Spring 2022

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Engineering Innovation @LehighU

ENERGIZING THE BLUE ECONOMY

and other innovative solutions for a greener future

Marine renewable energy / Offshore wind / Zero-emission public transport / Biopower from trash

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

Research labs are taking shape in Lehigh's new Health, Science and Technology Building, which opened earlier this spring on the Asa Packer campus (see page 2). The facility is designed to foster cross-disciplinary collaboration.

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Spring 2022

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LEHIGH UNIVERSITY

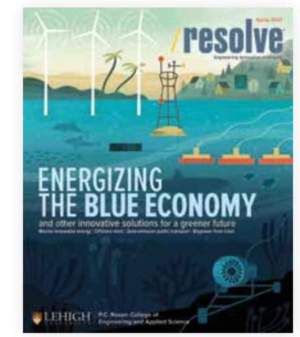
LETTER FROM THE DEAN

Focusing on questions that matter

Welcome to the Spring 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.

Surging energy consumption worldwide, climate change that grows more prominent with each passing season, and a war of aggression in Eastern Europe all point to the same underlying issue: the urgent global need to invest in new approaches to satisfying our energy demands in sustainable, equitable ways.

Energy research is, by definition, an interdisciplinary endeavor. The design of holistic approaches to energy generation, distribution, and usage, and the related environmental impact, requires a panoply of expertise from wide-ranging fields. It is a complex set of interrelated challenges that could be addressed adequately only through the development of an interdisciplinary team-based approach.



Interdisciplinary research is essential to identifying, exploring, and developing solutions to society's most pressing challenges, energy among them. Through Lehigh's Interdisciplinary Research Institutes, we have been steadily building activity and support structures that enable team science to flourish. A string of recent research awards—many of which are discussed in the following pages—is evidence that the strategy is bearing fruit.

In this issue, we highlight team science successes in the area of green energy. The Atlantic Marine Energy Center (page 14) is a clear example of interdisciplinary team science in action. Even in its earliest stages, this venture draws upon Lehigh's strengths in mechanical, electrical, computer, industrial, civil, and structural engineering (as well as sociology and anthropology) in its mission of "energizing the blue economy."

Also featured is a waste-to-energy project (page 18) that involves a fascinating mix of artificial intelligence, spectroscopy, and municipal trash processing (in some ways, the ultimate in recycling). Ongoing work with the Santa Clara Valley Transportation Authority (page 17) brings together experts in several fields of engineering with economists and political scientists. Yet another new interdisciplinary project around offshore wind turbine testing (page 21) seeks to better to better replicate the conditions encountered off the East Coast.

This issue's Q&A (page 8) turns our attention to the outer reaches of the cosmos through the eyes of electrical engineering alumnus Scott Willoughby '89, a vice president at Northrop Grumman who leads the firm's James Webb Space Telescope program with NASA. In an effort that has captivated the science press for months, Willoughby managed the successful design, build, and launch of an engineering marvel that traps photons that are 13.5 billion years old.

In "Data Driven" (page 22), we introduce the Rossin College's exciting new interdisciplinary master's degree program in Data Science, which is a testament to the pervasiveness of data across all fields of human endeavor. To be on the cutting edge, tomorrow's most successful professionals will complement their domain knowledge with computational and data science expertise.

Finally, you'll meet Karmel Shehadeh, an assistant professor of industrial and systems engineering and this issue's Rising Star (page 24). Shehadeh's work in the optimization of health care systems, in areas such as operating room scheduling and medical facility location planning, illustrates the direct human impact of data science research. Improved mathematical modeling, she says, can lead to better, more equitable care.

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

INTERDISCIPLINARY TEAM SCIENCE IS **ESSENTIAL** TO IDENTIFYING, EXPLORING, AND **DEVELOPING SOLUTIONS** TO SOCIETY'S MOST PRESSING CHALLENGES.

Stephen P. DeWeerth, *Professor and Dean*
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Dean DeWeerth met up with Scott Willoughby in July 2019 at Northrop Grumman's Space Park facility in Southern California.

Lehigh opens Health, Science and Technology Building

A revolutionary new space for interdisciplinary research

Lehigh's new Health, Science and Technology Building, home to the College of Health, has opened on the Asa Packer campus, signaling an expanded era of interdisciplinary research at the university.

In all, 32 faculty members and 15 labs from existing areas on campus, including the College of Health, the Rossin College, and the College of Arts and Sciences, were moved into the building in early 2022.

The facility features open-concept labs, integrated work spaces, shared meeting spaces instead of formal classrooms, and a forum area—all designed to encourage collaboration across disciplines and with the community.

"Being in HST at this early stage is very exciting," says Angela Brown, an associate professor of chemical and biomolecular engineering. "It feels like more than just a new building—it's more like an entirely new way of approaching research. The space is beautiful, and though we are just getting settled in, I can already see it working as intended."

> "IT'S MORE THAN JUST A **NEW BUILDING**—IT'S AN ENTIRELY **NEW WAY** OF APPROACHING RESEARCH."
>
> —Angela Brown

At 200,000 square feet, the HST Building is the largest ever constructed by Lehigh and the first with a community room featuring doors that open directly onto the South Bethlehem neighborhood.

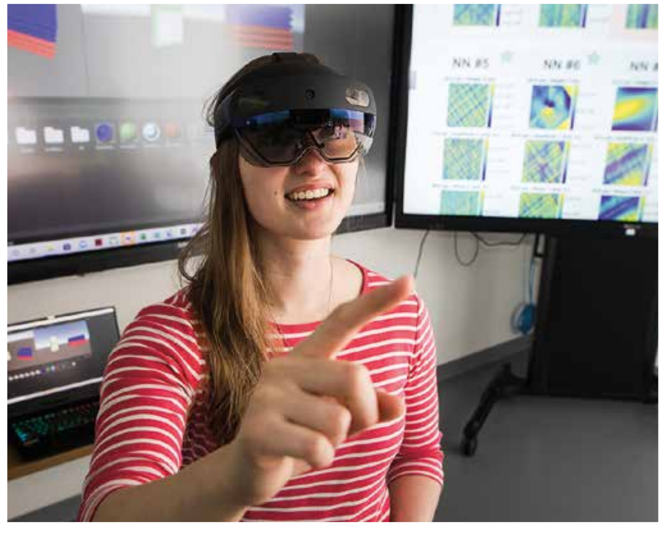
Research facilities "traditionally have been designed in such a way to create separate little boxes where particular labs, faculty, and projects can be done," says Provost Nathan Urban. The HST Building "eliminates walls [and] eliminates barriers to the kind of collaboration we think is critical for advancing research areas that are going to be a focus for Lehigh, for the country, and to some extent, the world."

Open staircases offer views between floors, encouraging interactions among faculty, staff, and students as they go about their day. Lab spaces can be easily reconfigured for the different disciplines. Glass walls replace closed-in offices and narrow hallways.

A bridge connects the HST Building to Lehigh's other core research facilities—Seeley-Mudd, Sinclair, and Whitaker labs—creating a "research neighborhood" for interdisciplinary projects. Research in the HST Building will be primarily related to biohealth and energy, which have historically been among Lehigh's academic strengths, Urban says.

The basement level has Lehigh's world-class surface characterization and x-ray diffraction and scattering tools. It also holds the Nano | Human Interfaces Visualization and Data Analysis Lab, with virtual and augmented reality capabilities, that provides researchers with the ability to access, analyze, and visualize massive amounts of data.

"Research that's focused on some of the biggest, most important questions requires that you bring together people who have different technical skills, different mindsets, and appreciation for different aspects of a question or problem," Urban says. "To work on those problems most effectively, you need to bring those groups together routinely so they are all part of the creative process of defining the problem and understanding the solution."



Materials science PhD student Mari-Therese Burton uses a mixed-reality headset in the visualization lab located in HST.

LEFT: CHRISTA NEU; CENTER: DOUGLAS BENEDICT/ACADEMIC IMAGE; RIGHT: ISTOCK/BFK92

STRENGTHENING GLOBAL SUPPLY CHAINS THROUGH MACHINE LEARNING

Over the past two years, you've likely heard "global supply chain" repeated over and over in news reports and everyday discourse.

Pandemic-borne story lines abound: empty shelves at the local Costco, container ships cruising the Pacific Coast in search of an accessible port of entry, car salespeople playing cornhole in dealership showrooms because there were simply no cars to sell.

With this global crisis swirling in the backdrop, Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC), with support from the National Science Foundation's TRIPODS+X program, convened a group of top researchers from across the country and around the world to explore innovative approaches to strengthening the global supply chain.

"Most of the prominent recent applications of machine learning for supply chains have been focused on descriptive or predictive analytics," says Larry Snyder, a professor of industrial and systems engineering and co-director of I-DISC. "For example, clustering methods have been used to segment customers or suppliers in a descriptive way, and deep neural networks have been applied predictively to forecast demand."

Snyder, who co-organized the December 2021 event, says the TRIPODS+X Workshop on Machine Learning & Supply Chain Management took a somewhat different direction: "We focused on the use of machine learning for prescriptive analytics within the supply chain—on using the power of machine learning to not just analyze but also optimize efficiency and resiliency across the global supply chain."

The two-day, hybrid (in-person and online) workshop was held on Lehigh's Mountaintop Campus and featured 13 invited speakers, a poster session for students, and a panel discussion to promote further exploration at the intersection of machine learning and supply chain management. Participants (including academic, industry, and government researchers focused on supply chain and logistics, artificial intelligence and machine learning, or associated fields) represented more than 70 academic institutions and numerous companies based in the United States, Europe, the Middle East, Asia, and South America.

Making the (whole) cut

ChBE team digs into the challenges of cultivating meat in the lab

“I jokingly say we're going to grow a chicken nugget,” says Steven McIntosh, professor and chair of the Department of Chemical and Biomolecular Engineering (ChBE).

It is a bit funny to think about, but the idea of growing protein in the lab is serious business. Meat production is responsible for 57 percent of global greenhouse gas emissions, according to a recent study published in *Nature Food*.

Among the many initiatives that have arisen to address alternatives to producing and eating animals is the cultivated—or cultured—meat industry, which uses cell cultures from animals to grow protein. (As in the real stuff, not Beyond- or Impossible-adjacent.)

“The problem with cultured meat is that they can't make ‘whole cut’ pieces that have the right texture and aren't super expensive,” says ChBE associate professor Kelly Schultz.

Schultz and McIntosh are part of a team that received a $250,000 grant from the Good Food Institute (a non-profit devoted to reimagining how meat is produced) to address the problem. The group also includes ChBE faculty Angela Brown and Mark Snyder.

“All four of us were trained as chemical engineers, but our research areas are so different,” says Brown.

It may take such a diversity of skill sets—coupled with an outsider's perspective—to address what is essentially a complex, twofold problem.

For one, the bigger the piece of meat that is being grown, the harder it is to get sufficient oxygen and nutrients to those cells in the middle. And if they're starved of either, they die. (“I assume you'd probably get really sick from eating that,” says Schultz.) Secondly, muscle cells have to be stimulated to grow in the right organizational pattern. It's the pattern that provides the texture and mouthfeel that tells us we're eating a steak, a hamburger, or a chicken nugget.

Schultz is the principal researcher, and it's her work that's perhaps closest in line with the project's intent. Her lab researches characterization of colloidal and polymeric gel scaffolds that can be used for human tissue engineering.

“THEY CAN'T YET MAKE ‘WHOLE CUT’ MEAT THAT HAS THE **RIGHT TEXTURE** AND ISN'T SUPER EXPENSIVE.”

