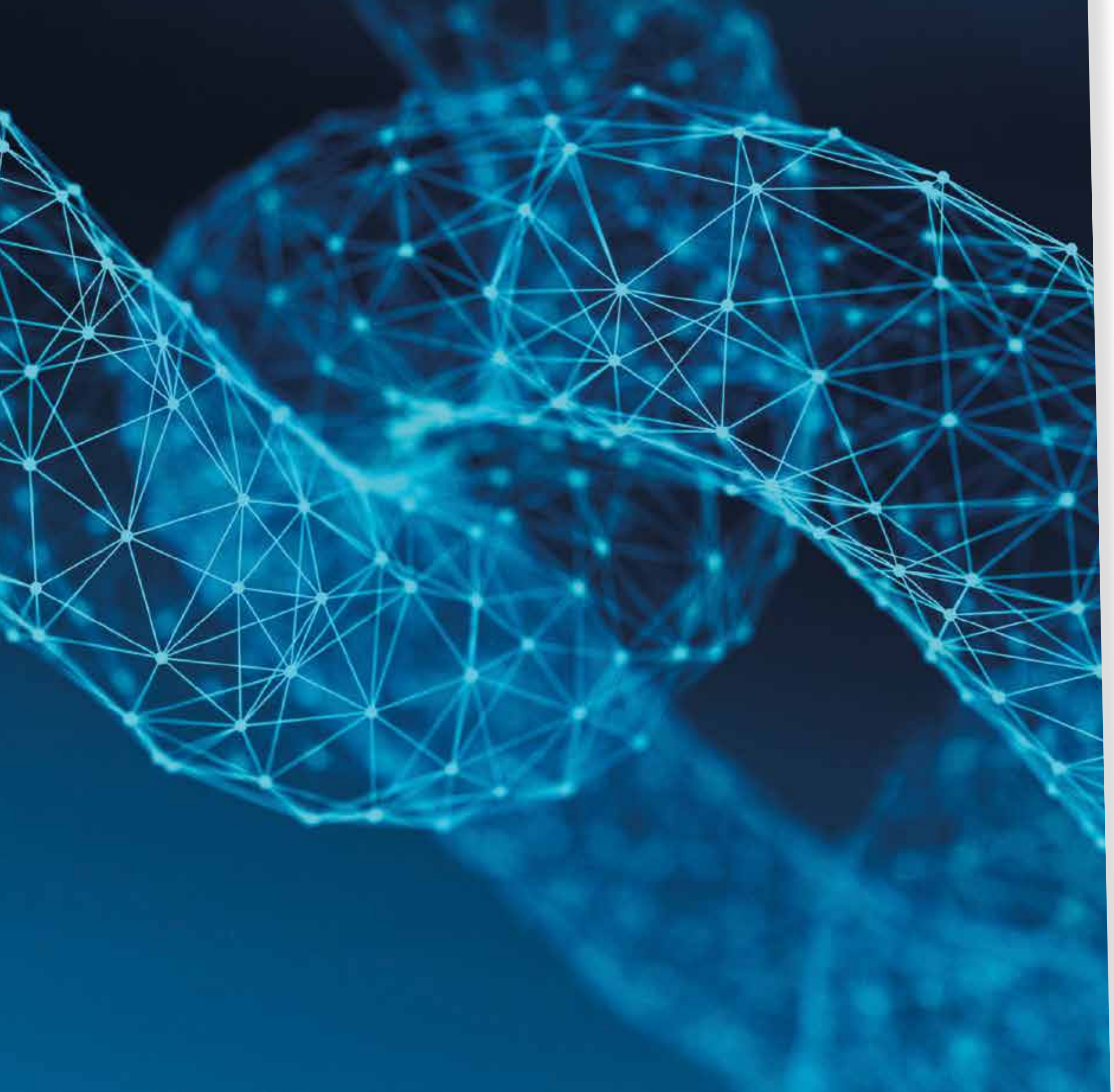
These observations will help improve the research experience by identifying potential barriers to accelerate scientific discovery, Harmer says, and will be used to develop a framework for an artificial intelligence user assistance capability that could guide researchers in deciding which experiments to conduct and "speed up the process of doing research."



Oversized touchscreens are among the advanced tools available to Harmer (center) and the NHI team in the new Visualization and Data Analysis Lab.

RETURN ON INVESTMENT

Through specialized courses and cutting-edge research opportunities, **LEHIGH BLOCKCHAIN**, a partnership between the Rossin College and Lehigh Business, propels students to tackle what's next for this transformational technology



Chances are—and no judgment!—you don't know a whole lot about blockchain.

But, says professor Hank Korth, you probably know more about it than many of the lawmakers crafting policies around the digital ledger system.

