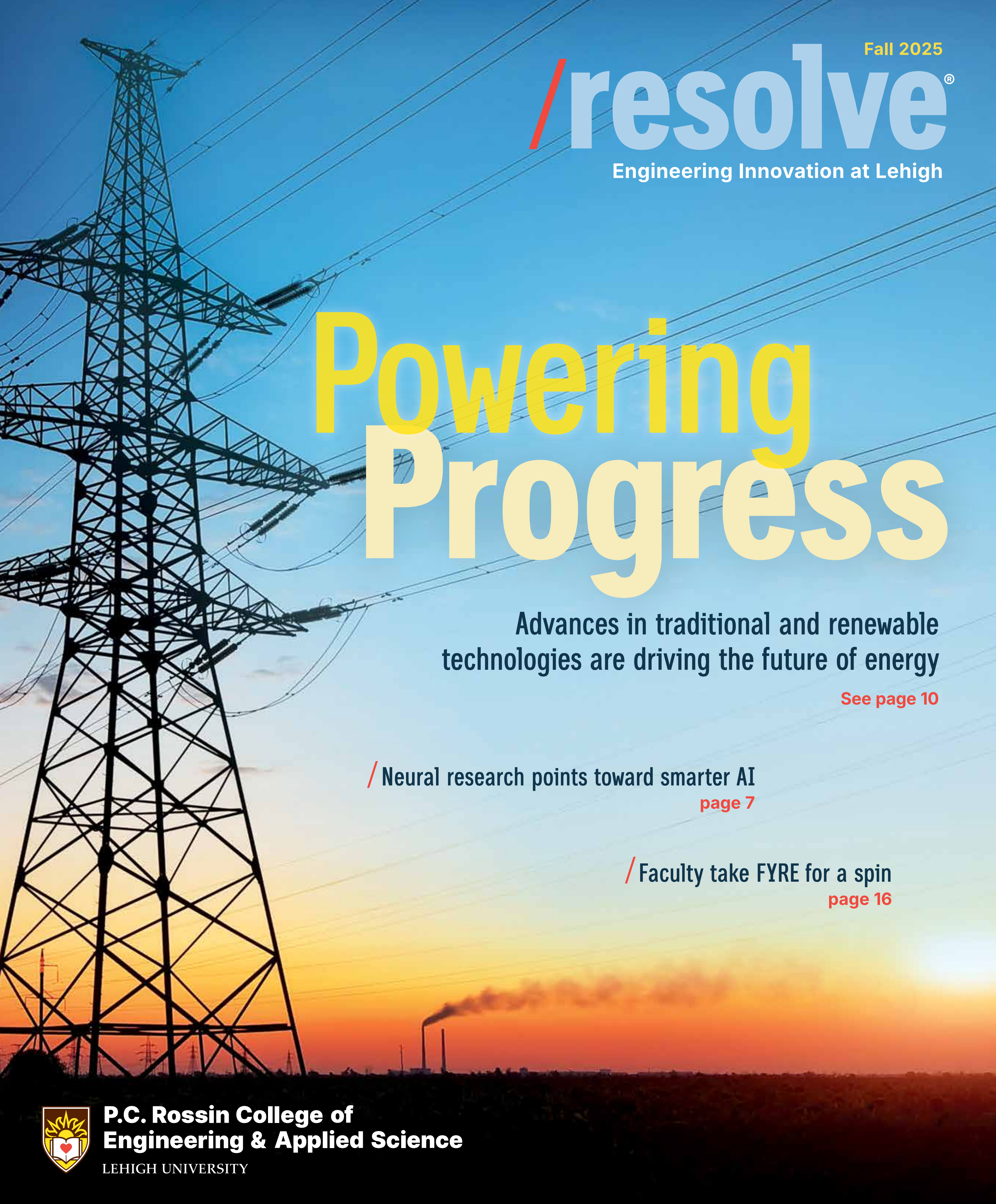

Fall 2025

/resolve®

Engineering Innovation at Lehigh

Powering Progress

Advances in traditional and renewable technologies are driving the future of energy

See page 10

/ Neural research points toward smarter AI
page 7

/ Faculty take FYRE for a spin
page 16

P.C. Rossin College of Engineering & Applied Science
LEHIGH UNIVERSITY

At the Fall Club & Community Expo, students explore campus organizations and opportunities. FYRE, the new First-Year Rossin Experience (see page 16), reinforces the importance of co-curricular involvement as an integral part of the engineering journey.

Features

Departments

Research Briefs

resolve® Fall 2025
Engineering Innovation at Lehigh

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LEHIGH UNIVERSITY

THIS PAGE: CHRISTA NEU; OPPOSITE PAGE: EMILY ROBERTI

Partners in discovery

Welcome to the Fall 2025 edition of *Resolve*—a magazine dedicated to research and educational innovation in the P.C. Rossin College of Engineering and Applied Science at Lehigh University.

This fall carried special significance for me and for our community, as I was installed as the Lew and Sherry Hay Dean during Founder's Weekend—a moment that reinforced the responsibility and promise of our shared mission.

I am honored to carry this title, which reflects not only the Hays' extraordinary generosity but also their deep commitment to Lehigh and to engineering research and education. Their gift strengthens our college in enduring ways—supporting faculty and students, fueling research, and enhancing the programs that prepare our graduates to lead. Progress happens through partnership, and I am grateful for their vision and trust.

The stories in this issue illustrate the breadth of that vision and showcase the innovative programs, such as FYRE, the new First-Year Rossin Experience (page 16), and the boundary-breaking work taking place throughout our college.

Artificial intelligence is one area of focus: You will read about a project that uses brain organoids to explore how biological computation could make AI more energy efficient. Another applies AI to better predict material reliability. A third develops strategies to defend water systems from cyber attacks. Taken as a whole, these efforts show how our community blends discovery with impact—AI being just one example of the many fields where Lehigh engineers are making a difference.

Our cover feature, "Powering What's Next," on page 10, highlights the ongoing leadership of Lehigh's Energy Research Center in reimagining how our society generates and uses energy. Since its founding in 1972, the ERC has been at the forefront of innovation. Its research has expanded to include critical emerging areas such as decarbonization, renewable energy integration, thermal energy storage, and the water-energy nexus, reflecting a commitment to addressing the evolving challenges of these essential systems.

This issue also showcases bioengineering research aimed at improving women's health (page 20). Through partnerships with clinicians, industry, and global collaborators, our faculty are working with wearable technologies, developing regenerative therapies, and designing 3D tissue models. Their projects demonstrate how engineering can advance understanding of and potential treatments for conditions that affect women throughout their lives.

In our Q&A (page 8), Lehigh Trustee and alumnus Drew Freed discusses the value of hands-on learning and real-world experience in engineering education. His philanthropy—including endowing the Undergraduate Research Symposium in honor of his parents and helping establish the Freed Family Robotics Design Studio, among other initiatives—has provided students with the resources and pathways to apply classroom knowledge in meaningful ways. These efforts continue to enrich undergraduate education and to nurture the next generation of engineers.

Finally, this issue's Rising Star article (page 24) spotlights two AIR Lab faculty members who recently earned NSF CAREER awards for their innovative work in robotics. Cristian-Ioan Vasile (mechanical engineering and mechanics) is developing methods to assess and plan around robot capabilities, enabling teams of autonomous machines to operate reliably in complex, real-world environments. David Saldaña (computer science and engineering) is designing drones that can manipulate flexible objects and adapt in real time, inspired by the ways animals navigate dynamic surroundings. Their research highlights how Lehigh faculty integrate creativity, engineering, and AI to push the boundaries of robotics and shape technologies with lasting societal impact.

PROGRESS HAPPENS THROUGH PARTNERSHIP, AND I AM GRATEFUL FOR THE VISION AND TRUST THAT MAKE IT POSSIBLE.

As I reflect on Founder's Weekend and the stories gathered here, I'm struck by how they reinforce one another. The Hays' gift amplifies everything we do—teaching, research, and partnerships—and inspires us to aim higher. With the dedication of our entire community, I am confident that together we are advancing Lehigh while shaping a better, more sustainable future.

I hope you enjoy this edition of *Resolve*; thank you, as always, for your interest in Lehigh Engineering!

Stephen P. DeWeerth, *Lew and Sherry Hay Dean*
P.C. Rossin College of Engineering and Applied Science
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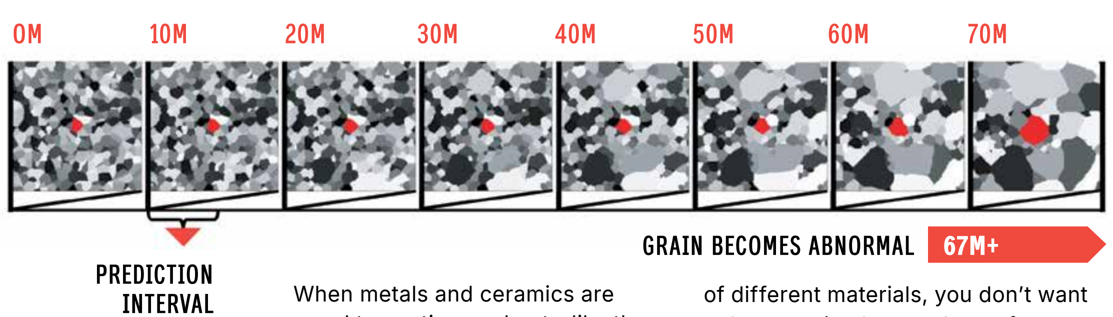
A leap forward in predicting material reliability

Novel machine learning model identifies early warning signs of abnormal grain growth

A Lehigh team has successfully predicted abnormal grain growth in simulated polycrystalline materials for the first time—a development that could lead to the creation of stronger, more reliable materials for high-stress environments, such as combustion engines. A paper describing their novel machine learning method was published in *npj Computational Materials*.

“Using simulations, we were not only able to predict abnormal grain growth, but we were able to predict it far in advance of when that growth happens,” says Brian Y. Chen, an associate professor of computer science and engineering and a co-author of the study. “In 86 percent of the cases we observed, we were able to predict within the first 20 percent of the lifetime of that material whether a particular grain will become abnormal or not.”



Snapshots taken every 10 million simulation steps show one grain (in red) growing abnormally large after 67 million steps. The model predicted this outcome using data from just 11 to 15 million steps—well before the change occurred.

When metals and ceramics are exposed to continuous heat—like the temperatures generated by rocket or airplane engines, for example—they can fail. Such materials are made of crystals, or grains, and when they are heated, atoms can move, causing the crystals to grow or shrink. When a few grains grow abnormally large relative to their neighbors, the resulting change can alter the material's properties. A material that previously had some flexibility, for instance, may become brittle.

“We'd like to be able to design materials intentionally to avoid abnormal grain growth,” says Chen.

Finding stability

Predicting abnormal grain growth has been a needle-in-a-haystack problem. There are countless combinations and concentrations that can go into the creation of any given alloy. Each of those metals must then be tested, which is expensive, time-consuming, and often impractical. The simulation developed by Chen's team helps narrow down possibilities by quickly eliminating materials that are likely to develop abnormal grain growth.

“Our results are important because if you want to look at that big haystack of different materials, you don't want to have to simulate each one of them for too long before you know whether or not abnormal grain growth is going to occur,” he says.

The challenge is that abnormal grain growth is a rare event and, early on, the grains that will become abnormal look just like the others.