—Kelly Schultz

Schultz will work with Snyder on developing a scaffold for the meat cells to grow on, and the structure they'll use is the same one she utilizes for wound healing in humans. Right now, however, it's not stiff enough.

“When you incorporate cells into the scaffold, you have to give them the right physical environment,” she says. “You have to make the environment feel like muscle so the cells remain muscle cells, and make more of them.”

To get to that proper stiffness, Snyder—whose work focuses on the design of nanomaterials for applications in areas ranging from energy to imaging—will synthesize and functionalize nanoparticles to essentially tune the properties of the gel structure.

“The idea is to control the properties through mechanical or chemical cues that lead those stem cells to differentiate into meat cells,” says Snyder. “But we also have to think about how the gel structure can reconstruct and adapt to growing cells. So the adaptability of the gel is another piece. And we have thoughts on how we could use this nano-composite gel to get the cellular structure that's growing to form in a more fibrous fashion.”

McIntosh will be using his expertise in electrochemistry to further promote that fibrous growth.

“My other joke is that I'm here to exercise the chicken nugget,” he says. “We're going to create its ‘workout regimen’ by figuring out the bioelectrochemistry required to guide the formation of this muscle tissue.”

That's because muscles grow by continually flexing and recovering, a function of the body's nervous system, which is an electrical system. McIntosh cites research showing the effect of an electric field on muscle cells: “It sets up chemical gradients in the cells that drive the cells to form fibers.”

Nothing can form, however, without a steady supply of nutrients and oxygen. And that's where Brown comes in. She studies lipid-protein interactions involved in bacterial diseases. For this research project, she'll be creating liposomal delivery vehicles.

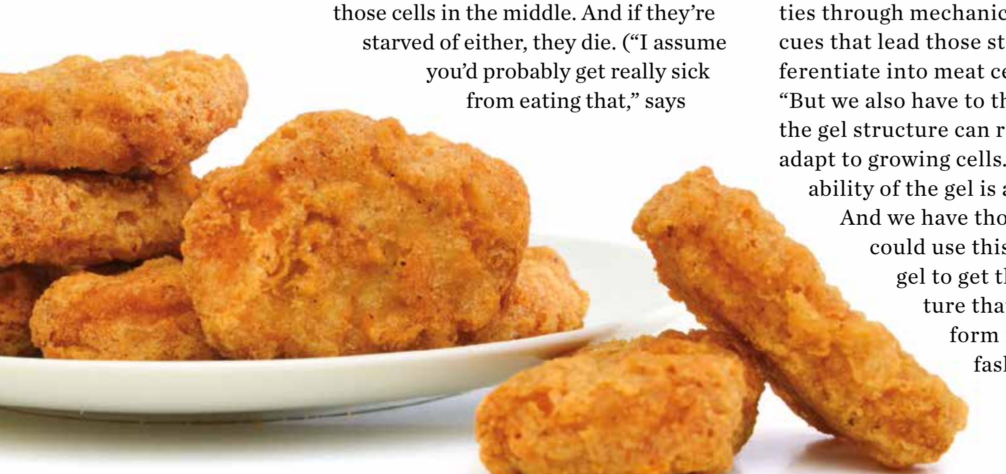
“Lipids are what cell membranes are made out of,” she says, “and they're nice because you can encapsulate things inside of them.”

She'll develop two such molecules: One will deliver glucose; the other, oxygen.

“We're going to tether these liposomes to the scaffold that Kelly and Mark are working on,” she says. “As the cells are growing on the scaffold, [the molecules] should be releasing these nutrients to the cells so they can continue to grow, rather than die.”

The team's ultimate goal is to establish a scalable platform for the production of “whole cut” meat, one that could be adapted for a range of protein products that will someday be available in supermarkets. It's a long way off, but in the meantime, there's the potential to answer fundamental questions in areas beyond their individual pursuits.

“When you put collaborative projects like this one together,” says McIntosh, “you end up doing things that none of us could do on our own.”



ISTOCK/HONG VO

Smarter catalysts through ‘induced activation’

The science of catalysis—the acceleration of a chemical reaction—is perhaps not the most recognizable branch of study, but it is absolutely embedded into the fabric of modern society.

The development and production of fuels, chemicals, pharmaceuticals, and other goods depend on catalysis. Catalysis plays a critical role in energy generation and the mitigation of humanity's impact on the environment, and it is involved in the manufacturing of some 25 percent of all industrial products in the U.S. If a thing is made, worn, lived in, played with, driven upon, or otherwise used by people, catalysis likely plays a fundamental role in its origin story.

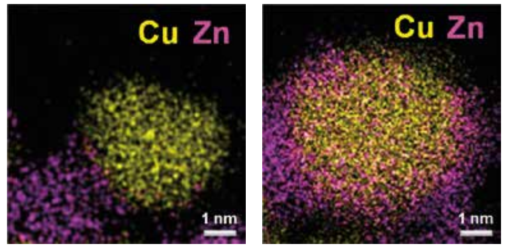
Research in the field enables new and improved products and more efficient ways of doing and manufacturing, well, just about everything. But advancement in industrial catalysis can be costly in a macroeconomic sense: Wholesale changes that require a “rip and replace” strategy do not sit well with firms and supply chains that power and provision our global economy.

In a paper published in *Nature Catalysis*, researchers from Lehigh and colleagues from the East China University of Science and Technology (ECUST) propose a novel method of significantly enhancing the catalytic efficiency of materials already in broad commercial usage, a process they've termed “induced activation.”

The team, supported by the National Natural Science Foundation of China and the U.S. Department of Energy's Office of Science, includes Israel E. Wachs, the G. Whitney Snyder Professor of Chemical and Biomolecular Engineering at Lehigh, PhD student Tiancheng Pu, and ECUST professor Minghui Zhu '16 PhD.

“The surface structure of heterogeneous catalysts is closely associated with their catalytic performance,” explains Wachs. “Current efforts for structural modification mainly focus on improving catalyst synthesis. Induced activation takes a different approach—manipulating the catalyst surface by controlling the composition of reducing agents at the catalyst activation stage where the catalyst is transformed to its optimum state.”

The team says that using the “tried and true” catalytic material copper/zinc oxide/aluminum oxide (Cu/ZnO/AlO_3) enables firms to take advantage of the breakthrough without costly retooling.



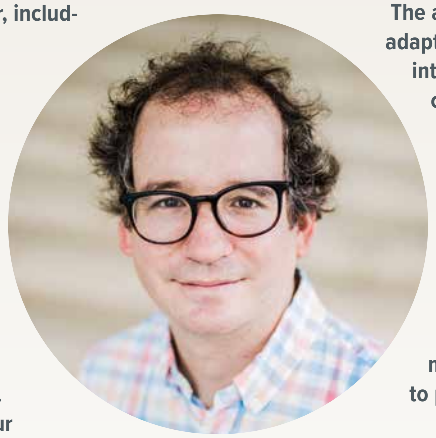
At left, the catalysts are mostly present as separate particles after activation with molecular hydrogen. At right, zinc oxide “decorates” metallic copper particles after induced activation.

“This development effectively doubles the catalytic efficiency of these materials, enhancing their productivity and extending the life of the catalyst,” Wachs continues. “And importantly, induced activation can provide significant benefit to industry without shutting down a chemical plant—or the building of a new and expensive one.”

SCANNING TRANSMISSION ELECTRON MICROSCOPY IMAGES COURTESY OF XUAN TANG AND PROF. SHENG DAI, ECUST

VISUALIZING PROTEASE ACTIVITY TO BETTER UNDERSTAND CANCER

Proteases are enzymes that act as catalysts in chemical reactions that break down proteins into peptides and amino acids. They play an important role in many physiological processes, such as the development and regeneration of tissue and the progression of cancer, including migration and metastasis.



Funded by a $400,000 grant from the National Institutes of Health, E. Thomas Pashuck, an assistant professor of bioengineering, will conduct a study to visualize the activity of proteases in cancer models. The findings could improve our understanding of cancer progression and support the development of better treatments.

Quantifying the activities of proteases within tissues is challenging and current options are limited, says Pashuck, who will use novel biomolecular conjugates that are sensitive to proteases to enable visualization of proteolytic activity in tumors.

“We will use confocal microscopy to visualize our model tumors and understand how cancer cells modify their local environment, and also how they modulate the proteolytic activity of other cell types within the tumor,” he says.

While other systems that enable the visualization of protease activity exist, Pashuck's method was designed to have lower background fluorescence (increasing imaging quality) and enable visualization of multiple proteases at the same time.

Pashuck is working with PhD student Sam Rozans to develop protease-responsive conjugates. They will incorporate them into hydrogels, including those containing both cancerous and noncancerous cells, and visualize spatiotemporal protease activity in model tissue to better understand metastatic processes.

The approach, according to the project summary, can be easily adapted by other labs, used for many proteases, and incorporated into most biomaterial systems. “Since proteases catalyze the cleavage of a peptide bond, they are especially useful for making stimuli-responsive therapies. Thus this research can help researchers across disciplines develop more effective biomedical interventions.”

Cancer is the second leading cause of death in the United States, and about 40 percent of people will be diagnosed with cancer at some time in their lives.

“Understanding the complex interactions that occur within the tumor microenvironment is crucial for creating more effective therapies to inhibit the processes that lead to poor treatment options,” Pashuck says.

Drugs targeting protease activity have entered clinical trials but, so far, have not been successful. New protease therapies that have improved enzyme specificity have been developed.

“Increasing our understanding of protease activity in the tumor microenvironment is needed to bring such promising drugs to the clinic,” he says.

Additive manufacturing as a 'shared language'

MechE professor Natasha Vermaak collaborates with a prominent fashion designer and a renowned architect to explore new applications of topology optimization

When designing an airplane, a bridge, or a building, engineers face trade-offs among factors like material strength, weight, and cost.

For decades, engineers have employed mathematical frameworks—through an approach called topology optimization—to determine efficient material distribution and connectivity in design, resulting in lightweight, durable, and high-performance solutions.

Vermaak (above) sees promise in working with designers like Daviy, who uses 3D printing to sustainably create handbags (right) and other fashions.

LEFT: JOHN KISH IV PHOTOGRAPHY; RIGHT: COURTESY OF JULIA DAVIY

"MOST OF THE CHALLENGES WE FACE TODAY **CROSS DISCIPLINARY BOUNDARIES**, AND A **DIVERSITY OF PERSPECTIVES** IS NEEDED TO DRIVE **INNOVATION**."

—Natasha Vermaak

Today, thanks to advances in computational tools and the rise of additive manufacturing, says Natasha Vermaak, an associate professor of mechanical engineering and mechanics, the benefits of topology optimization for materials design are within reach for a much wider swath of audiences and industries.

That includes the manufacturing of products such as medical devices and consumer electronics (where critical materials can be scarce and/or expensive), as well as more unexpected fields like fashion, where sustainability concerns are taking on greater focus.

Additive manufacturing (also known as 3D printing) can produce geometrically complex components, Vermaak says, which allows the near-full use of the freeform structural evolution of topology optimization.

In 2020, Vermaak received the Frontiers of Materials Award from The Minerals, Metals & Materials Society (TMS). This award is given to top-performing early-career professionals and includes the opportunity to organize a symposium and curate a collection of related articles for a special issue of *The Journal of the Minerals, Metals & Materials Society* (*JOM*).

Vermaak's vision for her symposium on leveraging materials in topology optimization stemmed from her interdisciplinary mindset and her interest in understanding and implementing tools and methods from disparate fields.