"Our society lacks people who understand what blockchain is and how it works," says Korth, who is a faculty member in the Department of Computer Science and Engineering (CSE). "And this is technology with a lot of current and potential implications for enterprise, regulation, digital currency, and how businesses relate to each other. So we need people who can go into government, who can make business decisions, who can explain to the general public what blockchain is, the impact it's having already, and the impact that it's going to have in the future."

Filling that need is the ultimate goal of Lehigh Blockchain, an interdisciplinary team that spans the fields of computer science and business through blockchain research, education, and applications. Korth says the initiative began in 2018 when a couple of undergraduates asked for a course on the topic. Blockchain is a digital ledger of transactions that allows users to securely deal with one another directly, rather than through a third party like a bank or government institution, and is the means by which cryptocurrency is exchanged.

Since its first class debuted in Spring 2018, Lehigh Blockchain has grown to include three undergraduate and three graduate courses; research projects focused on issues in the construction of blockchain systems and their applications; projects affiliated with companies including Algorand, ChainBytes, MacGuyver Tech, and Oracle; and research within the Scalable Systems and Software (SSS) lab.

The courses reflect both the need to approach this disruptive technology with an interdisciplinary mindset and the partnership between the Rossin College and Lehigh's College of Business, which has created its own Blockchain Lab (with Korth serving as director) within its Center for Financial Services. The classes span computer science, business, financial engineering, and project-focused courses. And very often, they're very full.

"We're probably talking about 120 students a year that we're interacting with, and they're largely undergraduate and master's students, because the opportunity cost for doing a PhD in blockchain is ridiculous," says Korth. "The job offers are lucrative. There's just so much excitement in the field that to commit to five or six years for a PhD is a tough decision to make."

Those offers can range from $150,000 to $180,000 for students who are just 22 or 23 years old, says Roberto Palmieri, an associate professor of computer science and engineering and co-leader of the SSS Research Group, which collaborates with Lehigh Blockchain.

"They graduate with skills that are really hard to find in the market because of the connection required between business, computer science, and systems concepts," says Palmieri. "They have this very unique expertise, and so they're getting these outstanding jobs with the highest pay around. And these students are going on to lead what industry, startups, and companies are doing next in the blockchain horizon."

Essential to building those skills and that expertise are the range of research opportunities available through Lehigh Blockchain. One of those projects focuses on zero knowledge proofs.

"These proofs keep information that you want to keep private, private," says Korth. "They're easy to verify, but extremely computationally hard to generate. One way to deal with that difficulty is to use modern parallel architecture. So we have a business problem, which is blockchain. Our SSS Research Group does parallel and distributed computing. These problems are numerical algorithms, and we have a numerical person in SSS, [CSE assistant professor] Arielle Carr. It's a project that really reflects the synergy across both the engineering and business colleges and within our own lab here in computer science."

And that synergy plus human capital is a rare commodity, says Palmieri.

"Generally speaking, it's hard to assemble a team that understands all the different aspects of a single technology that are needed for that technology to work," he says. "Our ability to do that has created this very unique time that we're at right now with Lehigh Blockchain."

In fact, he says, their work on zero knowledge has attracted the attention of some very big players in the community. Google recently invited Lehigh Blockchain to give a talk on the subject for one of the company's internal seminars. Korth adds that the inventor of one of the landmark algorithms in the zero knowledge space recently hired one of Lehigh Blockchain's master's students. Another student was hired by a digital currency startup funded by former Google CEO Eric Schmidt.

"People who are really significant folks in this space are recognizing that we're producing some very good students and doing a lot of good work," says Korth.

That good work will soon extend to doing good as well. One proposed Lehigh Blockchain project involves using the technology to prove the "fair" in fair-trade coffee. Essentially tracking the arc of a bag's creation to ensure that, indeed, the workers were fairly paid.

"Our business partners are talking to countries across Central and South America, and this could have a phenomenal impact," says Korth.

It's an impact that might not be fully appreciated yet by most. But both Korth and Palmieri say that blockchain represents a fundamental transformation in how information is exchanged. It eliminates traditional authority figures—the bank, the government, the audit firm—and allows users to put their trust in a decentralized source of truth. And it will impact fields and professionals within those fields who don't even realize it yet.

"BLOCKCHAIN TECHNOLOGY CAN TAKE OVER A LOT OF THE **TASKS** THAT ARE REALLY **LABORIOUS** NOW AND ACTUALLY **DO THEM BETTER."**

—Hank Korth

"One of the research projects we have is with a professor in the Department of Accounting, and I jokingly say, if we succeed, we'll put most accountants on the dole," says Korth. "Because blockchain technology can take over a lot of the tasks that are really laborious now and actually do them better."