Unlocking hidden patterns

To address this, the team developed a deep learning model that combined two techniques to analyze how grains evolve over time and interact: A long short-term memory network modeled how the properties—or features—of the material would be evaluated, and a graph-based convolutional network established relationships between the data that could then be used for prediction.

Initially, the researchers simply hoped to make successful predictions. They didn't anticipate being able to make predictions so early.

“We thought that the data might be too noisy,” he says. “Maybe the properties we were looking at wouldn't reveal very much about distant future abnormalities, or maybe the abnormality would only reveal itself just as it was about to happen, when it might be obvious even to the human eye. But we were surprised that we were able to make predictions so far in advance.”

By studying how grains evolved long before abnormalities appeared, the team identified consistent trends useful for early prediction.

In this project, Chen and his team conducted simulations of realistic materials. The next phase is to apply the approach to images of real materials and see if they can still accurately predict the future. The long-term goal, says Chen, is to identify materials that are highly stable and can maintain their physical properties under a wide range of high-temperature, high-stress conditions. Such materials could allow engines to run at higher temperatures for longer before failure.

The team also sees the potential of their novel machine learning method to predict other rare events, thanks to its ability to identify warning signs in complex systems. For example, it might help predict mutations leading to dangerous pathogens or sudden shifts in atmospheric conditions.

“This work opens up an exciting new possibility for material scientists to ‘look into the future' to predict the evolution of material structures in ways that were never possible before,” says Martin Harmer, Lehigh's Alcoa Foundation Professor Emeritus of Materials Science and Engineering and a co-author of the paper. “It will have a major impact in designing reliable materials for defense, aerospace, and commercial applications.”

TOP: ID1974/ADOBE STOCK; BOTTOM: COURTESY OF BRIAN Y. CHEN

Bridging research and rehabilitation

Lehigh has formalized a partnership with Good Shepherd Rehabilitation to improve the lives of people living with disability. The rehabilitation network specializes in the treatment of spinal cord injury, brain injury, stroke, major multi-trauma, pulmonary disease, respiratory failure, musculoskeletal/orthopedics, and complex pediatric conditions.

The partnership, led by Lehigh's College of Health (COH), creates new opportunities for engagement and collaboration across the university. COH and Rossin College faculty members have already partnered with Good Shepherd on multiple research projects.

“Growth of research and enhancing partnerships with regional and national organizations are important priorities within Lehigh's *Inspiring the Future Makers* strategy,” says Nathan Urban, provost and senior vice president for academic affairs.

Good Shepherd Rehabilitation President and CEO Michael Spigel sees the partnership as an opportunity to turn research into practical solutions through new discoveries, techniques, and tools that make a difference in the lives of patients.

“This partnership is so exciting because it helps deeply integrate engineering, neuroscience, and data science expertise—all things Lehigh University excels at—directly into Good Shepherd's programs and services for people with disabilities,” he says.

In August 2024, the institutions signed a Memorandum of Understanding outlining a 10-year vision that includes research collaborations, joint faculty appointments, and a seed program for new projects.

A milestone is the appointment of two joint faculty members, the first-of-its-kind hire for both institutions. COH data scientist and motor control researcher Shirin Madarshahian studies how the brain and body control movement and uses data to improve clinical treatments for individuals with disability. Bioengineer Juan Aceros works on medical device solutions that enhance accessibility and independence for this population.

> “PARTNERING WITH GOOD SHEPHERD REHABILITATION CREATES A POWERFUL ENGINE FOR INNOVATION.”
> —Stephen P. DeWeerth

The partnership also advances Lehigh's Center for Community-Driven Assistive Technologies, one of three new University Research Centers. CDAT aims to transform the lives of people with disabilities through interdisciplinary research and cutting-edge emerging and existing assistive technologies.

Even before the partnership was formalized, CDAT's core faculty team engaged in discussion around shared space and models of collaboration with Good Shepherd.

Aceros is eager to “translate our evidence-based research into practical, technology-driven solutions that directly benefit the community.”

“The synergy between Lehigh's engineering and health colleges, combined with Good Shepherd's clinical expertise, creates a powerful engine for innovation,” says Stephen P. DeWeerth, professor and the Lew and Sherry Hay Dean of Engineering. “It's truly inspiring to witness the collaborative energy of our faculty, particularly the CDAT team. This partnership is a testament to their commitment to improving the lives of people with disabilities through innovation in technology.”

The partnership will allow Lehigh students to gain real-world training in rehabilitation and healthcare through internships and other opportunities at Good Shepherd. Early projects include a way-finding app that uses robotic mapping to improve indoor accessibility, wearable tech that helps people with dysphagia, and a community health needs assessment to understand the needs of people with autism and other neurodivergent conditions.

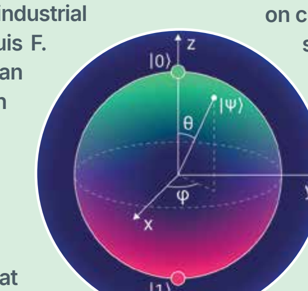
TOP: CHRISTA NEU; BOTTOM: CALIN/ADOBE STOCK

EXPLORING QUANTUM APPROACHES TO COMPLEX SYSTEMS

Quantum computing is emerging as a powerful tool for solving problems that push the limits of classical methods. A new project led by industrial and systems engineering professors Tamás Terlaky and Luis F. Zuluaga will explore how quantum and classical computing can work together to tackle large-scale optimization challenges in process systems engineering.

The collaboration is supported by a National Science Foundation grant and includes research partners from Lafayette College, the University of Southern California, and Purdue University.

The team will focus on hybrid algorithms—approaches that combine classical and quantum devices—to address computationally demanding problems in critical industries such as chemical production and energy systems.



“For over a decade, research in quantum optimization has concentrated on combinatorial problems that, while important, are fairly narrow in scope,” says Terlaky. “Our goal is to take the first steps toward showing how quantum devices can support decision-making across a wider range of industrial applications.”

Zuluaga's expertise in polynomial optimization and energy systems complements Terlaky's background in conic optimization and quantum computing. Their collaborators bring strengths in quantum linear algebra, applied computing, and chemical engineering optimization, creating a team positioned to investigate how quantum methods might expand into new areas of engineering practice. Their work could provide a foundation for advances in applying quantum technologies to real-world systems—bridging the gap between theory and practical implementation.

Solving big problems, one burrito truck at a time

Web-based optimization game draws thousands of global users and sparks classroom engagement

When trying to teach a complex subject, sometimes the best strategy is to wrap it in something familiar.

Like a burrito.

An ideal candidate for such an approach? Mathematical optimization, which uses math and computing tools to make decisions about complicated systems. It has the power to help a range of people from professionals in data science, engineering, and business, to individuals looking for a better route to work. But to the uninitiated, its promise can be a hard sell.

"People who know a little bit about optimization either think it's trivially easy, or it's impossibly hard," says Larry Snyder, a professor in the Department of Industrial and Systems Engineering and Lehigh's deputy provost for faculty affairs. "What they don't realize is that there is theory and software available that can help solve really complicated problems."

Enter the Burrito Optimization Game, which has surpassed 50,000 plays by users around the world.

In 2022, Snyder collaborated with Gurobi Optimization, a company that develops mathematical optimization software, to create a free, web-based learning tool that would make the concept of optimization more approachable to more people.

Here's how it works: The game opens with a colorful map of a city that identifies buildings where there is some demand for burritos. Players can drag and drop their burrito truck at locations where they believe they will sell the most wrapped wonders and best balance their costs and revenues. When they are done placing their trucks, their solution to that day's demand is compared with the mathematically optimal solution.

"The player might learn that their solution is 20 percent worse than optimal, for example," says Snyder. In the game, suboptimal translates to lots of disappointed eaters, much missed revenue, or too many trucks per hungry mouth. "They'll then get feedback in the form of light bulbs that appear on the map, which reveal little tips like, 'You missed some demand here,' or 'You should have located a truck here,' so you understand where you went wrong."

The game progresses in difficulty across days (as opposed to levels). One day, the map might become more complex with more locations to consider. On another, it might rain, which limits how far people would be willing to walk to a truck. Or, perhaps, a disruption in the supply chain means cheese suddenly costs more. As the days go on, more uncertainty is added. Early in the game, you may know that 12 people in a particular building are die-hard burrito fans. But later on, all you know is between 10 and 14 people might be craving one.

> "GAMES HELP MAKE THE JUMP FROM NOT UNDERSTANDING SOMETHING TO SPARKING INTEREST IN LEARNING MORE."
>
> —Larry Snyder

"All these scenarios change the decisions you have to make," says Snyder.

The team designed the game initially with data scientists and other "optimization-adjacent" people in mind, but they quickly realized that the format made it an effective tool for users of all ages. Professionals use it to learn the basics of optimization, but Snyder and other faculty at Lehigh have employed the game in introductory mathematical optimization courses and as an outreach tool in local high schools to bring optimization into their young orbits. The game's "championship" mode allows users to compete against each other, a feature that's well-suited for both classrooms and, says Snyder, academic conferences.

"My kid played it when they were 10 years old," he says. "So it's easy to start the game without knowing anything about optimization."

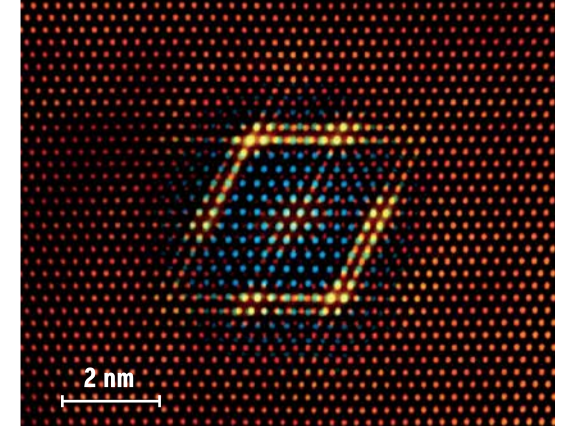
Ultimately, the team set out to create a tool that could introduce people to optimization and its unique ability to solve what Snyder calls "overwhelmingly complicated" problems.

"We wanted people to have a sense of why these problems are hard to solve by hand, and to realize that there are algorithms that can solve them for you," he says. "Games just make learning more fun. They're really useful in helping someone make the jump from not understanding something at all to understanding enough of it to spark their interest in learning more."

The interactive game challenges players to deliver burritos in a way that maximizes profit through supply chain optimization.

GUROBI OPTIMIZATION

Learn more about the Burrito Optimization Game in this video.



TOP: COURTESY OF MARTIN HARMER; BOTTOM: CHRISTA NEU

A new class of copper

Copper's exceptional thermal and electrical conductivity has made it a cornerstone of modern technology. Yet its weakness at high temperatures has kept it out of applications where both strength and conductivity are essential. Superalloys based on nickel and other metals have long filled that role, but they lack copper's ability to conduct heat and electricity efficiently.

Now, researchers from Lehigh and the U.S. Army Research Laboratory (ARL), working with collaborators at Arizona State and Louisiana State universities, have developed a copper-based alloy that defies those limits. Their findings, published in *Science*, introduce a Cu-Ta-Li (copper-tantalum-lithium) alloy that combines copper's conductivity with the high-temperature resilience of superalloys. The material could lead to next-generation defense, aerospace, and industrial technologies.