"I wanted to engage researchers, designers, and artists around the topic of the optimization of materials and structures, with additive manufacturing as a shared language," she says.

With that in mind, Vermaak contacted innovators Julia Daviy and Virginia San Fratello. Daviy has paved the way for sustainable digital 3D-printed clothing, accessories, and jewelry, while San Fratello is a professor, author, and thought leader in additive manufacturing, architecture, and interior design.

Together, they published the article, "Leveraging Materials in Topology Optimization: Inspiration from Design, Fashion, Art, and Architecture," which prefaced a special issue of *JOM* in 2021. They are also preparing research proposals on topics such as design for additive manufacturing of structures that are seeded with end-of-life pathways (like fungi), and simultaneously optimizing manufacturing processes and materials for bio-textiles.

Combining diverse perspectives, they say, can lead to inventive approaches.

"Most of the challenges that we face today cross disciplinary boundaries, and a diversity of perspectives is needed in order to drive impactful innovation," Vermaak says.

For example, engineers and fashion designers working together can identify production models, based on both digital design and additive manufacturing, to better use recyclable/biodegradable materials with the potential to achieve near-zero levels of waste, carbon emissions, and water usage.

As a researcher, Vermaak sees untapped potential in thinking more broadly about materials, waste, economy, craft, and design.

"When we ask a broader audience of designers what they consider as materials objectives and constraints, and which materials they find most challenging to work with and why, new research questions that may require reimagining topology optimization frameworks themselves may emerge."

Large-scale NSF-backed partnerships support innovation

Lehigh is taking part in two new multi-university efforts, funded by the National Science Foundation, that aim to advance the societal impact of cutting-edge research and technological breakthroughs.

Center for Integration of Modern Optoelectronic Materials on Demand (IMOD)

Supported by a five-year, $25 million grant, IMOD seeks to transform fields like information technology.

Scientists and engineers from 11 universities—and a range of academic disciplines—will endeavor to bring atomic-level precision to the devices and technologies that underpin much of modern life. Research will center on next-gen semiconductor materials and scalable manufacturing processes for new optoelectronic devices for applications ranging from displays and sensors to a technological revolution that's based on harnessing the principles of quantum mechanics.

Elsa Reichmanis, Professor and Carl R. Anderson Chair in Chemical Engineering, serves as Lehigh's lead investigator and IMOD's Director for Integrative Partnerships. She will work to establish a knowledge transfer program that prepares students to interact with industry, academia, and government partners, while encouraging entrepreneurship and spin-offs.

Says Reichmanis: "We seek to accelerate the pace at which NSF research has translational impact and enhance the capabilities of a diverse, inclusive cohort of young and emerging researchers in conducting team-based science across professional environments."

She will also lead the creation of an industrial partnership program to provide opportunities for direct engagement with students around research mentorship, internships, and other initiatives.

External partners include companies such as Amazon, Corning, and Microsoft, as well as government organizations such as the National Renewable Energy Laboratory and the Pacific Northwest National Laboratory.

Northeast Region I-Corps Hub

Five new I-Corps Hubs—launched by the NSF last summer as the next iteration of its successful decade-long Innovation Corps program—will provide experiential entrepreneurial training to academic researchers across all fields of science and engineering. The goal is to accelerate the transformation of scientific discoveries into technologies that improve everyday life.

Each I-Corps Hub is funded at $3 million per year for five years and comprises at least eight universities.

Lehigh is one of five initial affiliate members of the Northeast region I-Corps Hub, led by Princeton University, with the University of Delaware and Rutgers University as partner institutions. New affiliates will be added each year.

"The innovation and entrepreneurship culture at Lehigh has always been strong," says John Coulter, the Rossin College's senior associate dean for research, "but being part of this multi-university team focused on more inclusive innovation will enable us to take it to a new level."

Coulter leads Lehigh's involvement in the I-Corps grant. "Through this program we will create not only additional entrepreneurial teams, but better, more inclusive teams poised to handle the inevitable hurdles and pivots that go along with successful innovation," he says.

The I-Corps Hubs form the new operational backbone of the National Innovation Network, a network of universities, NSF-funded researchers, established entrepreneurs, local and regional entrepreneurial communities, and other federal agencies that helps researchers learn how to translate fundamental research results to the marketplace.

RYAN HULVAT/MERIS

NHERI LEHIGH EXPANDS CYBER-PHYSICAL TESTING CAPABILITIES

Lehigh's NSF-funded Natural Hazards Engineering Research Infrastructure Experimental Facility (NHERI Lehigh EF) has unveiled additional lab space and new equipment for conducting real-time cyber-physical experiments, which are ideal for testing large-scale structural systems that are impractical—or impossible—to test in a normal laboratory.

The enlarged facility can accommodate more users and a broader range of hybrid simulation applications for natural hazards researchers to explore structural mitigation solutions for windstorms and earthquakes.

"Our facility is unique in the nation—one of the few laboratories dedicated to supporting large-scale, real-time, 3D cyber-physical testing," says professor James Ricles, principal investigator and director of the NHERI Lehigh EF. "With these upgrades, Lehigh can be an even stronger partner to researchers around the country and the world seeking to design more resilient, sustainable infrastructure."

The facility's new Real-time Cyber-Physical Structural Systems testing laboratory consists of 4,000 additional square feet of lab space and includes five new test beds (each with a dedicated dynamic actuator), a multidirectional shake table, a dedicated high-speed data acquisition system, and a multichannel digital servo-hydraulic control system.

"Our new multidirectional shake table can realistically emulate combined translational and twisting motions that structures sometimes demonstrate under extreme 3D wind loading due to nonuniform wind pressures acting over the façade of the building, along with possible vortex shedding," says Ricles, Lehigh's Bruce G. Johnston Professor of Structural Engineering. "Further, our new shake table can be deployed in quasi-static testing as well as real-time hybrid simulation experiments."

GOLD STANDARD

Northrop Grumman VP Scott Willoughby ’89 on the unparalleled engineering behind the James Webb Space Telescope

NASA’s James Webb Space Telescope—hailed as the most complex space exploration project in human history—is expected to be fully operational in June. Webb will begin a new era in astronomy, capturing photons that are 13.5 billion years old and allowing scientists to study the earliest stars and galaxies. Those behind the scenes, including electrical engineering alum Scott Willoughby ’89, vice president and program manager for the JWST at Northrop Grumman, have pushed the boundaries of possibility. Willoughby spent the past 12 years leading the interdisciplinary team that designed, built, tested, and deployed the infrared observatory (which was packaged like origami for its million-mile journey). “The hardest part is not actually surviving space,” Willoughby says, “it’s testing on the ground to make sure you didn’t fool yourself into thinking it was going to work in space. And, I’m proud to say, the team just nailed it.”

Q: What are the mission’s ultimate goals and why do they matter?

A: We want to answer questions: Where did we come from and are we alone?

We want to know how the elements in the periodic table formed. It may give us an understanding of how our own planet and star are evolving. Webb will also train our eye on planets that are closer to us—only millions of light years away. And it will look at those planets to see if they have an atmosphere around them that could be Earth-like, meaning it may support life like ours. Everybody wants to know: Is there life out there in the universe? Are we this one-of-a-kind pale blue dot where magic occurred, or is there something there and we just don’t know it yet?

Q: Webb is considered the successor to the Hubble Space Telescope, but it looks completely different. Why is that?

A: When you look at Webb, you might think the engineers were artists, but the design is functional. Webb’s optic is so big—seven times bigger than Hubble’s—that we couldn’t put it in a can. It’s this beautiful set of 18 hexagonal segments that are coated in a thin layer of gold, because gold reflects infrared. It’s a giant mirror that’s 22 feet in diameter. Huge. Bigger than the top of the rocket, meaning it had to be folded.

Every object confesses its heat in the infrared spectrum. It’s why night vision goggles work. Webb not only has to find this very faint light, but has to find it where every other thing in the universe is in our optic with infrared heat wavelengths. So we have to be colder than what we’re looking for.

One of the things that makes Webb unique from Hubble is, on orbit, we’re going to run our optics at -400°F. That’s an engineering marvel to design something to survive cryogenic temperatures. To create that thermal condition, we have to block the close infrared light, which is our own planet, our moon, and our sun. To do that, we deploy a diamond-shaped sun shield, the size of a tennis court, that’s coated in aluminum.

OPPOSITE PAGE: JOHN MCGILLEN; THIS PAGE: NASA/CHRIS GUNN (2); ILLUSTRATION: NORTHROP GRUMMAN

Q: What was the hardest problem to solve?

A: The number one challenge was that we had to build a telescope bigger than could fit on the top of the rocket. To get out of Earth’s atmosphere safely, you have to be protected in a payload fairing. And that fairing, for decades, has been 5 meters in diameter. Webb’s optic is 6½ meters in diameter. So we had to build it in segments that can be folded back and then deployed on orbit. And that giant sun shield…it had to be folded like a parachute.

Never in the history of humankind has an invention had to go into space, and have to get built up as it traveled. It was amazing how flawless that went. But it took us 20 years to make that work.

On the ground, we had to simulate space. We had to off-load gravity with an incredible amount of mechanisms that counterbalanced it—we either hung [Webb] from the ceiling or pushed it from below with just slightly enough force to trick gravity, but not over trick it. We had to put it in a vacuum chamber and simulate thermal conditions.

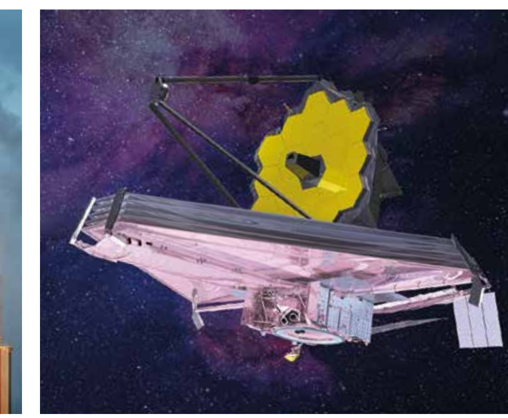
Q: Webb was designed with 344 “single-point failures.” What did that mean?

A: It meant a lot of stressful days on the ground, making sure they worked. Not all of them meant end of mission, but many of them did.

There’s never been something built that had that many single-point failures and that level of testing to prove they’re working. You don’t test something to what it needs to do on orbit. If it needs to be strong, you design it to be sometimes two times stronger. If it needs to work at -380°F, we test it at -400°F.

We had an entire plan if our solar array didn’t deploy. They gave them cute names—we had the shimmy and the shake, we had the twirl, and the fire and the ice. If something stuck, what if I change the sun angle and make it either expand or contract? Maybe that will release it. What if I fire my thrusters and shake it a little? Turned out, we didn’t need any of those, but I had a team that spent years coming up with contingency operations.

And there was the comment, well, if it went so perfectly, was it ever really as hard as you said it was going to be? [laughs] It was like, yes, what we did was hard on the ground. The tests we did had to confess every weakness to us, even weaknesses that probably would’ve never been an issue on orbit. We corrected those also. You can’t take a chance.



Folded for launch, Webb was rocketed into space on Dec. 25, 2021, and successfully deployed (artist’s depiction, far right) over a two-week period.

Q: Has the project spawned any new technologies?

A: Each of Webb’s mirrors has a surface figure accuracy (meaning how well they represent the intended concave shape) that’s better than 20 nanometers. To put that in perspective, what if I gave you the job to perfectly flatten out the US? Get rid of the Appalachians and the Rockies and fill in the Grand Canyon. Your error bar could only be about 3 inches across the entire 2,500 miles from California to New York.