Maxim Vezenov '21 '22G is now contributing to this impact. His initial interest in cryptocurrency as a first-year student eventually led him to Lehigh Blockchain. He participated in one of the initiative's capstone projects—creating an app within blockchain that verifies letters of reference—and after presenting the project to an audience that included industry leaders, was offered a summer position in a startup.

The capstone also ignited his interest in research, which led him to create—along with a few of his peers—a student research group (run by Korth within the SSS lab) that now includes up to 20 students pursuing rigorous work in computer science and mathematics with applications in business, finance, accounting, and the supply chain.

Driven to learn more, Vezenov went on to complete a master's degree working with Korth examining how to compute zero knowledge proofs more efficiently. Before he'd even graduated, he'd landed a job at a small startup using zero knowledge technology to scale Ethereum, a blockchain platform second only to Bitcoin.

"There is so much value in these Lehigh Blockchain courses, the capstone projects are a great chance to really dive into the technology, and the research group is the best place to learn alongside other people who are as into the technology as you are," says Vezenov. "There's no question it all contributed to where I'm at now."

ISTOCK/SASHKINW

Taking flight

Through innovative, hands-on learning, professor Christina Haden cultivates a ‘symphony of curiosity’ and inspires critical thinking in a new generation of engineers

Growing up, she wanted to understand it all. How birds flew, how trees grew, how nutrients fueled all of it. Why the rotary phone in the box of dead electronics didn’t work and what she could do to fix it (by soldering a random wire, it turns out, at the age of 8 or 9). Christina Haden was an insatiably curious kid. And it was her father, more than anyone else, who stoked that curiosity, spending hours with her talking about subjects that varied from biology to planetary travel and answering (most of) the million questions she lobbed back at him.

For their final project, students designed a piece of kinetic art. “It blew my mind what they came up with,” says Haden.

“My mind would just explode talking to my dad,” says Haden, a teaching associate professor in the Department of Mechanical Engineering and Mechanics. “I loved how there seemed to be no end to how deep the questions could go. I was always asking, ‘Well, what about this? What about that?’”

Haden is now the one answering questions and stoking the curiosity of her students, but she has lost none of her wonder and delight over how things work. In fact, it’s become one of the guidelines of her teaching philosophy.

“If I want my students to be excited about the material I’m teaching them, I have to be excited about the material,” she says. “And so that’s what I do. I make sure I come into the classroom, and I’m saying to them, ‘This is so cool! And here’s why it’s so cool.’”

Turning her students on to the coolness of engineering concepts got even easier this past spring. Together with Melpomene Katakalos, an associate professor of theatre in Lehigh’s College of Arts and Sciences, Haden created the course Leonardo da Vinci, the Artist and Engineer. The pair designed the class to combine art and engineering and encourage students—from both engineering and non-engineering majors—to draw inspiration from the Italian polymath’s ability to observe and create.

“We live in a digital world,” says Haden. “But we need our students to have gained experience that becomes reference knowledge and intuition for their future as engineers, and that doesn’t come from a screen. It comes from seeing things and building things.”

Like da Vinci, students kept a sketchbook to write about, draw, and explain the concepts they observed, and Haden constantly reinforced those ideas with props—a tiny engine powered by the steam off a coffee cup, crank toys, a cam and follower mechanism that illustrated da Vinci’s early robot design. And she didn’t just show them these devices. She combined her ability to closely read her students with her very real fascination with what she was teaching them.

“We learn through multisensory inputs, not simply by being spoken to,” she says. “So how I move my hands, and how animated I am is one part of that. Having props that students can see, feel, and envision is another way. So with me, every class is like, ‘Look at this! Look at that!’ And when I’m hitting the right tone, it’s almost like I hit resonance. There’s this symphony between what I’m saying and how the students respond.”

When it came to their final project for the class—designing a piece of kinetic art—that resonance was in full effect. What they came up with blew Haden’s mind. One student created wings with an eight-foot span that gently flapped when he lifted his shoe. Another built a garden operated by a cam system that caused flowers to emerge, open, and close.

“Everyone built something that was moving,” she says. “My goal was for them to infuse art into engineering, and that’s exactly what they did. Their brains just lit up, and wow, did they go above and beyond.”

Such an infusion is key, she says, because art is essential to engineering. Blending the two encourages students to use both sides of their brains, and she believes that tactile experiences will make for the best generation of engineers.

“Engineering is boring without art, and as a discipline, art has inspired so much progress, allowing us to dream outside the scope of what we see, into the realm of what could be,” she says.