"This is cutting-edge science, developing a new material that uniquely combines copper's excellent conductivity with strength and durability on the scale of nickel-based superalloys," says Martin Harmer, Alcoa Foundation Professor Emeritus of Materials Science and Engineering and co-author of the study. "It provides industry and the military with the foundation to create new materials for hypersonics and high performance turbine engines."

> "THIS STRATEGY TURNS WHAT WAS SEEN AS A WEAKNESS INTO THE MATERIAL'S GREATEST STRENGTH."
>
> —Martin Harmer

The breakthrough centers on a new strategy for stabilizing copper at extreme temperatures. The team created nanoscale Cu_3Li precipitates, which are stabilized by tantalum-rich bilayer "complexions," or atomic-scale structures that form along grain boundaries. Grain boundaries normally migrate and weaken materials exposed to high heat. Here, the complexions lock the structure in place, maintaining strength even close to copper's melting point.

The alloy holds its shape under extreme, long-term thermal exposure and mechanical stress, resisting deformation even near its melting point, notes Patrick Cantwell, a research scientist at Lehigh and co-author of the study.

"These tantalum bilayer complexions make the alloy so stable, it can be held near its melting point for over a year without losing its nanostructure," Harmer says. "It's unprecedented for copper."

The Cu-Ta-Li alloy offers a new balance of properties not found in existing materials. By merging copper's conductivity with superalloy-like stability, the material could impact technologies including turbine engines, thermal management systems, hypersonic vehicles, power generation, and advanced electronics. It also establishes a broader design principle: that atomic-scale features at grain boundaries can be engineered to overcome long-assumed limits in materials performance.

"This discovery opens up an entirely new strategy for alloy design," says Harmer. "By manipulating what happens at the boundaries, we can stabilize structures in ways that were not previously possible."

The research builds on more than a decade of collaboration between Lehigh and ARL, supported by a $25 million cooperative agreement to develop advanced metallic alloys. Additional support came from NSF and Lehigh's Presidential Nano | Human Interfaces Initiative.

ARL has been awarded a U.S. patent for the Cu-Ta-Li alloy, underscoring its potential in strategic defense applications. And earlier this year, the Falling Walls Foundation, based in Berlin, named Harmer's involvement in the team's discovery as one of the Top 10 Global Science Breakthroughs of 2025 in the physical sciences category. Falling Walls highlights advances that "break walls" in science and society.

"This is a profoundly humbling honor," says Harmer. "Falling Walls highlights not only the science but the human aspiration to push boundaries. To be recognized alongside such extraordinary work from around the world is a privilege. This research was a true team effort of world-class collaborators."

The team is now working to measure the alloy's thermal conductivity against nickel-based alternatives and explore ways to adapt the design approach to other metals.

"This is a new design strategy for materials at the atomic level," he says. "It's about turning what was once seen as a weakness into the material's greatest strength."

For Lehigh, the breakthrough reflects institutional strength and a history of collaboration in microscopy and materials research. "This is a great example of how federal investment in fundamental science drives U.S. leadership in materials technology," Harmer says. "Scientific discoveries such as this are key to strengthening national security and fueling industrial innovation."

DEFENDING WATER SYSTEMS FROM CYBER ATTACKS

Turn on the tap and water comes out.

It's a system that we generally take for granted—but probably shouldn't—with infrastructure now being a target for hackers.

"Cyber attacks are happening here in the U.S. and all around the globe," says PhD student Nazia Raza '24G. "There's an urgent need to develop techniques and solutions to identify and mitigate those threats to water distribution, energy, and other infrastructure systems."

Raza, who is advised by Farrah Moazeni, an assistant professor of civil and environmental engineering, published a paper in *Water Research* outlining a novel holistic cybersecurity framework for smart water distribution systems. Raza describes it as a "comprehensive guide" for water authorities that will allow them to detect attacks, localize them, and assess their severity. Although other models have addressed detection or localization in isolation, such a three-part model is the first of its kind.

"The first step is to be able to detect an attack when it happens," says Raza. "Then, you need to know where it's being launched, because you might have thousands of pipes and valves within a system."

For example, if the attack is located at pipe number 3000, she explains, the water authority would need to prioritize the range and types of attacks to best allocate the resources needed to resolve them.

"For this, you need a severity assessment," she says. "We've come up with a framework that solves each of these three problems and can be directly deployed to enhance the cybersecurity protection layers of our smart water distribution systems."

Testing tall buildings against nature's fury

When the journal *Engineering Structures* named a Lehigh-led article one of its Best Papers of the Year for 2024, it wasn't just an honor for a single study. It was recognition of decades of work that have positioned Lehigh as a global leader in structural simulation.

The winning paper, "Development of Multi-directional Real-Time Hybrid Simulation for Tall Buildings Subject to Multi-natural Hazards," describes a framework for real-time hybrid simulation (RTHS) that makes it possible to capture how skyscrapers respond when earthquakes and strong winds strike together.

Tall buildings behave in unpredictable ways under natural hazards. Earthquakes and wind create nonlinear, constantly shifting stresses that can't be fully captured with conventional analysis. Hybrid simulation tackles that challenge by dividing a structural system into two subsystems: one modeled by a computer, the other tested physically in the lab. A simulation coordinator synchronizes the two in real time, producing a detailed picture of how the entire system reacts under changing conditions.

> "THIS IS RECOGNITION OF MORE THAN 30 YEARS OF TEAMWORK, INNOVATION, AND MENTORSHIP."
> —James M. Ricles

In this study, the team examined a 40-story building designed under California's Tall Building Initiative guidelines. They combined earthquake records from the 1989 Loma Prieta quake with wind data generated at Florida International University's "Wall of Wind," and then ran a real-time hybrid simulation at Lehigh. The results confirmed that the method can reproduce the multi-directional demands on tall structures, capturing subtle interactions and failure points.

This level of testing is possible because of the capabilities at Lehigh's Advanced Technology for Large Structural Systems (ATLSS) Engineering Research Center and the NSF-supported NHERI Lehigh Experimental Facility. Together, they provide the high-performance computing systems, dynamic servo-hydraulic actuators, and large-scale test beds required for sophisticated cyber-physical experiments.

"Our paper directly advances the core mission of the NSF NHERI Lehigh Experimental Facility and the ATLSS Center: to improve the sustainability and resilience of civil infrastructure," says James M. Ricles, Bruce G. Johnston Professor of Structural Engineering and director of both facilities.

Ricles joined the faculty in 1992, and since then, Lehigh has steadily built the algorithms, hardware, and networks needed to support real-time hybrid simulation. What began as fundamental research two decades ago has evolved into an internationally recognized facility that anchors Lehigh's leadership in structural resilience.

The award-winning project team includes then-PhD student Safwan Al-Subaihawi (now at Cal Poly San Luis Obispo); Spencer Quiel, an associate professor of structural engineering; and research scientist Thomas Marullo. The team's work demonstrates not only the potential of the method itself, Ricles says, but also the value of the infrastructure developed at Lehigh to support it.

ADVANCED COMPUTATIONAL TOOLS FOR MATERIALS DISCOVERY

Lehigh researchers are developing new computational methods to accelerate the design of materials critical to energy, sustainability, and advanced manufacturing.

Supported by the Department of Energy's Office of Advanced Scientific Computing Research, the project brings together Akwum Onwunta, an assistant professor of industrial and systems engineering, and Lifang He, an associate professor of computer science and engineering, with lead researcher Chinedu Ekuma, an associate professor of physics in Lehigh's College of Arts and Sciences, and Bao Wang, an assistant professor of mathematics at the University of Utah.

The team is creating scientific machine learning (SciML) algorithms that can handle the enormous complexity of high-dimensional materials data. By combining "deep learning–assisted nonnegative matrix factorization" with diffusion models, their framework is designed to reveal hidden structure-property relationships and make accurate predictions about material behaviors. Unlike traditional "black box" models, this physics-informed approach emphasizes interpretability and addresses data scarcity, making the results more transparent and broadly applicable.

An open-source platform will share these tools with the wider research community, extending the project's impact across disciplines.

OPPOSITE PAGE: TOP: RYAN HULVAT/MERIS; BOTTOM: WINDAWAKE/ADOBE STOCK; THIS PAGE: COURTESY OF YEVGENY BERDICHEVSKY

Brain organoids could unlock energy-efficient AI

An interdisciplinary team is studying how neurons process information to design smarter, more sustainable artificial intelligence

Our brains are masters of efficiency.

"Biology is very energy optimized," says Yevgeny Berdichevsky, an associate professor of bioengineering and electrical and computer engineering. "The amount of energy the brain uses at any given time is roughly equal to a light bulb in terms of wattage. Replicating those computations in hardware would demand orders of magnitude more power."

Berdichevsky and his collaborators were recently awarded a $2 million grant from the National Science Foundation to explore the complex information processing that occurs in the brain and harness it to make artificial intelligence more powerful and energy efficient.

> "WE WANT TO INSPIRE THE NEXT GENERATION OF MORE EFFICIENT AND CAPABLE AI ALGORITHMS."
> —Yevgeny Berdichevsky

The funding comes from NSF's Emerging Frontiers in Research and Innovation program, which supports research into using biological substrates (what Berdichevsky calls "wetware") to replicate the countless computations our brains perform—such as processing sensory input to create a picture of the world and directing our muscles to act on it.

"People have long built hardware-based neural networks to mimic the human brain," says Berdichevsky. "But real brain circuits perform complex tasks that hardware still can't. We want to identify those computations to inspire the next generation of AI algorithms—improving not only their efficiency, but also their capacity to process information."

The team will study neurons within a brain organoid, a millimeter-sized, three-dimensional structure grown in the lab from adult stem cells that is similar to a developing brain. Their first challenge is to organize the neurons to resemble the human cortex.

"In organoids, neurons connect randomly," says Berdichevsky. "In our brains, they're highly ordered—and we need that control for computation."

To solve this, Lesley Chow, an associate professor of bioengineering and materials science and engineering, will fabricate 3D-printed biomaterial scaffolds that guide neuron placement.

"We've learned that we can insert neural spheroids—clusters of different neural types—into scaffold sockets, stack the layers, and essentially engineer the whole organoid from the bottom up," he explains.

Next, they will test whether the neurons can perform dynamic computations, such as interpreting moving images. Drones and autonomous vehicles rely on an "optical flow" algorithm within computer vision software to track motion. But, says Berdichevsky, the software is less effective than hoped.

"My goal is to use the complex dynamics of cortical neurons to do this better and with less energy," he says.

The team will adapt methods from earlier studies where they stimulated neurons with light. They encoded an image into a sequence of optical pulses, then directed the pulses to specific neurons, allowing the cells to "see" the images.

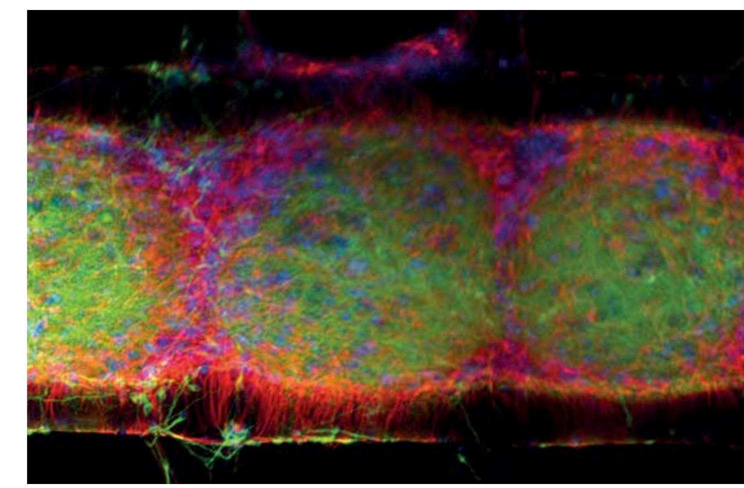
"It's not so different from the way it works in our brain," he says. "Our eyes essentially transform optical information into electrical information that then travels to the neurons in the cortex. Here, we bypass the eye and stimulate the neurons directly."