How do I prove that the surface of this mirror really is that good? We use the speed of light to our advantage with laser interferometry. I bounce light off of a spot on the mirror. And depending on how long it took for the light to return, I know how far it traveled. So if there was a little dip in that mirror, it would have to travel just a little bit further and then come back to me.

NASA and Northrop came up with such a precise technique to test these mirrors that ophthalmologists now use that to measure your eyes when you go in for LASIK or they need to know the shape of your eye and understand the curvature.

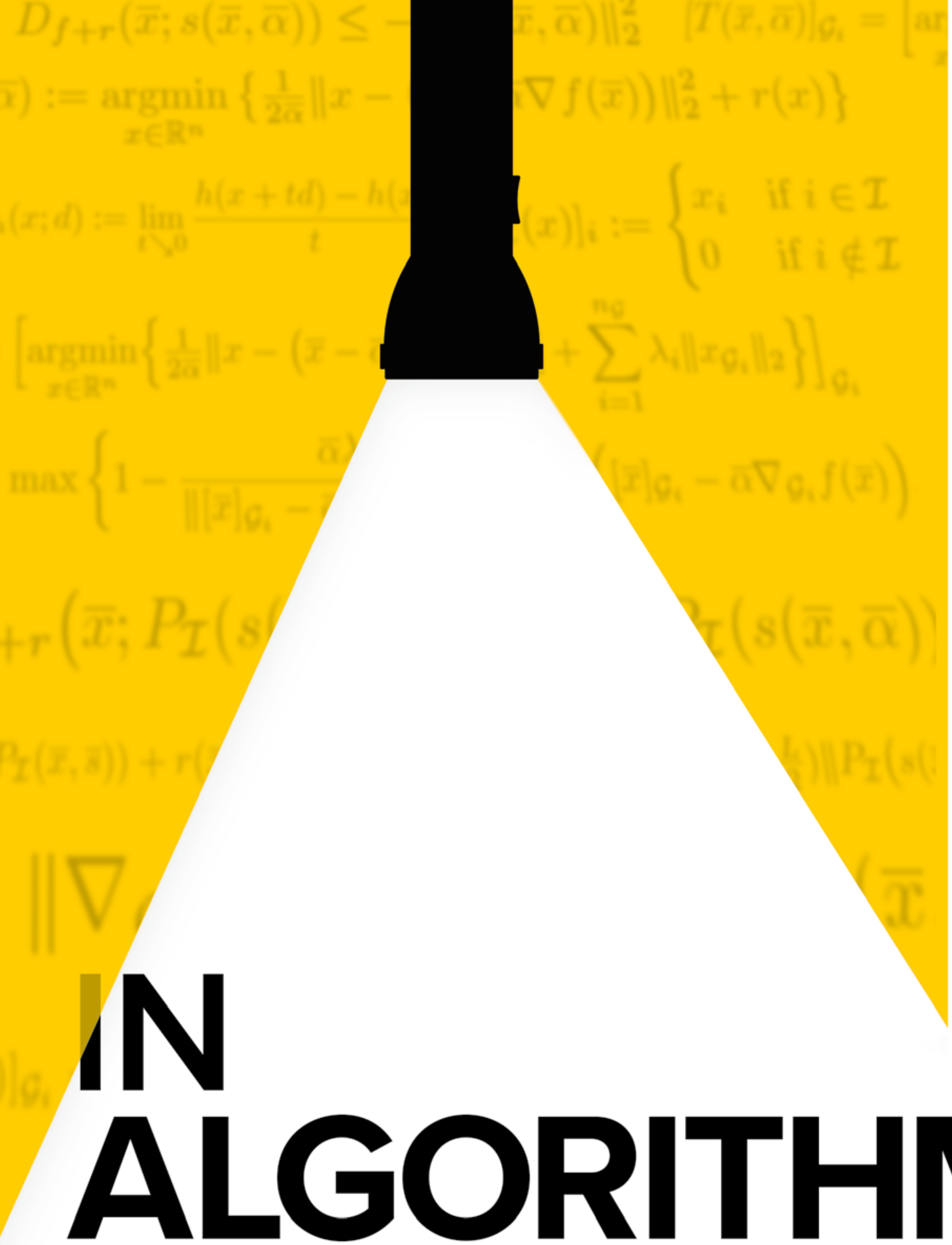
And it isn’t just the testing techniques. Now that we’ve proven we can build something bigger than the top of the rocket, we’ve built a new “set of shoulders” for the next decades of observatories. The bigger the mirror, the more light you collect, the more sensitive the observatory. Now that we’ve built a mirror bigger than the top of the rocket, the appetite will never be sated again with something that fits inside.

Q: What can aspiring engineers take away from your experience?

A: As an engineer, everybody is focused on what product they’re going to design, right? You want to make the next greatest thing—the next electric car, the next spacecraft. But there are other incredible roles. I consider myself more of a test person than a design-for-engineering person. I use my engineering knowledge in what’s called “integration and test,” and the jobs of the folks who have to solve the problem of how to prove something works are every bit as complex and valued as the people who create the product itself. And there’s a tremendous need to do that. In the end, team success is a very powerful feeling.

UNFOLDING THE UNIVERSE

Hear more of our conversation with Willoughby in a new episode of the Rossin Connection Podcast. Listen at **engineering.lehigh.edu.**



IN ALGORITHMS WE TRUST?

BY STEVE NEUMANN, CHRISTINE FENNESSY, AND EMILY COLLINS

Computer science and engineering researchers shed light on critical questions about fairness, privacy, and the spread of disinformation powered by AI

If you're like most people, when you have a question, you get your answer from an algorithm.

Internet search. Your email and social media. The navigation, shopping, and news apps on your phone. They all run on algorithms—sets of rules for solving a problem or completing a task—that are incredibly powerful in analyzing data when paired with machine learning, a form of artificial intelligence.

And, if you're like most people, although you interact with algorithms from the moment you wake up (and check your weather app) until your head hits the pillow (and late-night Twitter scrolling ensues), you're basically in the dark about what's going on behind the scenes.

While most of us mindlessly click through the latest software update or privacy agreement, computer science and engineering researchers in the Rossin College are raising questions—and working toward answers—as to why algorithms make certain decisions, what impact they have on privacy, and how to improve our digital literacy.

INCREASING TRANSPARENCY IN DECISION-MAKING

Imagine that you and a colleague are active on a social network of job-seekers, akin to LinkedIn. You're both in the same field, and equally qualified, but as you discuss your prospects over a cup of coffee, it's clear that your friend has been seeing more high-quality job postings than you have.

It makes you wonder: What information did the site use to generate the recommendations in the first place?

Algorithms that can learn from data and make predictions are still somewhat of a black box to the end user, says Sihong Xie, an assistant professor of computer science and engineering.

If you're not seeing some postings because of your age or your gender or something in your past experience, he explains, the algorithm that produced the recommendations is suboptimal because its results are unfairly discriminatory.

Xie, who is a 2022 recipient of the prestigious NSF CAREER award, and his team are investigating the transparency and fairness of machine learning models. He's one of a number of Lehigh Engineering researchers applying an optimization technique called the stochastic gradient method in their work (see "Optimizing Machine Learning," page 13).

In machine learning, "these optimization algorithms are becoming more and more important, for two reasons," he says. "One is that, as the datasets become larger and larger, you cannot process all the data at the same time; and the second reason is that we can formulate an optimization problem that will analyze why the machine learning algorithm makes a particular decision."

The latter is particularly important when applying machine learning to make decisions involving human users.

In late 2021, Xie's PhD students Jiaxin Liu and Chao Chen presented the results of their work at two renowned meetings on information retrieval and data mining. The team found that the current state-of-the-art model, known as a "graph neural network," can actually exacerbate bias in the data that it uses in its decisions.

In response, they developed an optimization algorithm that could find optimal trade-offs among competing fairness goals that would allow domain experts to select a trade-off that is least harmful to all subpopulations.

For instance, the algorithm could be used to help ensure that selection for a specific job was unaffected by the applicant's sex, while potentially still allowing the company's overall hiring rate to vary by sex if, say, women applicants tended to apply for more competitive jobs.

"Our work on 'explainable graph neural networks' seeks to find human-friendly explanations of why the machine learning model makes favorable or unfavorable decisions over different subpopulations," says Xie. "We want to promote the accountability of machine learning as our society is rapidly adopting the techniques."

> "We want to promote the accountability of machine learning as our society is rapidly adopting the techniques."
>
> —Sihong Xie

EXAMINING PRIVACY THROUGH 'SOCIAL COMPUTING'

It's no secret that internet heavyweights like Google, Facebook, and Amazon collect all kinds of data from users.

However, "these companies don't release a lot of information about how their [algorithmic] programs work," says Patrick Skeba, a fifth-year doctoral candidate, who is advised by Eric Baumer, an associate professor of computer science and engineering.

When Skeba originally decided to attend graduate school, he figured he'd pursue machine learning, but he soon realized he could satisfy his wide-ranging curiosity working in a field he'd never really considered: social computing.

"All computing is social, in that computers are used by humans and humans are social beings," says Baumer. "While it is easy to forget that fact when you are tuning a model's hyperparameters or benchmarking your system's throughput, computers are mostly interesting in so far as the kinds of human interactions they enable."

Baumer's research examines the interrelations between the technical implementation details of algorithmic systems and the social and cultural contexts within which they operate.

Algorithms are everywhere, but what's behind their decision-making remains a mystery to internet users, says Xie.

ISTOCK/ALEXEY YAKOVENKO

TOP: ISTOCK/COFOTOISME

Social computing research by Baumer (right) and Skeba (left) explores human interactions with algorithmic systems.

“My first day in the office, [Baumer] was giving me books on computers, on philosophy, on sociology, on all kinds of things,” says Skeba, who was intrigued by Baumer’s interdisciplinary approach. “And so I got less and less interested in building machine learning models, and more interested in asking, ‘What are these models doing to us?’”

In other words, what are they doing to our privacy?

Skeba’s research uses two different approaches to answer that question. The first is what he and his team call their “folk theories of algorithms” study. Skeba uses interview and survey methods to query regular internet users on their understanding of how their personal data is collected.

The dearth of information, he says, leads people to make all sorts of assumptions about how vulnerable their privacy is when they do certain things, like post comments online. “And so what we see sometimes are guesses that are quite far off.”

Some people think algorithmic systems can’t infer much, if anything, from their comments, so they post without concern. Others, however, are convinced that the algorithms can derive all sorts of information about them, and are too paranoid to post anything at all.

“You end up in a situation where there’s a disconnect between how these systems work and how people understand them,” says Skeba. “So figuring out how people are imagining these systems can help us better understand their behaviors. And that, in turn, can help us educate users and give them the tools to understand how their information is being used.”

Skeba’s second research project involves evaluating the privacy risk of an online forum. The forum is run by a nonprofit dedicated to helping drug users minimize the harm associated with drug use.

“These are people posting anonymously about things that are stigmatized, or illegal, or dangerous, and so there’s a lot of fear that law enforcement, family, or employers might try to figure out who these people are,” he says. “So, from a privacy perspective, this was an important issue to look at.”

Users of the site generate thousands of words of content, he says. So the question was: How much of a privacy risk did that pose?

He and his team built a model called a stylometric classifier that can identify the author of a piece of work based on their writing style. Then, using algorithms known to work with identity matching, the researchers attempted to link specific pieces of content on the forum to accounts from websites like Reddit. If a link was made, the Reddit account could potentially expose the identity of the forum user.