It’s a boundless realm. One in which Haden believes all students are capable of succeeding, of making an impact with their own unique perspective. So along with Katakalos, Haden will continue the course’s evolution, expanding its creative potential and committing herself fully to achieving a symphony of curiosity, excitement, and understanding as students discover how art and engineering can collide to beautiful, meaningful effect. Her gauge for that resonance is simple.

“They get a spark in their eye,” she says. “And when that spark is there, that’s when all that raw talent and raw potential starts to shine.”

BREAKING THE STEREOTYPE

Haden talks about empowering women engineers on the Rossin Connection Podcast. Listen at **engineering.lehigh.edu**.

CHRISTA NEU

HELP REALIZE THEIR POTENTIAL

Together through GO: The Campaign for Lehigh, we can ensure the vitality of the Lehigh experience for generations of engineering students and researchers to come.

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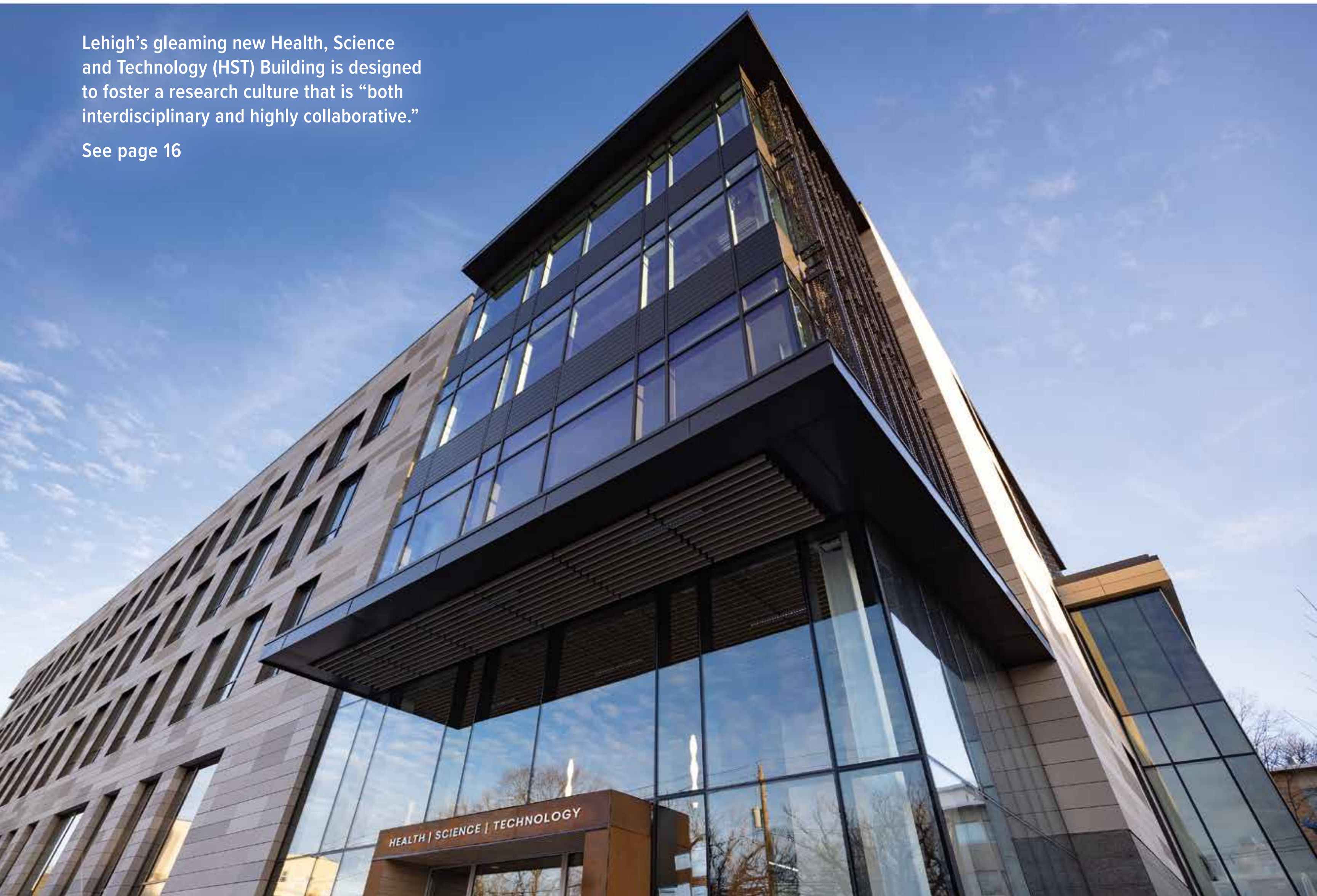

Lehigh's gleaming new Health, Science and Technology (HST) Building is designed to foster a research culture that is "both interdisciplinary and highly collaborative."

See page 16