Once stimulated, input neurons can relay information to output neurons, and the team can measure neural activity using a microscope. "Based on this previous work, we know we can get information into the network. The next step is to have the network do something useful with it, which is the purpose of this new project."

The researchers plan to implement a biological version of the optical flow algorithm by playing a movie of nature scenes through optical pulses to determine if the network detects motion.

"We'll be expressing a gene in these neurons that turns into a fluorescent protein," he says. "The protein increases its fluorescence when the neuron is active, and decreases when it's not. We can then take snapshots of which neurons are active and which are not."

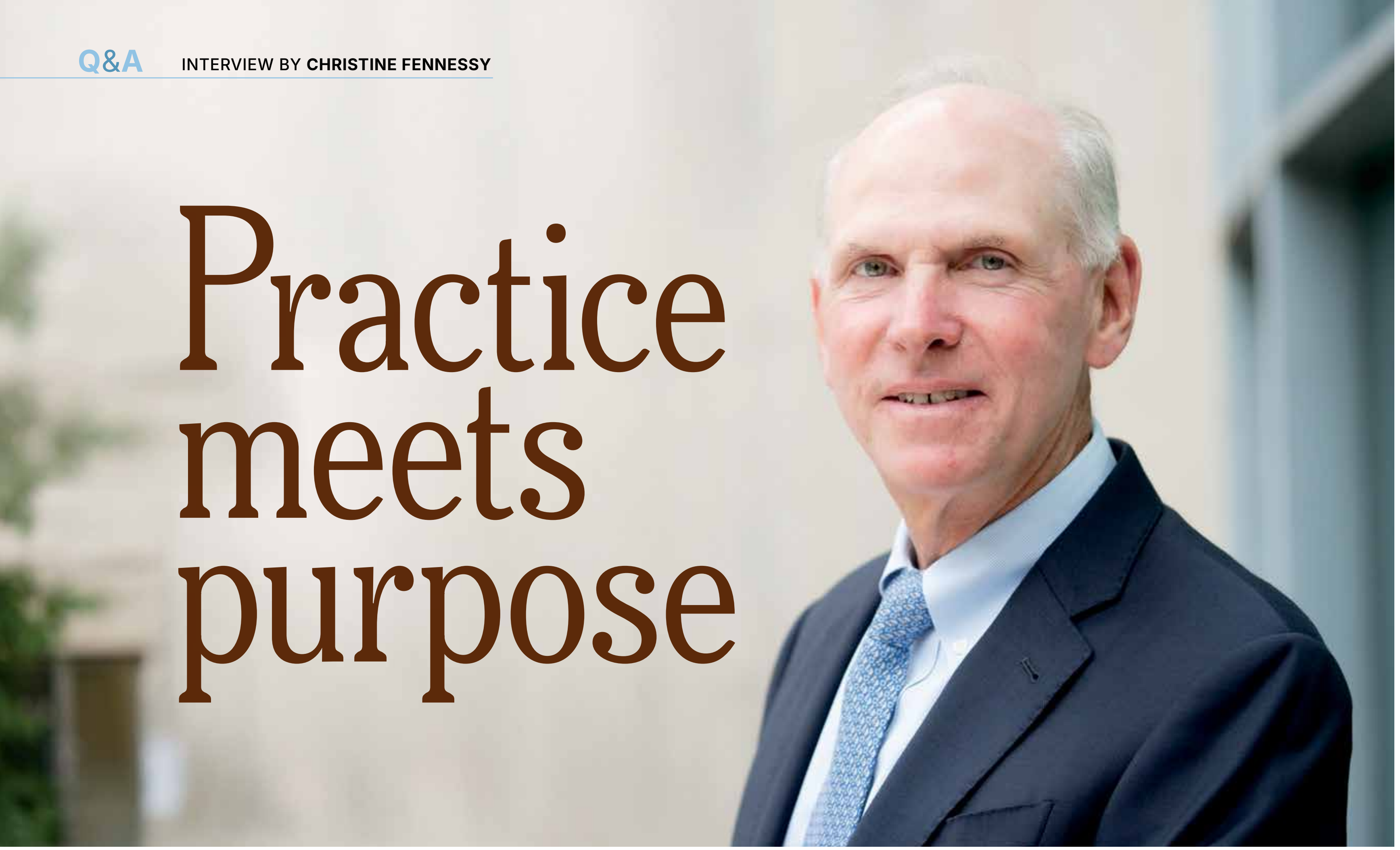
Yuntao Liu, an assistant professor of electrical and computer engineering, and Berdichevsky will then develop a decoding algorithm and a computer model to interpret these patterns. By analyzing which neurons light up, the algorithm should reveal not only what the network is perceiving, but also the speed and direction of moving objects. The computer model will help the team design learning and training protocols for the engineered organoid.



A neural organoid in a 3D-printed scaffold.

Berdichevsky and his team hope to develop a proof of concept that engineered organoids can support biological computation and to use those findings to inspire more efficient and more powerful artificial neural networks.

Ally Peabody Smith, an assistant professor in Lehigh's College of Health, will explore the ethical, social, and legal implications of utilizing brain organoids. "We don't expect these organoids to be conscious—they're far too small and simple," Berdichevsky says. "But we recognize the ethical concerns and want to demonstrate that our work stays well below any threshold of consciousness."



Practice meets purpose

Drew Freed shares his vision for hands-on learning and real-world impact in engineering education

Andrew D. "Drew" Freed '83 '17P '25P has long believed that engineering is about applying theory to real-world problems in ways that matter. As chairman and CEO of UTI Corporation, he and his team helped shape the emerging field of medical device development, producing some of the first minimally invasive surgical instruments for arthroscopy and designing intellectual property for a radiopaque stent visible under X-ray. These advances, as he puts it, "weren't earth-shattering," but they made a tangible difference for clinicians and patients alike.

That same belief has guided his philanthropy. Freed—who also served as CEO of Micro-Coax, Inc.; currently leads Freed Capital Partners, a boutique firm investing in the manufacturing of highly engineered products; and is a Lehigh Trustee—has endowed the David and Lorraine Freed Undergraduate Research Symposium, in honor of his parents, and created the Freed Family Robotics Design Studio in Wilbur Powerhouse. His two children are Lehigh Engineering alumni, and his giving supports initiatives that strengthen research and hands-on education, preparing graduates to bridge innovation with impact.

Q: What do students need most from their engineering education right now?

A: From my point of view, it's all about having the facilities—and more specifically, the equipment and the capabilities—so they can build things and learn not only what to do, but what *not* to do. We need to return to fundamental engineering skills and to understanding how to apply those skills in a hands-on way. I think higher education has gotten away from that.

As an example, in my career, I've seen recent engineering graduates, hired from all over, walk through a tool and die shop and not know the difference between a mill and a lathe. You shouldn't be able to get through engineering school as an undergraduate without knowing that difference.

Q: The Robotics Design Studio is Lehigh's newest Design Lab. What inspired you to support its creation?

A: We hired many engineers over my career, and the best were those who could combine theoretical knowledge with hands-on experience. I had been preaching that perspective to Dean [Steve] DeWeerth for a long time, and he felt the same way. The robotics gift was an extension of previous efforts to help students understand how different pieces of equipment work, and how to combine classroom knowledge with hands-on experience so they can apply those skills in the real world. And that's really what Wilbur Powerhouse is all about, right?

Now, through FYRE [see page 16] and the transformation of the first-year experience, eventually all engineering students will rotate through Wilbur. But I've already moved on from this. The real question is, what do we do next?

Freed and his family support initiatives that spark curiosity and advance student achievement.

Q: In that case, what *is* next?

A: There's a lot of work being done on the Mountaintop campus, where students are flying drones and taking the idea of fully autonomous vehicles to the next level. Advanced robotics is the next step in furthering undergraduate education and ensuring that when students graduate, they know how to use the equipment they'll encounter in industry. The fundamental mechanics behind these technologies don't change, but the automation that goes along with them changes a great deal. It's important that our students have access to those technologies.

Q: What do you want students to gain from their experiences in the Robotics Studio?

A: An undergraduate engineering education should allow you to join industry and take off running. Back in the olden days, we had all kinds of training programs, and our new engineers would spend time in different business units. It would take them a while to get up to speed. Today, technologies are changing so quickly that we need young engineers to be on their game, adaptable to emerging technologies, and immediately productive. Those are the skills and mindsets that we're instilling in the Robotics Studio.

Q: In what ways have you seen Lehigh evolve as a research university?

A: As an R1 research institution, we've hit the peak. We've come a long way, but we can't rest on our laurels. Lehigh continues to invest in new faculty and emerging specialties so we can attract the research funding that will strengthen both our graduate and undergraduate academic programs.

Q: The Undergraduate Research Symposium recently marked its 20th year. How did you get involved?

A: The symposium was the brainchild of materials science and engineering professors Himanshu Jain and Wojciech Misiolek. They wanted more undergraduates to participate in fundamental research, which is critical for developing new ideas, inventions, and applications of technology. These all come from fundamental research. Throughout my career, we took interesting research and developed practical applications for it. The symposium needed funding to grow. My parents had recently passed, and education had been extremely important to them. I was the first in our family to go to college, so it was an easy decision to have them forever be the sponsors and champions of the Undergraduate Research Symposium.

Q: What are the takeaways for symposium participants?

A: Focusing strictly on fundamental research gives students the opportunity to design novel experiments and approaches. In industry, if you're not sure something will work, it's wise to bring newer people onto the team. They don't have blinders on and aren't afraid of failure. More seasoned engineers often focus on why something won't work instead of asking how we can make it work. It's refreshing to see young engineers approaching problems this way.

At the symposium, the students present their research to a panel of very seasoned researchers. The judges ask difficult questions, and it's fun to watch the students defend their work. Some even continue their projects through graduate school.

Q: Do you see philanthropy to Lehigh as an extension of your family values?

A: I do. Lehigh took a chance on me, and I'm forever appreciative of the education and experiences I had as an undergraduate studying metallurgy and materials engineering. I don't consider myself a philanthropist, though. We're just fortunate to be in a position to help people who need it—and it's fun and rewarding. Nothing beats watching students use the tools you helped provide and seeing their excitement over their accomplishments.

With the problems in the world today, it's easy to get down on humanity. But then I go into Wilbur Powerhouse, and the students show off their Mars rover project and explain how it works, how they redesigned the wheels…In that moment, I feel a sense of hope. I'm sure what's going on in the world bothers them, too, but when they're working on these projects, they're engaged, thoughtful, and bright. It makes me think that if we work hard enough, maybe things will get better.

By funding initiatives like the Robotics Studio, we want to provide Lehigh students with the tools that can turn hope into an effective strategy to advance technology and humanity. The way the United States succeeds in the long run is by providing a high-quality education to people who really want it. We're able to help with that, in a small way.