“We found that the stylometric classifier did a really good job. We could get around 80 percent of users on two different websites linked just through this writing style,” says Skeba. The purpose of the study was to highlight that the simple act “of posting online introduces certain risks, and this is something we need to consider much more, moving forward.”

We already knew that we needed to protect our passwords. But now, algorithms could potentially mine the thoughts, opinions, and advice we share online to uncover our personal information. And that could affect anyone who spends time on the internet.

“If you create enough content, you could become a potential target for these kinds of analyses,” he says. “We wanted to highlight that there’s a need to critically analyze the algorithms that are being developed and deployed to ostensibly stop things like cybercrime and terrorism, and make sure they aren’t also harming people who rely on anonymity to do things that are acceptable and beneficial to themselves.”

[redacted]

“There’s never been a greater time to educate the public on how to discern and address online misinformation.”

—Dominic DiFranzo

TOP: DOUGLAS BENEDICT/ACADEMIC IMAGE

BUILDING DIGITAL LITERACY

And It’s not just our personal information at stake. The algorithms designed to keep us engaged with—and boost the bottom line of—social platforms, search engines, and websites don’t necessarily have our best interests at heart.

Recommendation systems can both lead people into echo chambers of misinformation and make it difficult to notice and disengage, says Dominic DiFranzo, an assistant professor of computer science and engineering.

“Watching a video that questions the efficacy of vaccines can get you more extreme anti-vax recommendations,” he says. “It’s a downward spiral that can be hard to see when you’re in it. These algorithms weren’t designed to radicalize people per se. They’re designed to give you more of what they think you want, regardless of what that content is.”

DiFranzo is part of a multi-university team, supported by a $750,000 NSF grant, that is developing digital literacy tools to counter this online threat. Experts in computer science, cybersecurity, psychology, economics, the humanities, and education will share advanced techniques and timely materials to increase disinformation awareness and improve user resilience.

The team also includes community collaborators from K-12 schools, senior citizen centers, and nonprofits promoting disinformation literacy in the Global South. Researchers will consider the psychological and cultural differences in the standards of trust and the distinct vulnerabilities of these populations.

DiFranzo’s focus is on developing the digital tools, primarily assisting in designing, building, and deploying the platform. The project will use a number of the technologies his lab has built, like the Truman platform—a system that creates interactive social media simulations for large-scale online experiments.

“There has never been a greater time to educate the public on how to discern and address online misinformation,” he says. “But it’s not enough to just inform them about these challenges. We need to provide them with the tools, training, and experience in how to navigate this new informational environment.”

OPTIMIZING MACHINE LEARNING

“The stochastic gradient method is the workhorse of machine learning—and thus most of artificial intelligence,” says Luis Nunes Vicente, chair of the Department of Industrial and Systems Engineering (ISE).

It’s an optimization algorithm that essentially fine-tunes models used in large-scale applications of machine learning, whether that’s a streaming service suggesting what movie to watch next, or a credit card company monitoring online transactions to detect fraud.

The main idea behind the stochastic gradient method comes from a seminal 1951 paper by mathematician Herbert Robbins and his graduate student Sutton Monro, who later joined the Lehigh ISE faculty. Today, ISE professor Frank E. Curtis, an expert in continuous mathematical optimization, is leading the charge to advance the use of the stochastic gradient method in machine learning.

A machine learning algorithm works by creating a model that learns from the historical data it’s been fed to make predictions about new data it receives.

The process usually goes poorly at first, which is to be expected, says Curtis, who is a founding member of Lehigh’s OptML Research Group. For instance, an image classification algorithm might initially misinterpret a picture of a cat as a dog. The typical solution, he says, is to feed the machine more and more data so the algorithm can update its model to make better predictions.

Machines learn through what’s called a “loss function,” which measures the predictive accuracy of a model for a given set of data. If predictions deviate too much from actual results, the loss function is represented mathematically as a very large number.

The job of the data scientist is to minimize the loss function—i.e., to reduce the degree of error in those predictions. That’s what optimization means in the context of machine learning, Curtis says, and it’s critical to advancing the technology that is driving innovation in areas such as medical diagnostics, autonomous vehicles, and speech recognition, to name a few.

With the stochastic gradient method, the loss function used by the algorithm acts as a kind of barometer, gauging accuracy with each iteration of updates to its model, and continually adjusting it to yield the smallest possible error.

In the image classification example, it would be a very slow process for a computer to go through all of the images in a dataset, Curtis says, and then update its model (a full-on “wash, rinse, repeat” approach).

The magic of the Robbins-Monro algorithm, he says, is that it employs a sampling method.

“Rather than going through all the data first and then updating its model,” Curtis says, “the algorithm randomly chooses a small bit of it and uses that to update it; and then it grabs another random bit of data, and does it over and over again until it has gone through all the data.”

“WE’RE DESIGNING ‘ADAPTIVE’ ALGORITHMS THAT ADJUST WITHOUT THE WASTED EFFORT FOR TUNING.”

—Frank E. Curtis

By using a stochastic gradient method, the machine ends up processing the same amount of data as with other methods, but many more updates of the model that have led to improvements in its predictive accuracy will have been done. Essentially, you get a better result more quickly with the same amount of computation.

In a new project funded by a $250,000 NSF grant, Curtis and his team will develop modern improvements to the stochastic gradient method.

According to the project summary: “Despite the successes of certain optimization techniques, large-scale learning remains extremely expensive in terms of time and energy, which puts the ability to train machines to perform certain fundamental tasks exclusively in the hands of those with access to extreme-scale supercomputing facilities.”

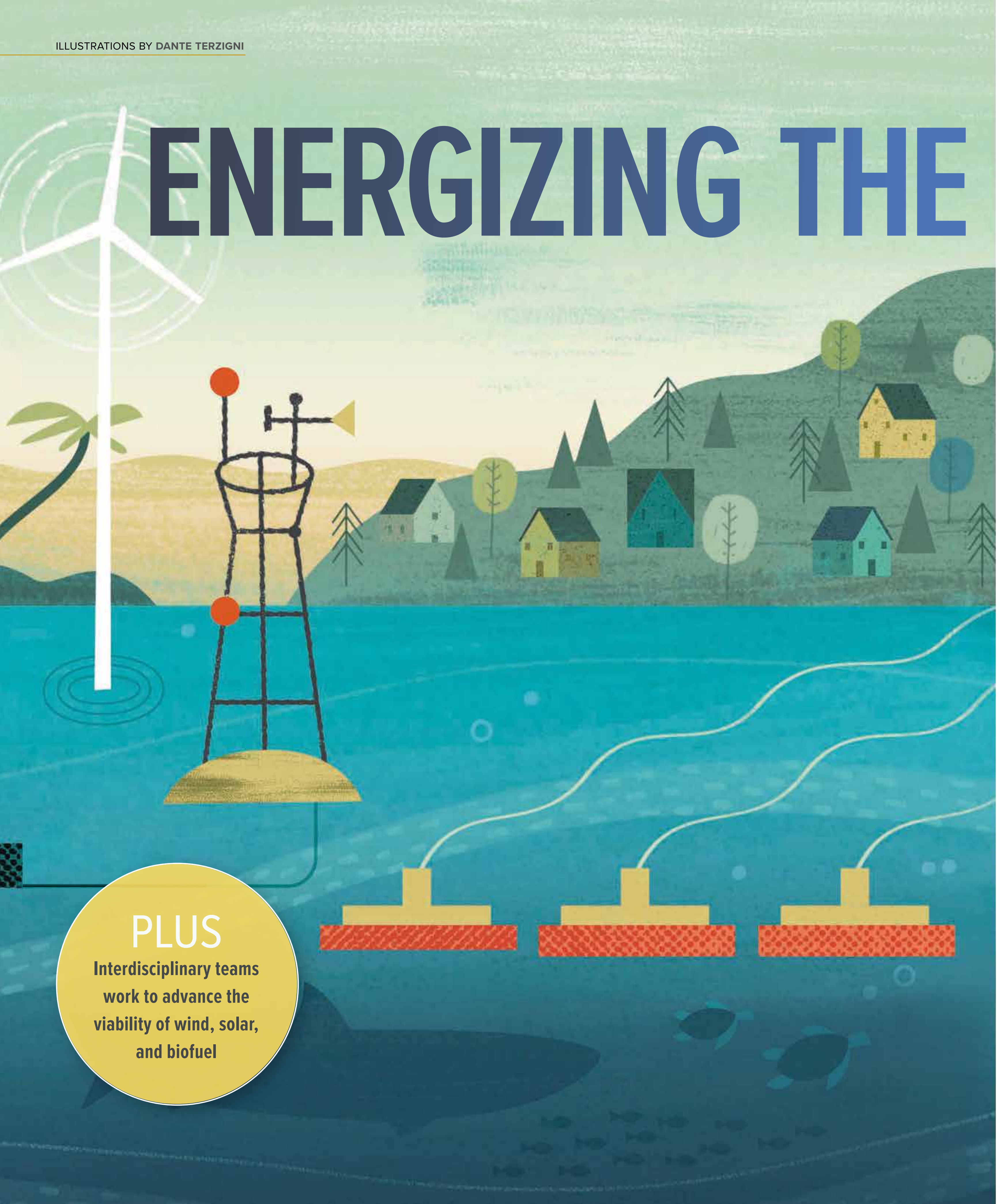
One downside of the stochastic gradient method is that it requires a lot of “tuning,” Curtis explains. For example, “Google may need to run the algorithm a very large number of times with different parameter settings in order to find a setting in which the algorithm actually gives a good result.”

This tuning can essentially waste hours or weeks—or even months—of computation, which translates into a lot of wasted electrical power. It’s one of the reasons that only the big internet companies can afford to train very large-scale models for complicated tasks.

“We are designing ‘adaptive’ algorithms that adjust their parameter settings during the training process, so that they might be able to offer equally good solutions, but without all the wasted effort for tuning.” *—Steve Neumann*

ILLUSTRATIONS BY DANTE TERZIGNI

ENERGIZING THE BLUE ECONOMY



Lehigh takes a leading role in the new DOE-funded Atlantic Marine Energy Center, charged with harnessing renewable power from the ocean

In the face of climate change and environmental degradation, how can we maintain the health of our oceans and the communities that depend on it? In the U.S. alone, nearly 40 percent of the population lives in coastal areas, according to the National Oceanic and Atmospheric Administration.

It's one of the questions at the heart of what's known as the "blue economy," a concept focused on the sustainable use of ocean resources to promote economic growth, improved livelihoods, and the health of marine ecosystems. And according to the World Bank, it encompasses activities related to maritime transport, fisheries, tourism, waste management, climate change, and renewable energy.

Lehigh engineers have long been working in the field of renewable energy, often as part of interdisciplinary teams. Instead of looking at problems within the silos of their respective disciplines and focusing on individual components, they've used a holistic approach to design system-wide solutions. That process and expertise was recognized in late 2021 when Lehigh, together with three other academic institutions, was awarded a four-year, $9.7 million grant from the Department of Energy (DOE) to create the Atlantic Marine Energy Center (AMEC). It will be one of only four National Marine Renewable Energy Centers in the country.

The grant reflects the university's leadership in the field, says professor Arindam Banerjee, chair of the Department of Mechanical Engineering and Mechanics and co-leader of AMEC. "I think Lehigh is at the forefront when it comes to solving these energy challenges," he says. "And now with AMEC, we'll be advancing collaboration in the marine renewable energy sector to provide engineering solutions to developers who power the blue economy."

There's a broad range of potential applications for marine renewable energy (MRE). For example, adding a wave energy device to ocean observation buoys currently powered by batteries would reduce the need for servicing conducted by fossil-fuel-burning ships. Similar devices could recharge autonomous underwater vehicles while at sea, allowing them to stay on mission longer. Fish and marine algae farms could generate their own electricity instead of relying on traditional fuels brought in by boat. MRE devices would help run desalination facilities for island communities. And they could offset the extraordinarily high prices these communities currently pay for electricity; rates that Banerjee says can be nine or 10 times that paid by mainland customers.

> "There's just so much expertise, and at Lehigh, there aren't any barriers in doing these cross-disciplinary collaborations." —Arindam Banerjee

RYAN HULVAT/MERIS

AMEC will allow Lehigh to make improvements to testing infrastructure like Banerjee's tidal turbulence testing facility, which mimics tidal site conditions.

"Our goal is to try to understand, what are the blue-economy applications?" says AMEC co-leader Shalinee Kishore, Iacocca Chair Professor of Electrical and Computer Engineering and associate director of Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE). "What kind of demand do they have for electricity? How does it match with what marine renewable energy systems will deliver, and how do you offset the difference between the two by using energy storage in the best way possible?"

"People on islands in the Northeast pay up to nine times more than mainlanders, which means a ridiculous amount of their monthly income is going toward electricity." —Shalinee Kishore

As co-leader of AMEC, Kishore will focus on energy storage and how to better tune that storage to the electricity demands of various blue-economy applications.

DOUGLAS BENEDICT/ACADEMIC IMAGE

Increasing reliability, reducing cost

The Lehigh AMEC team comprises faculty members representing mechanical, electrical, computer, industrial, civil, and structural engineering. Members of the team, including Banerjee and Kishore, have collaborated on previous work, funded by the NSF, that showed the viability of bringing ocean wave energy to the grid. One aspect of that study involved looking at how to design a farm of sorts of multiple buoy-like devices to maximize their hydrodynamic interaction.

"Imagine you have one device heaving up and down from the ocean waves," says Kishore. "That device ends up creating its own waves. The device downstream from it will get those waves in addition to the ocean waves. It's possible these add up constructively and the second device gets more energy, but it could get less because waves can add up constructively or destructively. One aspect of that project was to design these farms in a way that enabled more energy conversion, so the hydrodynamic interaction was positively correlated."

The other aspect of the project involved bringing that energy back to shore and integrating it into the power grid, which required understanding what it meant for electricity generators and grid operators to manage ocean wave energy versus wind or solar power.

"So from the grid operator's perspective, when a lot of solar and wind comes onto the grid, it's great, because it's low-cost renewable energy. The downside is that you can't control it," she says. "One of the major benefits of ocean wave energy is that it's much more predictable than solar or wind. But we also recognize that marine renewable energy systems are still expensive. So one of the goals of AMEC is looking at how to develop these systems at scale and reduce cost."

It's not an easy proposition. Decades of research and development coupled with government subsidies have driven down the cost of wind and solar energy and made them a viable choice for consumers. MRE devices capable of delivering grid-scale power are still 10 to 15 years away, says Banerjee.

The next step then might be to develop MRE systems for use within island communities where the cost of energy is already high, says Kishore. The actual components might still be expensive, but the operational costs will be low, as the communities make use of the abundant energy source that surrounds them.

"As an example, people on islands in the Northeast, like those in the Gulf of Maine, pay up to nine times more than mainlanders, which means a ridiculous amount of their monthly income is going toward electricity," says Kishore. "And that's because cables have to bring that electricity to the island, or fuel needs to be brought in to operate their generation resources. Drinkable water is an issue in these places, too. Water remediation is very energy intensive. So now we're no longer talking about esoteric blue-economy applications. We're talking about places that are energy poor and people who experience scarcity when it comes to the electricity they need to run their homes, provide their drinking water, and give them internet access."

That next step involves more than just the development and deployment of MRE technologies, says Banerjee. It requires studying the intricate interdependencies between communities, energy, water, and communications. He envisions the scope of the Lehigh AMEC team expanding beyond its current mandate of powering the blue economy to address socioeconomic problems related to the blue economy. At the heart of those questions are interdependencies related to the energy-water-communications network.

WENDY FONG

"One of our goals is to move into research questions associated with these interdependencies," he says. "I can sit in my office and say a certain coastal community needs energy to run a desalination system. But what are the issues surrounding that need? Is there a bottleneck associated with the power required to run that system? How will renewable energy affect the utility companies on these island communities and their power grid? Or if we're talking about fisheries, what is the energy resource that industry thinks would best suit its needs? There are stakeholders associated with each of these problems, and as engineers, we don't fully understand their scope. We have expertise in communication networks, water systems, and energy systems. So we're building a bridge between those areas and going after these grand challenges."

For Kishore, who will be focusing on energy storage systems, it will be an opportunity to learn how to better tune storage to the electricity demands of various blue-economy applications. It's also an extension of the work that the Institute for Cyber Physical Infrastructure and Energy has been doing for quite a while now.

"In I-CPIE, we talk about how the physical components, the sensors, and the algorithms that run these infrastructure and energy systems all have to be designed to better meet the needs of the folks that they serve," says Kishore. "It's not just about technology, it's also about the communities that technology is designed to impact. And I feel like all of that comes together really nicely in this particular space with AMEC."

ROLLING OUT AN EMISSION-FREE BUS FLEET

California is on the road to big change. By 2040, its entire fleet of transit vehicles must be emission-free.

Since 2018, faculty affiliated with Lehigh's Institute for Cyber Physical Infrastructure and Energy (I-CPIE) have been contributing to that goal by assisting the Santa Clara Valley Transportation Authority (VTA) in the development of a smart microgrid that will power a fleet of electric buses.

Such a microgrid needs to account for the complex interplay of factors required to get riders from point A to point B using zero-emission vehicles: The fleet has to generate a portion of its own energy from solar-paneled bus depots; it has to be able to store some of that energy locally to offset the daily price spikes as the sun sets and the main grid loses cheap solar generation; and it must be able to operate when the main grid goes down.

"You have generation, chargers, storage, the schedules the buses have to follow, plus all the data around bus and driver performance, traffic congestion, predicted weather forecast, as well as the solar forecast, and our research has focused on coordinating all of that," says Shalinee Kishore, Iacocca Chair Professor of Electrical and Computer Engineering and associate director of I-CPIE.

Kishore and her team are developing algorithms with the VTA that will help the agency schedule bus charging, design routes, assign bus operators, use local energy storage and solar generation, and coordinate with the main grid. Kishore credits an exceptionally driven cohort of graduate and undergraduate researchers with the progress they've made to date on solving many of these problems.

"This project has a lot of traction with students," she says. "They're passionate about developing sustainable futures for our cities and communities. And the VTA has loved what they've done so far in giving them new solutions for their system."

In January, the VTA was granted an additional $4.7 million from the California Energy Commission's Clean Transportation Program to install 34 new bus chargers, solar panels, and a microgrid at one of their bus yards. (The award completes a $16.4 million funding goal for the project, which is slated to come online in 2023, per the VTA.) The I-CPIE team will continue its data analysis as these new deployments come on board, says Kishore, and optimize the algorithms as required. They'll also be involved in community outreach, she says, creating content that the VTA will disseminate to stakeholders, and in particular, to disadvantaged communities. In part, the outreach is meant to alleviate safety concerns people might have around energy storage infrastructure and communicate what the VTA is doing to address those concerns.

"We've already had such a fruitful relationship with the VTA, and now we have this grant to show for it," says Kishore. "This project is a fascinating opportunity for Lehigh. It leverages our strengths across such a range of disciplines. The system is undergoing a revolution, and while Lehigh hasn't had a traditional strength in transportation, a project like this is going to help us grow into a space that, I think, is part of our future."

Examining energy equity

Grand challenges are often largely in pursuit of equity. And achieving equity is, in part, an optimization problem.

Indeed, making energy and water more affordable and sustainable for coastal communities requires co-optimizing those objectives with the related infrastructure, says Farrah Moazeni, an assistant professor of civil and environmental engineering, and one of the theme leaders of AMEC. Moazeni and Javad Khazaei, an assistant professor of electrical and computer engineering, will be studying interdependent critical infrastructures, particularly the interplay between water systems and infrastructure like that related to electricity and transportation.

Historically, she says, these utilities have been optimized individually. Lehigh's approach will be to look at them as a whole.

"For example, how can you convert saline water to drinking water without increasing the electricity consumption?" says Moazeni. "We want to see if we can co-optimize all this infrastructure at the same time to minimize energy consumption, minimize freshwater consumption, and enable these communities to operate off grid."

The ultimate goal—"my dream," she says—is to close the loop. To enable ocean communities to use waves to create the energy that runs their homes and desalinates their water and powers their wastewater treatment. In the meantime, she believes that the optimization work she and her team will be doing will help many of those communities paying exorbitant rates for energy by making systems more efficient and thereby reducing costs.

"Many people don't have easy access to these resources, so this is really about energy and environmental equity, and that's what I find so compelling about trying to solve these problems," she says. "If we could offer a model that could reduce energy consumption by 30 percent, that will make a huge impact not only on sustainability but on people's lives."

Upgrading research infrastructure

With AMEC's creation, Lehigh will be making significant improvements to its testing infrastructure. One of those upgrades will take place in Banerjee's tidal turbulence testing facility. The system mimics tidal site conditions, but it currently can't replicate the flow velocities in high-energy sites.

"So we're going to speed up the water tunnel in Packard Lab to get the kinds of velocities you would have in open-water tidal sites like the East River in New York City where the flow is between 1.8 to 2.4 meters per second," says Banerjee. "We're aiming to get up to 2 meters per second."

Improvements will also be made to two test bed facilities within Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center. One, led by Richard Sause, will conduct fatigue loading on tidal turbine blades. Sause is the Joseph T. Stuart Professor of Structural Engineering and also serves as director of ATLSS and the Institute for Cyber Physical Infrastructure and Energy.

"Right now, there's only one test bed like that in the United States, and it's in Golden, Colorado," says Banerjee. "So if you're a developer, that's the only place you can go to get that testing done."

The second ATLSS improvement will be to a soil test bed for marine foundations. In 2019, an I-CPIE team, led by Muhannad Suleiman, a professor of geotechnical engineering, received a DOE grant to upgrade Lehigh's offshore wind multi-directional, soil-foundation interaction testing facility and its structural-testing and modeling capabilities. The award supported better understanding of the behavior of offshore wind turbines, specifically as it relates to the unique weather and geology of the coastal United States (see "Tackling Offshore Wind Challenges 'From the Ground Up,'" page 21). AMEC will further support that work as it pertains to underwater

Clockwise from left, Thomas Marullo, Suleiman, James Ricles, Sause, and Qasim Abu-Kassab in the control room for the offshore wind multidirectional soil-foundation interaction testing facility.

RYAN HULVAT/MERIS (2)

PAVING THE WAY TO INCREASED WASTE-TO-ENERGY PRODUCTION

According to the Environmental Protection Agency, in 2018, Americans generated 292 million tons of trash, aka municipal solid waste (MSW). That's triple the amount generated just 60 years ago.

While recycling and composting have increased, the majority of the waste produced goes into landfills, the most inexpensive option. About 12 percent of MSW was converted into energy by waste-to-energy plants in 2018, according to the Energy Information Administration.

"There are different ways to process trash," says Carlos E. Romero, principal research scientist and director of Lehigh's Energy Research Center (ERC). "One is to take it to a landfill, another is burning it to produce electricity, and another is utilizing it as a feedstock for producing biofuels and bioproducts. However, the nature of MSW, a very heterogeneous material, with large variability in its physical, chemical, and biological characteristics, poses significant challenges in optimizing MSW conversion processes."