LEFT AND CENTER: CHRISTA NEU; RIGHT: JOHN KISH IV

Powering what's next

STORY BY
CHRISTINE FENNESSY

PHOTOS BY
CHRISTA NEU

At Lehigh's Energy Research Center, researchers are pursuing many paths—making traditional energy cleaner and more efficient while advancing new technologies for a sustainable future

OPPOSITE PAGE: PETOVARGA, BK666, ADOBE/ADOBE STOCK

WHEN IT COMES TO ADDRESSING the future energy needs of the country, the best approach is a comprehensive one. The energy sector is the largest contributor to greenhouse gas emissions, but it also holds the key to get us to net-zero emissions by 2050.

"It requires all hands on deck," says Carlos Romero, a research full professor in the Department of Mechanical Engineering and Mechanics. "If we want to achieve energy independence, we need to explore innovative technologies around both renewables and fossil fuels."

As director of Lehigh's Energy Research Center (ERC), Romero currently oversees nearly two dozen projects and more than $3 million in research expenditures annually, spanning the continuum between conventional power generation and a cleaner, more sustainable, and cost-effective energy future. While renewables may seem the obvious path, Romero stresses that research on conventional power generation must continue and progress.

"The fossil fuels we are currently using, we'll be using in innovative ways," he says. "For example, putting a carbon capture system in a coal-fired power plant could potentially capture 95 percent of the carbon, and the plant could continue operating with a much lower contribution to climate-warming emissions."

Since 1972, the ERC has been on the leading edge of innovative research into solutions to national and global energy challenges and related problems. Researchers at the center collaborate with agencies at every level of government, as well as with industry leaders, technology developers and suppliers, research labs, and other academic institutions, both in the U.S. and abroad. Within Lehigh, faculty and staff collaborate on research and educational opportunities for students. In its early days, the center was dedicated to solving problems for the power generation industry. Its agenda has since evolved—and diversified.

> "You can't flip a switch on a century-old energy system.

"Today, the center also focuses on advancing cleaner, sustainable energy solutions that benefit industry and society with cost-effective technologies," says Romero. "We address complex, multidimensional problems by supporting partnerships with academic researchers, industry consortiums, energy firms, and government agencies with cutting-edge research testbeds and education. And we help society by reducing environmental impact and promoting energy independence."

The ERC is advancing the energy transition on multiple fronts, including the recovery of rare earth elements, the integration of artificial intelligence in energy systems, and the development of energy storage—what Romero calls the "holy grail" of renewable energy. They are making measurable progress, yet he stresses that achieving a sustainable energy future will take a long time. It took more than a century, after all, to get to where we are today.

"We built an entire infrastructure around fossil fuels," he says. "You can't flip a switch and say you

LEHIGH'S ENERGY RESEARCH CENTER

50+ YEARS OF ENERGY RESEARCH LEADERSHIP → **20+ ACTIVE PROJECTS** FOSSIL FUELS, RENEWABLES, ENERGY STORAGE, CRITICAL MATERIALS → **$25 MILLION** ERC RESEARCH EXPENDITURE SINCE 2018 don't want to use oil or coal or gas anymore, and just eliminate millions of miles of pipeline in the U.S. Consider the argument that many people cite for not buying electric cars: They say there aren't enough charging stations. The infrastructure for that future is nowhere near as developed, and it will take many decades and a lot of investment to make it happen."

> "Fossil fuel assets are a bridge to a sustainable future.

Acknowledging that reality, the ERC operates on both tracks by advancing technologies for fossil fuels and renewables.

"We have a large sponsor base that operates fossil fuel–based assets," he says. "We believe that those assets are a bridge to a sustainable future, and that our role should be facilitating that connection in the most environmentally responsible and efficient way possible."

With 20-plus projects underway, and many more completed, the ERC's portfolio is broad and emblematic of the creative problem-solving needed for such a monumental shift.

"Energy is an exciting field," says Romero. "And there is a huge transformation happening right in front of us—from the way we generate power to the way we harvest and store energy, and how we secure the supply chains for critical materials. At Lehigh, we're at the forefront of these critical areas."

ERC SUCCESS:
95%
REDUCTION IN POWER PLANT MERCURY EMISSIONS

Improving technologies for power generation and decarbonization

ERC researchers have long investigated ways to improve power plant operations. One path involves mitigating the emissions of mercury, a neurotoxin that can accumulate, especially in aquatic systems, and enter the food chain. ERC teams have worked on instrumentation to measure mercury levels, optimized operations to reduce its production, and developed sorbents to capture it.

"Mercury is naturally found in coal," says Romero, "which means coal-fired power plants are one of the major emission sources. But it's a difficult element to capture because it's released in very small concentrations."

The team devised a novel approach of activating anthracite coal both physically and chemically. When injected into the flue gas (the gas exiting the smokestack), it attaches to the mercury and prevents it from being released into the atmosphere. The sorbent reduced emissions by 95 percent.

In a separate project, ERC researchers characterized the physics behind the transformation process mercury goes through in a power plant, in particular, its interaction with air pollution control devices like wet scrubbers (which spray a liquid to remove sulfur dioxide from flue gas). They found that when mercury is oxidized—in this case, by reacting with elements like chlorine or bromine in the coal—it can be precipitated in the scrubber solution and more easily captured.

"The paper that came out of this work has been widely cited," says Romero. "Companies like Mitsubishi have used this study to improve their own pollution control technologies, and our work has informed and enabled industry advancements and instrument development."

Improving power plant operations is also about reducing reliance on vital resources like water.

"Power plants consume an enormous amount of water to absorb and carry away excess heat," says Sudhaker Neti, an emeritus professor of mechanical engineering and mechanics and senior scientist at the ERC.

PETOVARGA, BK666/ADOBE STOCK

RIGHT: HOLLY FASCHING '26

Typically, that process takes place in enormous hourglass-shaped structures called wet cooling towers. Hot water from the plant enters the tower, and as the water evaporates, heat is removed. Cool water collects at the bottom of the tower, while warm moist air releases into the atmosphere.

"You often see clouds on top of these towers," says Neti, "and that evaporation represents a significant loss of moisture, which, when you consider how many plants there are across the country, is very expensive from a resource perspective."

One potential solution has been the use of dry cooling towers, which channel steam in pipes. Fans then blow ambient air over the pipes to cool and condense the steam, resulting in no water loss. The problem, says Neti, is that these towers are more expensive to build and less efficient in hotter climates like in the western United States where water is an increasingly scarce resource.

"If it's 110 degrees outside, you can't cool the steam much below that," says Neti. "And that reduces the ability of the plant to efficiently generate electricity, especially in low-pressure turbines, which rely on very cool steam."

In collaboration with academic and industry researchers, an ERC team has developed a cold storage method using specialized compounds to store cool nighttime air and release it during the day to help cool steam.

"We used phase-change materials, which are substances that absorb or release heat when they change state from a solid to liquid or vice versa," he says.

At night, the (relatively) cooler air was used to freeze calcium chloride hexahydrate. As temperatures rose during the day, the material melted, which allowed it to absorb heat and keep the cooling tower operating at peak conditions. In lab experiments, the technique increases a plant's efficiency during the hours of peak energy and prevents the power generation units from being derated, which indicates a loss of power generated by the unit.

"We're not the first to think of cold storage, but we were the first to find the right medium for it that's both inexpensive and nontoxic," says Neti. "We also addressed issues around corrosion and longevity of the material to ensure it's economical. And our method could be integrated into existing dry cooling systems."

MODERNIZING POWER PLANTS

ERC teams are advancing technologies that improve efficiency, cut emissions, and support the transition to cleaner energy.

- **Employing AI and smart software to optimize coal use, improve maintenance, and enhance power plant performance**
- **Reducing pollutants beyond mercury, including nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter (PM)**
- **Developing carbon capture, utilization, and storage (CCUS) methods, such as sorbents for CO_2 capture**
- **Advancing thermal energy storage to improve power plant flexibilization**
- **Producing hydrogen from waste feedstock and solar thermal water splitting**

The Lehigh Thermal Battery prototype stores heat in concrete using embedded thermosiphons for efficient operation up to 500°C.

Innovating more reliable renewables

The holy grail of renewable energy is storage—the ability to provide reliable, consistent power when the sun won't shine and the wind won't blow. The ERC, working with support from the Department of Energy (DOE), has made a significant breakthrough in that area with an innovative Lehigh Thermal Battery, a modular thermal energy storage system built with engineered concrete.

"The way you store energy in concrete is to heat it up, and then when you want that energy, you cool the concrete," says Neti. "But concrete is a very poor conductor of heat, and so the ERC innovation was using thermosiphons, or embedding tubes that contain a fluid, which moves the energy in and out of the material."

Thermosiphons are sealed tubes (about the width of a finger and six to eight feet long) that contain a fluid that boils when heated and condenses to release heat, operating in a continuous cycle. The tubes act as superefficient thermal conductors, enabling rapid heat transfer, maintaining isothermal operation (meaning the temperature of the system remains constant), and operating independent of thermal input and output rates, which improves flexibility for varied temperature scenarios. The combination of these hybrid approaches, consisting of phase-change (liquid to vapor and back again) thermosiphons and engineered concrete is the novelty, says Neti.

> "A huge transformation is happening right in front of us.

Lab and field prototypes have shown high levels of efficiency in storing and retrieving energy. In tandem with Lehigh University, Romero and Neti have formed a company called Energy Storage Technologies to commercialize the Thermal Battery, as it has applications across the conventional and renewable energy industries.

The Lehigh Thermal Battery can store coal-plant heat produced during low-demand hours for use during peak demand. It can capture and repurpose low-grade waste heat into usable energy. And it could solve the reliability problem inherent in renewables—storing the energy for later dispatch so the lights come on, and stay on.

ERC SUCCESS: >70% EFFICIENT THERMAL ENERGY STORAGE

EXPANDING RENEWABLE OPTIONS

ERC researchers are developing solutions to make renewable energy more efficient, scalable, and reliable.

- Enhancing geothermal systems with supercritical CO_2, which improves heat transfer and enables carbon sequestration
- Using solar concentrators to generate steam for industrial processes or electricity production
- Testing multiple storage approaches: sensible heat (temperature rise), latent heat (phase change), and thermochemical reactions
- Integrating storage with existing plants, capturing excess energy during low demand and releasing it during peak demand

A powerful solar concentrator system at Lehigh supports hands-on research and testing in renewable and thermal energy.

SHAPING NEXT-GEN SOLUTIONS

ERC projects span digital tools, advanced materials, and new applications for coal.

- Building cyber-physical systems and digital twins to optimize and test industrial processes virtually
- Creating AI-based software to reduce emissions, improve efficiency, and lower maintenance costs of energy generation
- Designing advanced sensors and smart controls for systems monitoring and automation
- Repurposing coal into graphene, nanotubes, activated carbon, and electrode materials for electronics and environmental cleanup

ERC researchers use a laser-based system enhanced by machine learning to analyze material blends with greater speed and accuracy as they move along a conveyor.

Cross-cutting technologies

Waste accumulated from power generation could be a source of metals and minerals vital for electronics, batteries, vehicles, and clean energy. ERC researchers have been developing methods across three research pillars to identify rare earth elements (REEs) and other critical materials (such as lithium), and designing technologies that could extract those elements from what's known as coal combustion residuals (CCRs), the solid and liquid byproducts of energy production.