The ERC has been awarded a new $3.5 million project by the Department of Energy for the development of advanced technology for rapid detection and analysis of MSW streams. This project is part of a $34 million effort to support high-impact research and development to improve and produce biofuels, biopower, and bioproducts.

Lehigh will lead a team that includes the Energy Research Company (ERCo), the DOE's National Energy Technology Laboratory, ThermoChem Recovery International, Covanta Energy, the University of Toledo, and SpG Consulting. Lehigh participants include (pictured, from left) ERC principal research scientist Zheng Yao, civil and environmental engineering assistant professor Farrah Moazeni, Romero, and graduate student Jincheng Liu.

The team will work on streamlining one of the most complex aspects of the waste-to-bioenergy process: analysis of the material. The project will bring together two types of leading-edge spectroscopy, laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy, in combination with artificial intelligence (AI).

The technology will be designed to provide rapid, *in situ* characterization of MSW feedstock, providing critical characterization and chemical analysis data for feed-forward process control of downstream biofuel production processes. Together, the hardware and software elements will be capable of improving MSW characterization throughput over baseline methods by at least 25 percent. The approach could make it possible to process waste material in minutes instead of hours.

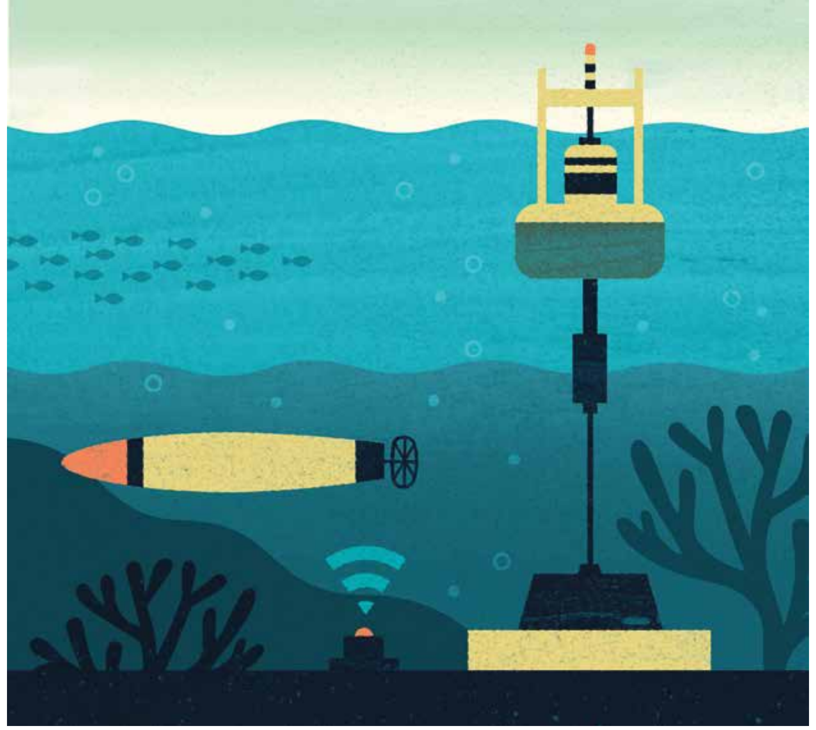
The ERC and ERCo have previously worked on a method of using LIBS and AI to better analyze coal for power generation. "With LIBS alone," says Yao, "we were only able to measure the elemental composition of the fuel. But, by using AI neural networks, we were able to improve measurement accuracy and correlate elemental composition to other high-order parameters such as calorific value and ash fusion temperature, for example."

Romero explains that waste-to-energy producers need an accurate analysis of the waste material in any given lot. "There are standardized procedures for how a representative sample is arrived at and analyzed," he says. "The team's innovative LIBS-Raman spectroscopy, combined with AI, has the potential to significantly improve the accuracy of the analysis as well as the speed at which it occurs, while facilitating the incorporation of this information into the bioenergy reactor process control."

The project could lead to a process that is both easier and less costly, making waste-to-energy a more attractive alternative to the landfill, and moving the U.S. closer to a waste-processing approach that is sustainable.

"Reducing the load on landfills will be one important impact of this project," says Moazeni, who is leading the machine learning development and training of the AI algorithms. "There are so many factors that must be considered when a landfill is created. How close is it to the nearest town? What is the wind flow? The soil conditions? Will there be leachate? This method can have a huge impact on the amount of waste we're sending to our landfills. And because we're recycling material, we're helping to close the loop, which takes us one step closer to sustainability."

"This method can have a huge impact on the amount of waste we're sending to our landfills. And because we're recycling the material, we're helping to close the loop, which takes us one step closer to sustainability." —Farrah Moazeni



"When you look at rural communities or island communities where the cost of energy is really high, people often end up making poor choices about their power resources."

—Arindam Banerjee

turbines; in particular, how these marine energy structures and their foundations will interact with the soil.

"There are a lot of unknowns when it comes to generating energy from water," says Suleiman, who is a member of the AMEC team. "I'll be focusing on water-soil-foundation-structure interaction and how to support these structures in a river environment versus an ocean environment. We need to consider erosion and the impact on biological systems. We also want to explore the feasibility of designs for foundation systems that are economical, reliable, and resilient. We may design them for the behavior of today, but do we really know how they'll behave in 20 years? Also, we could design a system that might not fail, but may deform or displace with time, reducing its energy output. That's not a resilient infrastructure."

Problem-solving across disciplines

The interdisciplinary team is uniquely positioned to address these many unknowns, from the component level to structural behavior, to energy harvesting and storage, to stakeholder concerns, supply chain, and resiliency.

In addition to Banerjee, Kishore, Sause, and Suleiman, the team also includes industrial and systems engineering (ISE) professor Larry Snyder and civil and environmental engineering (CEE) professors Panayiotis "Panos" Diplas and Paolo Bocchini. These collaborations are expected to expand as Banerjee and Kishore form a team that will address interdependence problems in energy-water-communications networks. This team would include Moazeni and Khazaei, College of Arts and Sciences professor David Casagrande (sociology and anthropology), and Rossin College faculty members Y.C. "Ethan" Yang (CEE) and Karmel Shehadeh (ISE).

"It's a unique group," says Banerjee. "And that's what makes us one of the leaders in this field. There's just so much expertise, and at Lehigh, there aren't any barriers in doing these cross-disciplinary collaborations."

Those collaborations may soon extend to Lehigh's College of Health and College of Business. Banerjee says they've had preliminary discussions with affiliated faculty members, specifically around questions of energy justice.

"When you look at rural communities or island communities where the cost of energy is really high, people often end up making poor choices about their power resources. They might use diesel generators or burn wood for heat. And these choices can have adverse health effects. So if you just look at the problem from that perspective, the type of solutions we are providing through AMEC could be used to address broader questions around health and equity."

While the AMEC grant will be used in part to enhance his own research facility, Banerjee's position with the center allows him to step outside the lab and pursue leadership opportunities that can help grow the industry.

"I'm now at the policy-making table where a lot of these decisions are being made around the blue economy," he says. It's a position that has coincided with Banerjee recently being named associate editor of the journal *Renewable Energy*. Over the course of a year, he oversees the review of nearly 600 submissions from researchers around the world in the area of offshore renewable energy, a portfolio that includes both wave/tidal and offshore wind energy.

"In my role, I get to see what people are doing around the globe, which allows our team to reach out to researchers who are working in marine renewable energy," he says. "And that will give Lehigh international visibility."

Successful partnerships depend on a knowledgeable workforce. And to that end, as a department chair, Banerjee is also now focused on how to best prepare students to meet the needs of this rapidly evolving industry. He envisions a time when companies will be recruiting a minimum of 10 Lehigh engineers every year.

"So in preparation for that," he says, "we need to make sure we've got the proper courses, grants, and research opportunities that will allow our students to compete for those jobs."

There are plenty of challenges that lie ahead in the development and deployment of marine renewable energy devices and structures. But as climate change continues to alter our coastal systems and communities, there is the possibility that some of those changing weather patterns can be utilized for good, and seen, at least in part, as opportunities. Opportunities to harness the rising tides and broaden our capacity to generate reliable electricity—and improve the day-to-day lives of millions of people. It may not happen in his lifetime, but Banerjee is optimistic.

"I'm hopeful that our children will live in a world where these technologies are regularly being used and are a viable part of their energy portfolio."

RIGHT: RYAN HULVAT/MERIS

TACKLING OFFSHORE WIND CHALLENGES 'FROM THE GROUND UP'

Improvements to testing facility could help push forward an energy industry with huge potential

The United States has the capacity to generate 7200 terawatt-hours per year from offshore wind. "That's twice the total electricity use in the U.S. in 2020," says Muhannad Suleiman, a professor of civil and environmental engineering (CEE) who specializes in geotechnical engineering. "But right now, the U.S. produces only approximately 40 megawatts, which is the equivalent of about 7 wind turbines."

Suleiman says there has been a push from industry, coastal states, and the federal government to increase production to 30 gigawatts by 2030 and 110 gigawatts by 2050. Rossin College researchers are now one step closer to assisting with that push. The offshore wind multidirectional soil-foundation interaction testing facility the team has been building within Lehigh's ATLSS Engineering Research Center is nearly complete and will be ready for testing later this spring.

Improvements to the structure came via a 2019 DOE award meant to advance wind energy nationwide. Six projects, including Lehigh's, received a total of $7 million for testing and upgrades to facilities to conduct innovative offshore wind energy R&D.

"The U.S. had limited testing facilities for offshore wind infrastructure," says Suleiman, the project's principal investigator. "And to date, a very limited number of researchers have looked at the behavior of the whole offshore wind turbine structure including its foundation support system. Most researchers have focused on a single component. So the main idea was to build on concepts that ATLSS and mechanical engineering faculty have been working on."

In addition to the soil-foundation interaction, those concepts include large-scale multidirectional real-time hybrid simulation, which was developed by CEE professor James Ricles. The simulations will be performed involving mix mode load and displacement control, a research topic that CEE professor Richard Sause is leading. The proposed concept also requires developing forces applied by waves and wind, the research areas of mechanical engineering and mechanics professors Arindam Banerjee and Justin Jaworski, respectively, who are also part of the DOE offshore wind energy project team. The Lehigh team is also collaborating with Dr. Mohamed Mekkawy, a consultant, professional engineer, and leading expert in geotechnical offshore site characterization.

"In a hybrid simulation, the offshore wind turbine structure is divided into substructures (parts). Some parts are modeled using analysis (analytical substructures), while the remaining parts of the system are modeled in the laboratory (experimental substructures) and tested using the offshore wind multidirectional soil-foundation interaction testing facility," says Suleiman. "The analytical and experimental substructures are interfaced with a real-time hybrid simulation coordinator, which is used to solve for the response of the whole offshore wind turbine structure."

Turbines in Europe are typically placed in shallow water, up to 30 meters deep, he says. But turbines in the U.S. could be installed in deeper water, thanks to the continental shelf, and could be subjected to severe conditions like hurricanes and earthquakes.

So while there will be some transfer of the European experience, he says, the industry in the U.S. needs new technology for these different loading conditions from waves, wind, and other sources.

"The offshore wind turbine structures are expected to be in service for a few decades, and will be subjected to long-term normal, operational loading from waves and wind," he says. "That creates several challenges. For example, how do those long-term cyclic loads change the behavior of the foundation and the soil over time? The structures could also be subjected to extreme loading conditions such as storms. What are the long-term effects of those high wind and wave conditions on the soil and the foundation? How does that affect the response of the structure and energy production?"