The first pillar was initiated about five years ago and employed a hydrometallurgical approach using supercritical carbon dioxide along with a solvent to extract REEs.

"This method was innovative in its application of supercritical carbon dioxide, which is a byproduct of carbon capture and sequestration, to extract REEs from waste coal and acid mine drainage," says Zheng Yao, associate director and principal research scientist at the ERC. "The process was designed as a dynamic extraction system, operating continuously rather than in discrete batch modes."

The project yielded 50 percent efficiency when it came to the recovery of REEs—meaning it captured half of what was present in the waste.

"It was an impressive result with that kind of feedstock—both the solid, meaning the waste coal, and the liquid, meaning the acid mine drainage," says Yao. "It also gave us important insights into the potential to repurpose underutilized carbon dioxide for critical material extraction, which helped inform our next two research pillars."

The second pillar is built around an ongoing project funded by DOE. The project has two goals: to characterize CCRs from several utility companies to better understand REE content; and to develop an electrodialytic filtration process to selectively separate and concentrate REEs.

In terms of the first goal, the better the team understands what's being produced by the utility companies, the better they can inform them about process changes that could yield more meaningful REE byproducts.

"Every facility is unique and burns different kinds of coal, which contain different amounts and types of REEs," he says. "Some facilities, for instance, have legacy waste. They've been generating power for decades, and every year they have millions of tons of fly ash that has to be disposed of in landfills. Right now, that's considered hazardous waste, but if we can find a reasonable amount of REEs inside it, that waste could turn into a pot of gold."

Such a discovery is only valuable if REEs can be extracted—the focus of the project's second goal, developing a filtration technique.

"Electrodialytic filtration is a physics and chemistry process that allows us to selectively concentrate or recover an element of interest," he says. "So far, we've tested three different types of membranes, and we're getting impressive results. One test got us as close as 80 percent. Imagine a single drop of red ink in a swimming pool. Our procedure could recover 80 percent of that ink."

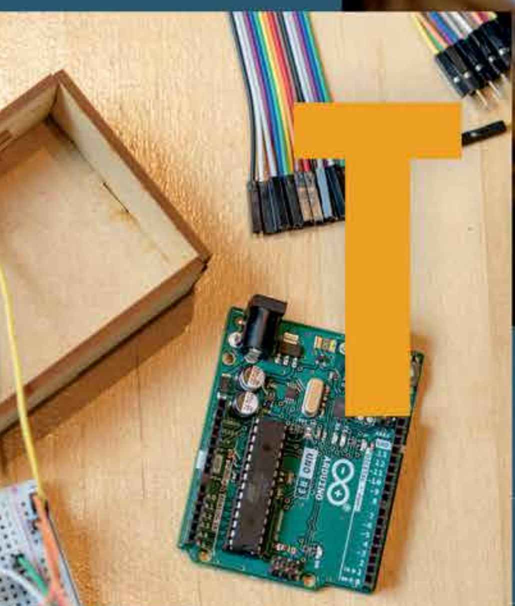
The third research pillar, still in early development, explores a new direction called electrodeposition. The process uses carbon nanotubes, rather than membranes, to capture REEs. The REEs, in solution, are directly deposited onto the surface of the nanotubes, which concentrates them into solid form.

"What's creative about our approach here is that we'll be using anthracite coal to create these nanotubes," says Yao.

The result would be circular: Waste coal is transformed into carbon nanotubes, which are then used to recover REEs from acid mine drainage or other coal-derived waste.

"Many coal suppliers near the anthracite region in northern Pennsylvania want to find more uses for anthracite beyond as a heating source," says Yao. "This could be a cost-effective approach where suppliers build a system, treat their own waste, and generate revenue."

ADOBE/ADOBE STOCK



Watch engineering faculty get hands-on in the summer FYRE workshop.

TRIAL BY FYRE

BY CHRISTINE FENNESSY

OPPOSITE PAGE: BOTTOM: KATIE KACKENMEISTER; ALL OTHERS: CHRISTA NEU

After a faculty test run this summer, students are now in the hot seat, providing insights that will shape the future of first-year engineering

This fall, a select group of students are learning how to design and build a machine—in just seven weeks.

They're participants in a pilot course that will serve as the core of the First-Year Rossin Experience (FYRE), an innovative program that re-envisions the way incoming students first engage with engineering.

In lieu of traditional courses and grades, FYRE will empower students to pursue their passions and assemble a digital portfolio of their accomplishments. They will learn how to conduct research and explore real-world problems through six collaborative, project-based learning modules focused on interdisciplinary challenges (such as building a functional machine and a working battery) that connect engineering with subjects like physics, chemistry, and calculus. They will master core engineering competencies through independent learning and mentorship. And they will engage in a yearlong, co-curricular experience—for example, joining a research lab or one of the college's competition teams, or taking part in a Creative Inquiry project—that will expose them to the range of perspectives and opportunities across the university.

It's a transformative, radical rethinking of how engineering is taught. It's also a huge undertaking.

"When FYRE is fully implemented, by the 2028 academic year, all first-year engineering students will go through it," says Derick Brown, a professor of civil and environmental engineering and associate dean of undergraduate education in the Rossin College. "This pilot phase will help us determine the best way to design these modules. Our inaugural cohort of 34 students will complete two modules this fall, with another 70 students completing two more in the spring, in addition to their regular course load, providing invaluable feedback we will use to improve our approach going forward."

The feedback—and the improvements—have already begun. This summer, at the suggestion of Stephen P. DeWeerth, the Lew and Sherry Hay Dean of Engineering, who spearheaded the FYRE initiative, nine faculty members and a handful of students participated in an accelerated, two-week workshop version of the Maker Foundations module (the first of two consecutive modules students are taking this fall). The goals were to design and build a functional machine using the same process FYRE students will experience; to introduce faculty to the equipment and resources available on campus so they could potentially incorporate them into their classes; and to gather feedback on this novel approach to teaching engineering skills.

And it is indeed novel. Although these modules teach computer-assisted design (CAD) software and how to operate hardware like laser cutters and 3D printers, they also integrate subjects like math, physics, and chemistry into the creation of a tangible product.

"When I was a young engineer in college, I struggled with calculus," says Brian Slocum, director of the Lehigh University Design Labs, who teaches the Maker Foundations module alongside Kelly Zona, manager of the Design Labs. "I never understood the point, or how it related to the real world. With all the modules we'll be using in FYRE, we want to bring in that application piece so students see the value behind the theory."

A few of the undergraduates currently taking part in the Maker module pilot had some existing knowledge of the software and hardware, math and physics, and programming involved in making a machine. But many of them knew nothing at all, which spurred excitement, but also some intimidation. For many of the faculty this summer, that's exactly how it felt.

"I was a bit overwhelmed," says Kristen Jellison, a professor of civil and environmental engineering and the college's associate dean for faculty development. "I felt like a first-year student. I came in with no knowledge of what I needed to do to build a machine. I felt confused and unprepared."

Participants built machines, like this automated water sampler created by Jellison and Perry.

Jellison paired up with Susan Perry, full teaching professor in the Department of Bioengineering and the college's assistant dean for academic affairs, over the two-week workshop. She, too, felt somewhat floored by the task before them.

"While I've asked my students to do CAD design and 3D printing and different types of fabrication, and I understand what the components do and what their capabilities are, I had no hands-on experience building a machine," says Perry. "It was eye-opening—frustrating, overwhelming, exciting, and satisfying all at once."

> "WE'RE REDEFINING WHAT ENGINEERING EDUCATION SHOULD BE—BECAUSE THE WORLD IS CHANGING." —Brian Slocum

During the first week, Slocum taught CAD, a visual thinking tool that allows the user to see complex geometries or ideas in three-dimensional space. The instructors walked through programming the laser cutter to generate prototypes of those ideas. Participants learned how to operate the 3D printer, as well as the basics of soldering, circuit design, breadboarding (a way of testing electronic circuits), and Arduino, an open-source electronics platform that allows users to create and program interactive objects.

"In week two, they tied all those concepts together as they tried to solve an engineering problem," says

"I CUT NINE VERSIONS OF THE BOX THAT HELD OUR PIPETTE BEFORE I GOT IT RIGHT. FAILURE JUST BECAME PART OF THE PROCESS." —Kristen Jellison

Slocum. "They had to come up with a design, test that design, and make their machine move in three-dimensional space and do what they wanted it to do. It was a big challenge, especially in that condensed period of time."

But it was okay to mess up, he told them, and okay to have multiple iterations in pursuit of a vision, which for Jellison and Perry was an automated water sampler.

"I cut nine versions of the box that held our pipette before I got it right," says Jellison. "Every time I printed it out, the holes were in the wrong place or the wrong size. The thickness was wrong. At first, I was uncertain and asked a lot of questions, but by the end, I felt much more confident with the design software. Failure just became part of the process."

The information in that first week came fast, with much of it delivered verbally. Participants quickly realized what type of learner they are.

"I'm not a great auditory processor," says Perry. "There was a gap between listening, watching, and doing for me. I definitely struggled, and failed, early on. Kristen made nine versions, and I couldn't even get my first box to print."

But by the final day, the duo had a working device. Their water sampler moved a pipette to a beaker of water, dropped it down, drew water into the pipette, then raised it and moved it to a collection tube where the pipette again lowered, dispensed half the volume of water in one tube, and the other half in a second tube. They programmed it to repeat the action to minimize the need for human interaction. Ultimately, they envision an automated device that could take samples over the course of a storm, drawing and dispensing every 15 minutes from a lake or river to provide insight into the composition of water over the lifetime of a storm.

"Their experience over these two weeks mimics the one that many, if not most, students will have with the Maker module," says Slocum. "There will be problems, frustrations, failures, but then these incremental successes will start to build and get them over each hurdle until they've assembled this machine they previously couldn't have imagined creating."

Slocum received valuable feedback that he's incorporating this fall. He's adjusting the pace at which he teaches CAD, and augmenting his instruction with PDFs, videos, and homework to accommodate different learning styles. The team is also adding more programming and computer science to expand project possibilities.

For Jellison and Perry, the workshop reinforced valuable perspectives on behalf of their students. For example, learning something new is hard enough, but when you layer on being away from home (often for the first time), adjusting to college life, making new friends, and balancing a heavy academic workload, stress can snowball fast. As part of her feedback, Perry suggested that faculty devise a daily method to gauge their students' comfort level with the material.

"If I know how they're feeling at the end of the day, I can adjust my delivery, pace, or other parameters," she says. "As an educator, it's my responsibility to iterate my teaching machine."

Jellison says that although she has always told her students that having trouble with something doesn't mean they're not going to make great engineers, her most challenging moments during the workshop made her realize just how important that message truly is—and how often she needs to deliver it. And so she's keeping every piece from her nine failed printing attempts in her self-described "box of frustration."

"It's going to be a talking point with my students," she says. "When they're struggling, I'm going to pull that box out and say, 'Do you see how many versions I had to print out?' That's what engineering is. You make mistakes, and that's okay. It doesn't mean you're not cut out to be an engineer. We learn from those mistakes. I knew that intellectually, but I had to experience those mistakes to remember how important that message is. And by the end of this workshop, I was really proud of what we did, and felt empowered."

For Perry, the end of the workshop brought a renewed faith in her problem-solving skills. "The challenge of finding a solution to the problem was so fun," she says. "Whether it was figuring out how to reconfigure our box, or how to create a different force pattern to brace our machine, I enjoyed evaluating the scenario, and working with my teammate and the others around us to take my ideas about a solution to reality."

Perry tapped into that reinvigorated confidence when a part on her kayak recently broke. Her friend suggested that she buy a replacement online. "I looked at the part, and thought, *I bet I can 3D print this*"—a sentiment she would not have expressed prior to the workshop.

It's exactly that kind of self-discovery that FYRE was designed to instill in students. That sense of wonder, joy, and excitement in finding a niche as an engineer. This first cohort of students will be trailblazers as they move through the four modules over this academic year. Their experience will further refine and strengthen a new approach that seeks to build the engineering mindset from day one.

"FYRE will enable our students to be better prepared when they leave Lehigh," says Slocum. "Not only will they be better learners while they're here, but they'll have greater outcomes after they leave. We're redefining engineering education because the world is changing. We have to change with it, and FYRE is our opportunity to do that."

CHRISTA NEU

MARCUS SMITH '25

Designs on the future

Interdisciplinary Capstone Design marks 30 years of shaping young engineers into collaborative, career-ready problem solvers

A team of seniors advised by Ebru Demir, an assistant professor of mechanical engineering and mechanics, will soon present their drone design to NASA representatives. It's designed for vertical takeoff, horizontal flight, and capturing aerial images to create geomaps of a given area. Potential uses include search-and-rescue in difficult terrain or providing reconnaissance to inform military operations.

The students are part of the Interdisciplinary Capstone Design experience, a two-semester industry simulation that runs from the spring of their junior year through their senior fall semester. It's one of several capstone options offered across the college.

While FYRE, the new First-Year Rossin Experience, will introduce hands-on learning at the start of the undergraduate journey, capstone serves as its pinnacle, giving upper-level students the opportunity to apply those design-and-build skills in industry-driven projects.

Interdisciplinary Capstone Design spans three departments: mechanical engineering and mechanics (MEM), materials science and engineering, and bioengineering. Undergraduates work in small teams on real-world projects sponsored by roughly 30 external industry partners. In the first semester, students focus on conceptual design—understanding the problem, gathering stakeholder input, developing project management and communication skills, and building prototypes. In the second, they fabricate and test solutions. Through it all, they collaborate with industry and academic advisors, manage budgets, and work across disciplines.

"The problems industry faces are interdisciplinary and require multiple areas of expertise," says program director Emrah Bayrak, an assistant professor in the MEM department. "Students need to learn how to work with people from different backgrounds because that's what they'll be required to do in their jobs. This capstone experience reflects and prepares them for that reality."

This model of preparation began 30 years ago with the Integrated Product Development (IPD) program. At the time, engineering design was standard in engineering curricula, but such programs typically stayed within academia and addressed academic questions, says Sabrina Jedlicka, Lehigh's deputy provost for graduate education. Jedlicka, who is also an associate professor of bioengineering and materials science and engineering, led the effort to grow IPD into a campus-wide, interdisciplinary capstone design program following the retirement of its longtime director, MEM professor John Ochs, in 2018.

"IPD filled a gap in engineering training," she says. "It embraced an interdisciplinary mindset and was driven by real-world projects with outside mentors guiding students on work that mattered to their organizations. IPD served as a model for many subsequent programs."

Over the past three decades, IPD has grown, evolved, changed names, and spawned numerous success stories in terms of university facilities, programs, and student-led startups: The Baker Institute for Entrepreneurship, Creativity and Innovation; the Innovation Lab at Wilbur Powerhouse; the master's program in Technical Entrepreneurship; and startups such as EcoTech Marine (aquarium equipment), With Meraki Co. (probiotics for vaginal health), and Tick Mitt (a reusable, tick-removing glove) all have roots that can be traced to the program.

"So many innovative ideas and ventures have come out of the Interdisciplinary Capstone Design program," says Jedlicka. "Students are leaving Lehigh with an understanding not only of the technical skills that they need to be able to do their job, but also of the business acumen and process skills needed to create things that people want with limited waste. That is the definition of a future maker."

The NASA drone team, which is also mentored by Terry Hart, a teaching full professor of mechanical engineering and mechanics and a former astronaut (pictured above, second from left)—will graduate with a wide range of skills and experiences to draw on immediately.

"The stakes are high because many of our partners rely on Lehigh for solutions," says Bayrak. "They expect our students to deliver something that works—just like in the real world. When these students interview for jobs, they constantly reference their capstone experience. They're starting their careers with confidence."

Beyond supplying valuable experience to students, he says, "Interdisciplinary Capstone Design provides added value to our industry partners by strengthening the student recruitment pipeline, as many companies participate specifically to develop relationships with Lehigh and recruit our students." –CF

DESIGN. BUILD. LAUNCH. Explore three decades of innovation in Interdisciplinary Capstone Design.

CHRISTA NEU

CRITICAL COLLABORATIONS

Research and industry partnerships led by Lehigh bioengineers could pave the way for breakthroughs in women's health

Women's health challenges often go underexplored, but Lehigh bioengineers are bringing new tools and perspectives to the field. Their work spans tissue regeneration, wearable technology, and *in vitro* modeling, opening avenues to better understand conditions that affect women's daily lives and long-term well-being. *—By Christine Fennessy*

DHRUV SESHADRI

Wearable Insights

Wearable technology can play a significant role in addressing women's health, particularly when it comes to understanding the physiological effects of their menstrual cycles. Dhruv Seshadri, an assistant professor of bioengineering, and his team have partnered with Ultrahuman, an India-based company that calls itself "the world's most comprehensive self-quantification platform," on two projects addressing areas of unmet need relating to women's health.

The first uses the company's wearable tech to understand how female athletes respond to training, and how factors such as the menstrual cycle may affect recovery and injury risk.

"There's a significant need for objective data that can ultimately be used for training optimization protocols to mitigate injuries, especially given that female athletes are two to eight times more likely to tear their anterior cruciate ligament compared with their male counterparts," says Seshadri. "To date, very little is known about the effect of menstrual cycles on injury."

To that end, Seshadri and his team, in collaboration with Ultrahuman, have equipped 13 female athletes with Ultrahuman's Ring AIR. Sensors in the device, which is worn on the index finger, gather data on sleep, heart rate, movement, skin temperature, and more. The data is collected longitudinally to help researchers identify trends, especially in relation to menstrual cycles. Lehigh researchers will analyze the data, generate models, and provide actionable insights into how athletes are responding—or not—to their training.

The team is working closely with coaches, providing concise, data-driven feedback to guide training decisions. For instance, data derived from an athlete under the dual stresses of midterms and heavy training may reveal disrupted sleep and elevated metrics such as resting heart rate that, in combination, can increase chances of soft-tissue injury. In that case, the coach may decrease the player's training intensity and/or direct them toward more rehab.

"We want to normalize conversations around women's health and give athletes data to articulate and support their subjective experiences," says Hayley Whitney '24, a PhD student in Seshadri's lab who leads the project. "We also want to give trainers and coaches the tools to support every aspect of the athlete."

Seshadri also emphasizes leveling the playing field in sports science. "A lot of research has focused on professional or elite athletes. We want to make this technology and data accessible and meaningful for everyone."

In the second project, Seshadri and his team are leading a women's health initiative in South India that blends research, education, and service to address long-held taboos around menstrual hygiene and maternal care.

With support from Lehigh's Office of International Affairs, and again in partnership with Ultrahuman, the study aims to empower young women through education and data-driven health tools. The research component targets college students and young healthcare workers—many of whom have never participated in formal research—and uses the Ring AIR to track vitals and menstrual cycles. The 22 participants will wear the ring continuously for nine months, and Seshadri's team will collect and analyze the data and educate the participants on what the results mean for their health.

"Wearable technologies have the potential to revolutionize women's health by offering continuous, real-time monitoring and enabling early intervention," says Rupa Ravi, a global and women's health consultant for the Seshadri Lab. "In maternal and pregnancy monitoring, these devices can track critical indicators such as blood sugar levels in gestational diabetes and blood pressure in hypertensive disorders, providing valuable data that can drive timely interventions and significantly improve outcomes. Beyond maternal health, wearables also empower individuals to track menstrual cycles, manage pain, and monitor symptoms related to gynecological conditions. This real-time, personalized care is especially critical in remote and low-resource settings, where healthcare access is often limited and burdened by significant barriers."

For the education component, Seshadri and Ravi co-taught a course titled *Global Health and Bioengineering for Empowering Women's Health*, which reached more than 80 individuals across two cities in South India. The sessions covered menstrual health and education, wearable technology, and the bioengineering program at Lehigh. Ravi recently presented this work at the FIGO World Congress of Gynecology and Obstetrics in South Africa.

"We wanted to assess the knowledge gaps in this field," Seshadri says. "We collected a robust data set to identify critical path elements in women's health, where engineering can help bridge the gap with current healthcare challenges. Our goal is to ultimately develop low-cost, scalable, and equitable technologies to advance women's health."

The third arm of the project focused on direct service—delivering menstrual kits that included reusable, biodegradable pads and wipes and iron-rich sweets to impoverished tribal communities facing limited access to resources, cultural stigmas, and domestic violence.

"We wanted to better understand their living conditions and thoughts on menstrual hygiene and education," he says. "We also learned that they're very interested in using wearable tech and partnering with us to develop tools that could potentially help them."

The ultimate goal, he says, is to scale the entire initiative to all of India and use it as a way to break taboos around menstruation, while developing wearables that can have a measurable impact on women's lives.

In 2026, Seshadri plans to launch a new course focused on the nexus of sustainability, equitable innovation, and digital health in collaboration with enterprise software company KGiSL in Coimbatore, India. His aim is to ensure that his lab's work stays closely aligned with the United Nations' sustainable development goals and is translated into practical solutions that improve patient outcomes.

> **"WE WANT TO MAKE THIS TECHNOLOGY AND DATA ACCESSIBLE AND MEANINGFUL FOR EVERYONE."** —Dhruv Seshadri

"I went into academia to help people," says Seshadri. "And more than ever, the world needs this type of meaningful partnership between industry and higher education."

Rossin Connection Podcast
DRIVEN BY PURPOSE
Seshadri shares his perspective on mentorship and research that matters.

TANEKA JONES

3D Modeling

She calls herself a "tissue architect." Taneka Jones is a research assistant professor in the Department of Bioengineering, and a tissue engineer by training. She is also adept at forming the kinds of partnerships that help translate groundbreaking research into real-world medical practice. It's an ability she developed as a medical science liaison where she worked with clinicians and other stakeholders to identify problems that could be addressed through industry innovation.

"Lehigh may not have a hospital directly affiliated with it," she says, "but the university is extremely interested in building capacity and building capability. External partnerships will enhance our ability to support clinical translation."

Jones recently received grant funding to help gynecologists at the University of Michigan Medical Center, in collaboration with Erica Marsh, MD, a professor of obstetrics and gynecology at U-M Medical School, develop *in vitro* models to study uterine pathology.

"Doctors will send us both healthy and diseased uterine tissues that have been extracted from patients of different ages," she says. "With my biofabrication expertise, I'll use these tissues to create tissue mimics, or 3D models, that we can then use to identify new therapies to target extracellular matrix disease as it relates to the uterus." (The extracellular matrix refers to the noncellular tissues that support a healthy tissue environment.)