Jaworski and Banerjee will provide expertise on integrating wind aerodynamics and wave hydrodynamics into the hybrid simulation.

"Currently, the design process of offshore wind turbines is a sequential iterative process where geotechnical engineers, structural engineers, and mechanical engineers work separately," says Suleiman. "Our approach is holistic and interdisciplinary in nature, making it unique."

One of the main goals, he says, is to establish ATLSS as a national laboratory for offshore wind turbine foundations and substructures, where researchers and scientists can better understand offshore wind energy structures under different loading conditions, and ultimately push forward an industry with enormous potential.

"This project opens a whole new area for us on renewable energy infrastructure," he says.

DATA DRIVEN

BY KATIE KACKENMEISTER

Led by interdisciplinary faculty, Lehigh's new MS IN DATA SCIENCE program paves the way for graduate students to advance in their fields with some of today's most sought-after skills.

When talking about data, bigger doesn't always mean better.

"We've reached a point where getting more of the same kinds of data isn't as helpful as it used to be," says Daniel P. Robinson, an associate professor of industrial and systems engineering who specializes in mathematical optimization and data science. "For some applications and problems, even if we had much more data, we wouldn't see a significant benefit."

Where there *is* room for improvement, he says, lies in developing new scientific approaches and tools to handle that data—and educating more people with the specialized mathematical knowledge and computational skills to make sense of it all.

Robinson is one of three Rossin College faculty co-founders of a new cross-departmental master's degree program focused on training the next generation of data scientists to meet that need.

Accelerating opportunities

"If you want to be on the cutting edge of almost any field, you need computational and data science expertise," says Brian D. Davison, a professor of computer science and engineering. "If you can exploit your data in better, more intelligent ways—whether you're a microbiologist or a civil engineer—you're going to push your field further."

Davison directs Lehigh's undergraduate minor in data science and has taught the intro course in the discipline for the past six years. Recently, he's worked with Robinson and Parv Venkitasubramaniam, an associate professor of electrical and computer engineering, to design a data science master's degree program that's interdisciplinary from both faculty and student perspectives.

Lehigh's new MS in Data Science program brings together professors from computer science and engineering, electrical and computer engineering, and industrial and systems engineering to teach graduate students the fundamentals of data science from varying viewpoints.

On the flip side, the approach will allow students from a wide range of backgrounds to gain the qualifications necessary to tap into the wealth of data science jobs, many of which require an advanced degree. (The U.S. Bureau of Labor Statistics projects jobs in the field to grow by more than 30 percent between 2020 and 2030; the current median salary for a data scientist is nearly $100,000.)

The program, which launches this summer, "will provide a new opportunity for people who want to develop data science skills, even if they don't have a background in computer science or statistics, to get this valuable, in-demand credential," says Davison.

Leveraging 'domain expertise'

As Davison sees it, data science is a broad concept, encompassing methods of collecting and extracting data, processing and validating it, and putting it to a practical use, whether that's a graphic visualization of the spread of COVID-19, for example, or a prediction of a prospective borrower's likelihood to default on a mortgage generated through machine learning.

CHRISTA NEU (2)

There's an ethical component, too, Robinson adds: "How do we understand and use data in a responsible way, and apply and improve algorithms to avoid bias?"

And many of the techniques used in the field have roots in sensing, networking, and signal processing, where Venkitasubramaniam's interests lie.

Prospective students need a strong foundation in math (like calculus and linear algebra) and basic training in computer science (typical for many undergrad STEM degrees and some business-related majors), but no prior data science coursework is required.

Classes will be taught in a hybrid (both in-person and remote) format to accommodate full-time students—including those who desire to complete the master's degree over 12 months—as well as professionals who want to study part time.

"It's very valuable to have some 'domain expertise' in the area where you are applying computational and statistical or mathematical methods," says Davison. That's one reason why in the real world, he says, data science is often conducted in teams. "If you don't have that expertise, you can create a great system that is of no value, because you don't know what is valuable in the particular problem you are trying to address."

Tech giants like Google and Amazon typically come to mind as companies that employ data scientists, Robinson says, but as sectors like health care, finance, manufacturing, and even nonprofits in the "data for good" space latch on to data analytics, the career pathways—and opportunities for social impact—are expanding.

For example, he says, in medicine, the ability to combine data science with artificial intelligence tools can help improve the accuracy of diagnoses and predict health outcomes to better guide treatment decisions.

"If you're interested in making an impact on people, I can't think of a better way to do it, broadly speaking, than through data science," he says.

Looking down the road

Core coursework for the MS in Data Science covers topics such as algorithms, mathematical optimization, statistical modeling, advanced computing for machine learning, and ethics. Students will gain practical experience

developing and applying methods to extract relevant information from data. Elective courses allow for specialization in areas that match students' interests or current professional focus.

Robinson is particularly excited about the opportunity for master's students to engage in projects with computationally focused faculty, including those affiliated with Lehigh's Institute for Data, Intelligent Systems, and Computation (I-DISC).

"Getting involved in a research project can be life altering," he says. "It can change the course of a career."

As the program grows, the team envisions collaborations with faculty from Lehigh's other colleges.

"The buzz around data science isn't just about the impact it's had; it's also about potential," Robinson says. "What it can do hasn't been fully realized."

'DATA SCIENCE IS MY SUPERPOWER'

PhD student Zhiyu Chen will apply his specialized skills when he joins Amazon's Alexa Shopping team

"Data science is a tool that can satisfy my curiosity," says Zhiyu Chen, a doctoral student in computer science and engineering. "It helps me to understand a lot of questions without being an expert in certain fields."

With his advisor, Professor Brian D. Davison, an expert in search engines, Chen is applying advanced machine learning techniques to better understand datasets. The project involves building a search engine specifically for datasets, something that mainstream search engines aren't equipped to find.

"Traditionally, people"—perhaps a journalist or a government employee—"are searching the descriptions of datasets that have been indexed by search engines like Google," and then tracking down the information from there, says Davison. "But sometimes the information you're looking for is in the dataset itself, and not in the description. So we've been working on building better representations of the datasets so they can be found more easily."

Chen's focus on computer science developed out of his interest in PC gaming and his reliance on search tools. "I was always searching for gaming tips on the internet," he says, "so I decided to study in CS because I was very interested in the techniques behind game development, search engines, etc."

But he traces his curiosity back to his early childhood, when he dreamed of having a superpower—like the ability to control the result of a coin flip.

"When studying probabilities in primary school, the textbook often assumes that each flip of a coin has an equal chance of coming up heads or tails. But when I did the experiments, I found out that it was not an equal chance, and the result could be affected by some factors, such as the initial position of the coin and the force when you flip."

Today, Chen sees data science as a superpower, one that allows him to model those factors and see the possibility of controlling the outcome. "I have read a book about dice control written by a professional gambler," he says, "and from my perspective, the author is really a data scientist who demystifies dice control with data science techniques."

After completing his PhD, Chen will join Amazon's Alexa Shopping team as an applied scientist for the company's virtual assistant. "Our mission is to build new machine learning models, so that Alexa can better understand customers and provide better services such as search and recommendation."

During his graduate studies, Chen interned at Amazon, where he developed a new method for conversational question answering that enables a virtual assistant like Alexa to interact with users more naturally.

"I am lucky to see how AI/data science has been applied to almost everywhere in my life," he says, "and I am sure the coverage will increase even more in the future."

Better models for better medicine

Optimization researcher strives for greater equity and access in health care systems

"I am in love with mixed integer programming," says Karmel Shehadeh. "There's nothing in this world that's certain, so I really enjoy it when I solve problems that involve random factors."

"One of the reasons I joined Lehigh was because of the College of Health and the huge future and potential I see for it," Shehadeh says.

Shehadeh is an assistant professor of industrial and systems engineering (ISE) who joined the Lehigh faculty in August 2020. Her research areas include optimization under uncertainty, as well as mixed-integer programming, scheduling theory, and algorithm development. And the primary application of her work is in health care operations and analytics.

"Health care systems are one of the most complex systems to manage," she says. "They're expensive to operate, and there are so many sources of uncertainty like surgery duration, patient arrival, and tight capacity. And we have seen how the health care system pretty much broke down during the pandemic. So the complexity of the system, the unlimited number of research problems, and the impact you can have by solving these problems is what I think attracted me to health care."

Specifically, she and her team are working on the application of data-driven operations research and optimization methods to address problems around patient and operating room scheduling, ICU capacity planning, hospital readmission, and recently, facility location. By applying her scheduling models for example, she says, hospitals could best determine how many patients a provider sees in a shift, and in what order. And that order is important.

"If it's done arbitrarily," she says, "you might allocate 30 minutes for a complex patient who actually needs 40 minutes. The model then could tell you, okay, this type of patient needs 20 minutes, this type needs 30, this type needs an hour. So ideally, if these models are implemented, they can make the system run smarter so that everyone benefits. The provider has enough time with each patient, so there will be better outcomes for the patient and more satisfaction for the provider."

Shehadeh recently published a book chapter with ISE professor Larry Snyder focused on integrating equity into health care facility location algorithms. They looked at how equity is being modeled and recommended ways to make the models more "inequity averse" to prevent unequal solutions. Which would again, she says, benefit everyone.

"Better models could help the government determine where to locate federally funded facilities," she says. "They could help private investors who are concerned about equity. For example, if a company wanted to have a mobile outpatient clinic, they could use this inequity averse model to route and schedule the clinics to serve patients in previously underserved areas."

And, she says, better models could ensure that all patients, regardless of age, gender, location, or socioeconomic factors, have the same access to care.

"There's a recent report we included in the chapter that showed that in 2020, 20 percent of the population lived far away from COVID-19 testing clinics, while a huge percentage of the population lived within three miles or less. Distance to a facility is just one factor when it comes to equity, but it's a huge factor."

As an extension of her equity work, Shehadeh recently supervised a group of women engineering undergraduates as part of the Lehigh Outreach ISE program. One of the program's initiatives is to expose undergraduates to research. Shehadeh's student group was tasked with measuring access to hospitals in Pennsylvania. Using ArcGIS mapping software, the students located all hospitals in the state and measured the distance to them from each population center.

"That helped us learn how many people had access within 10 minutes, within 20 minutes, within 60 minutes," says Shehadeh. "So that's step one. The hope is to expand this approach to the entire U.S., and to include a range of health care facilities, including outpatient clinics, blood banks, and trauma centers. These amazing students got the data, cleaned it, added it to the geographical system, created these maps, and ended up with a report that hopefully will be turned into a paper that we can make publicly available to colleagues in the field."

Shehadeh is also part of a working group led by Fathima Wakeel, an associate professor in Lehigh's College of Health, that created a survey to study the various physical and mental health impacts of COVID-19.

"I joined this group a couple of months before I even came to Lehigh, and I've really enjoyed learning from everyone. I love solving problems in health care, so it's been a natural fit for me."

Another thing she loves is working with—and learning from—her students. "I'm a new faculty member, but so far I have two PhD students at Lehigh, and I'm co-advising two other PhD students at other universities. It's been great watching them grow and improve as researchers," she says. "I always say that working with them is the best part of my job."

FOLLOWING YOUR DREAMS

Hear more from Shehadeh in a new episode of the Rossin Connection Podcast. Listen at **engineering.lehigh.edu**.

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SEEING IT THROUGH

Electrical engineering alumnus and Northrop Grumman VP Scott Willoughby ’89 discusses what it took to make NASA’s revolutionary James Webb Space Telescope a reality.

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