One of the conditions the team is addressing is fibroids. These noncancerous growths inside the uterus can cause symptoms such as pain and heavy bleeding that can significantly degrade quality of life, and all women are at risk. Fibroids can be surgically removed, but they often grow back.

Currently, a hysterectomy is the only definitive treatment.

"We don't have a good grasp on fibroid development, and so we don't understand why they recur," says Jones. "There's a gap between what's happening at the tissue level, and what clinicians understand. I'll be using these tissues to study various time points in a woman's reproductive lifespan, and to build better *in vitro* models that will allow for earlier interventions so that a hysterectomy is no longer considered the gold standard for treatment."

ANAND RAMAMURTHI

Elastic Matrix Repair

Pelvic organ prolapse (POP) is a disorder that primarily affects older women who have experienced multiple vaginal childbirths.

Repeated vaginal deliveries can cause the muscles and connective tissue that hold the pelvic organs—the vagina, bladder, uterus, urethra, and rectum—to weaken, causing one or more of the organs to drop out of position and bulge or extrude outside the body.

"There's a breakdown and loss of the elastic matrix that contributes to tissue elasticity, similar to how a rubber band can stretch and recoil," says Anand Ramamurthi, professor and chair of the Department of Bioengineering. "In adults, those elastic fibers aren't regenerated or repaired because most of what exists in the body is produced just before or just after a woman is born."

The disorder affects approximately three to 11 percent of all women, according to the Cleveland Clinic. Although a history of multiple vaginal deliveries is the primary risk factor, others include being overweight, having connective tissue disease, and having a family history of the disease.

In addition to causing emotional stress and a degradation in quality of life, POP creates significant discomfort and pain, says Ramamurthi. "For some women in the early stages, specific exercises, called Kegel exercises, that strengthen pelvic floor muscles can help. But for those in more advanced stages, surgery is the only option."

The problem with surgery, he says, is that the mesh traditionally used to hold the organs in place is made of polypropylene materials that stimulate fibrotic thickening, or scarring, that causes pain. The FDA has since banned those polymer-based meshes, and surgeons must now rely on tissue grafts taken from the patient. However, these grafts can lead to complications, including infection, urinary retention, graft-related incontinence, pain, and recurrence of prolapse.

"So there are very few options for them," says Ramamurthi. "We want to develop a nonsurgical solution that could be applied in the early stages of POP to delay the disorder's onset and/or its progression. If we're successful in doing that, we believe that in the future, our treatment could be applied to reduce the severity of POP in patients at a more advanced stage."

Ramamurthi and his team, which includes Margot Damaser, a biomedical engineering researcher at the Cleveland Clinic, recently received an approximately $3.2 million, five-year grant from the National Institutes of Child Health and Development, with approximately half of the total funding going to Lehigh.

The team will explore a three-phase research methodology. In the first, they will use cell cultures to investigate therapies that could inhibit the breakdown of the elastic matrix.

"We've developed nanoparticles that can be used to deliver a drug called doxycycline, which inhibits the enzymes that cause the breakdown of tissue structures," he says. "We've previously

OPPOSITE PAGE: LEFT: DOUGLAS BENEDICT/ACADEMIC IMAGE; RIGHT: DON GERDA/CLEVELAND CLINIC

shown that when we deliver this drug at very small doses, it not only has anti-degradative effects, but it also regenerates the elastic matrix, which is a novel finding."

The nanoparticles themselves, Ramamurthi says, are also modified to inhibit degradative enzymes and stimulate elastic matrix production, and so act synergistically with the drug. The team will test the nanoparticles in cell cultures of non-epithelial vaginal cells from patients who underwent POP surgery.

"The purpose of the first phase is to discover novel molecular targets for therapy," he says. "We want to identify what target proteins the drugs are acting on, and if there are other targets we're not yet aware of."

> "OUR EXPERTISE LIES IN REGENERATIVE THERAPIES. WHAT WE'RE PROPOSING IS AN EXTREMELY HIGH LEVEL OF INNOVATION."
>
> —Anand Ramamurthi

In the second stage of the research, the team will test the nanoparticles on surgically extracted tissues in a long-term culture to determine if the nanoparticles improve tissue health. In the third phase, they will evaluate the treatment *in vivo*.

"We'll be using a cutting-edge mouse model," he says. "The mice are missing a specific gene, called Loxl1, which means they lack the protein required for cross-linking elastin precursor molecules into a structural matrix in adult tissues. The mouse model is unique in that mice lacking Loxl1 spontaneously develop POP after multiple vaginal births in a manner that closely evokes the clinical condition. We will deliver the nanoparticles into the vaginal wall, and we want to know: Do the nanoparticles stay in place? Do they release the drug? Where does the drug go? Does the condition improve? We will essentially be looking at how the tissue structure improves across time."

If successful, such a nonsurgical intervention could prevent or even reverse the matrix degradation that leads to POP, reduce the severity of its later stages, and potentially help younger women with POP who want to have more children.

"Despite the prevalence of POP, it's a disease without mainstream visibility," says Ramamurthi. "There are only a few research groups focusing on it, and even fewer looking into regenerative therapies. Our lab's expertise lies in regenerative therapies for elastic matrix assembly and we've been collaborating with the Damaser Lab for 10 years. What we're proposing here is an extremely high level of innovation—a nonsurgical therapeutic that could reverse the pathophysiology of disease. There are very few groups in the world capable of doing this."

IMPACT FELLOWS IN ACTION

Impact Fellowships, offered through Lehigh's Office of Creative Inquiry, are immersive programs that blend learning, research, and hands-on collaboration. Students from across disciplines work with faculty mentors and external partners to tackle complex challenges. Within the Global Social Impact Fellowship (one of five program tracks), teams have taken on projects in women's health, diagnostics, sustainability, and beyond. Here's how a few bioengineering students recently put their learning into practice globally.

"Mothers of Sierra Leone is a project dedicated to improving maternal health by promoting health-seeking behaviors through the power of storytelling. This summer, our team completed a 12-month study on rural film efficacy, conducted community interviews and surveys, and shared our teaching module films across schools and universities. We were especially thrilled to launch a six-month filmmaking workshop where local women are learning to use film to share their own maternal health experiences—in their own voices and languages." —Eileen Kandie '27

"I traveled to India to host the HDSE Leadership Intensive, a five-day program for university students to learn about humanitarian design, social innovation, and sustainable venture development. My teammates and I served as mentors to eight student-led ventures that address local challenges through creative, community-driven solutions. Guiding students through design thinking exercises, stakeholder mapping, and business model development was an incredibly rewarding experience that deepened my passion for global education and impact-driven collaboration." —Juliana Magarelli '27

"SickleED is increasing the diagnosis, education, and awareness of sickle cell disease in Sierra Leone. This summer, I worked on optimizing a low-cost, point-of-care diagnostic test. We traveled to Sierra Leone for three weeks, collaborating with local nurses, doctors, and advocacy groups to formulate educational materials and strategies to expand the knowledge of sickle cell disease in community members and health workers. Our team collected data and interviewed more than 80 people, including patients, doctors, community members, and families. The information we gathered is being used to write a research paper on the experiences and healthcare challenges faced by patients." —River Knoblauch '27

Next-gen robotics: Two paths, one shared vision

NSF CAREER award recipients Cristian-Ioan Vasile and David Saldaña are pushing autonomous systems closer to real-world reliability

In Lehigh's Autonomous and Intelligent Robotics (AIR) Lab, researchers explore how autonomous systems can better collaborate with people and each other. This year, two AIR Lab–affiliated faculty members—Cristian-Ioan Vasile and David Saldaña—earned prestigious grants from the National Science Foundation's Faculty Early Career Development (CAREER) program.

Vasile, an assistant professor of mechanical engineering and mechanics, is developing ways to assess and plan around robot capabilities, enabling teams of machines—such as self-driving vehicles, drones, and robotic assistants transforming industries from transportation and logistics to healthcare—to function safely and effectively in complex environments.

Even as advances in hardware and artificial intelligence allow these agents to perceive and reason more effectively, deploying them in dynamic, real-world settings—and getting them to do what we want—remains difficult.

"The overarching problem deals with robot capabilities," says Vasile. "Complex interactions between new hardware and new software that comes from machine learning–based approaches create new problems regarding how to use these components, like how to assign them tasks."

His NSF CAREER–funded research will develop structured methods for assessing the capabilities of learning-enabled agents and will use that information to improve the planning and coordination of robots working in teams, accounting for how performance varies depending on time, location, and situational context.

"It's not just about whether a robot has a camera or an arm," says Vasile. "We want to know if it can still operate in the dark, in a crowded space, or navigate a narrow corridor."

His approach involves three main tasks: creating a formal framework to describe and learn an agent's "capability profile"; designing planning methods that move beyond binary assumptions of capability; and detecting—and quickly recovering from—failures. Such dynamic reassessment is essential for safe, large-scale deployment of autonomous systems.

TOGETHER, THEIR WORK SHOWCASES THE BREADTH AND AMBITION OF THE AIR LAB'S CROSS-DISCIPLINARY MISSION.

The ultimate goal, says Vasile, is to enable widespread use of robots that are both efficient and effective—not to replace humans, but to augment them.

"A lot of the jobs that robots could do are ones in which there are currently worker shortages, or that are dangerous or hazardous to human health," he says. "In places where demographics are shifting and birth rates are declining, robots could potentially perform physical, strenuous work, which could free older adults to do more creative work."

Creative thinking plays a key role in Saldaña's NSF CAREER project. The assistant professor of computer science and engineering, who also leads the SwarmsLab, is taking inspiration from the natural world to design drones that can manipulate flexible objects.

"I was walking my dog and watching a squirrel jump from tree branch to tree branch," he says. "I started thinking about how quickly the animal has to adapt to the properties of each branch and to the forces generated by their movement. How could we get robots, especially aerial robots, to adapt like that?"

Saldaña is exploring how to expand the capabilities of aerial robots so they can manipulate and transport flexible objects such as cables, rods, hoses, and plastic sheets. Potential applications include construction, disaster response, and industrial automation.

Currently, aerial robots are limited to manipulating rigid objects, like boxes, because the dynamic and unpredictable forces associated with flexible materials present unique challenges.

Saldaña and his team are developing a novel methodology that integrates control systems and reinforcement learning to maintain stability, enable rapid learning, and ensure time-critical recovery.

"This integration and the ability to learn quickly means that the robot won't need to do something thousands of times before it can move one of these flexible objects," he says. "The more pieces it moves, the more efficient it becomes."

The project begins with an adaptive controller that ensures stability and provides real-time compensation for external forces without prior knowledge of an object's material properties. The controller establishes a baseline for reinforcement learning, which enables aerial robots to explore and optimize control strategies through interaction. By integrating adaptive control with reinforcement learning, the framework combines the reliability of baseline stability with the agility and efficiency of learned strategies.

"This type of integration has never been done before," says Saldaña, who also points to the potential human impact of the technology, especially in the construction of tall buildings.

In the future, drones could deliver and position cables and rods, he says, which could reduce costs and increase worker safety. Other applications might include assembling plastic sheeting over rooftops during hurricanes and manipulating fire hoses in emergencies.

The five-year grants will support Vasile (left) and Saldaña (right) as they build long-term research and education agendas.

MARCUS SMITH '25

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INNOVATING WITH FYRE

Faculty experienced the challenge of designing and building a working machine during this summer's two-week workshop.

See page 16