DUKE ENGINEERING 2024

INPUT / OUTPUT
I/O

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PURPOSE There's an old adage that you get out of an endeavor whatever you put in. But just as important as the inputs and outputs is the slash between them—the planning, the infrastructure, the programs, the relationships. We hope the content within these pages helps you not only discover a little more about Duke Engineering, but also ideas and inspiration that make your own slashes a bit bigger.

INPUT / OUTPUT

I/O

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Input/Output (I/O) is published annually by the Duke University Pratt School of Engineering

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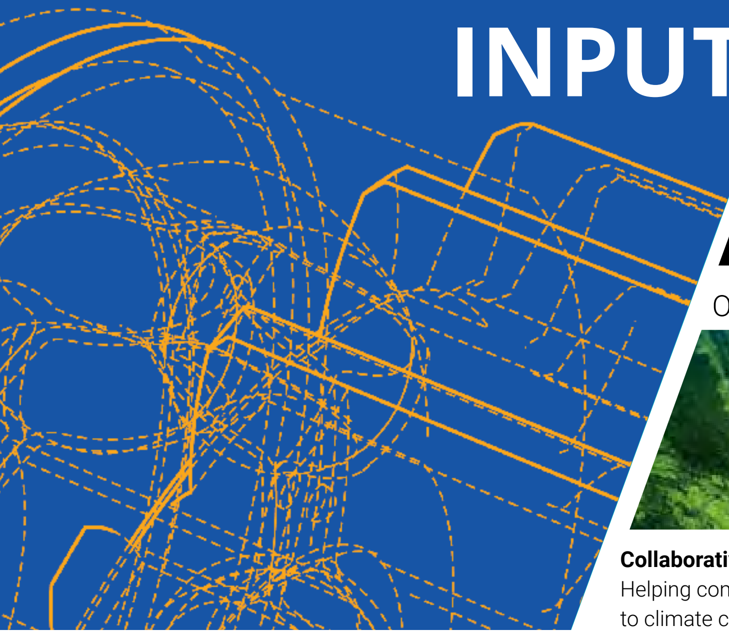

INPUT // OUTPUT Magazine

DUKE ENGINEERING **2024-2025**

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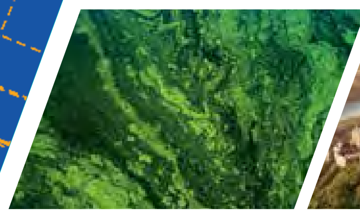

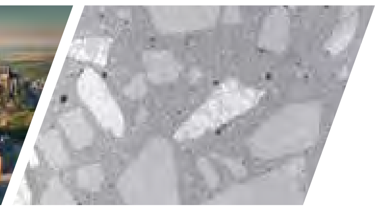

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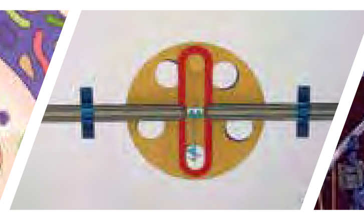

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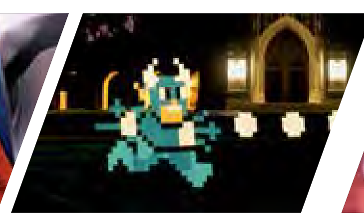


Avery Davis Lamb, who holds dual graduate degrees from Duke's Divinity School and Nicholas School of the Environment, leads an annual three-day retreat that brings together Duke climate researchers with state clergy leaders to discuss integrating climate issues into church messaging. Photo by Alex Mousan Sanchez.

Collaborative Diamonds

Form Under Pressure of Climate Change

Helping communities adapt to climate change through the Duke Climate Commitment requires engineers to work with unexpected partners | **By Ken Kingery**

AN INSURANCE SALESMAN, an engineer and a priest walk into a classroom. While that might sound like the opening line to a bad dad joke, it's exactly the type of unexpected collaboration being fostered by the Duke Climate Commitment.

Launched in September 2022, the campus-wide program is an "impact-oriented initiative to address the climate crisis by creating sustainable and equitable solutions that place society on the path toward a resilient, flourishing, carbon-neutral world."

For Duke Engineering and other STEM-focused faculty, that means going far beyond obvious climate-related research looking to reduce carbon emissions through better solar panels, batteries and carbon-capturing technologies. It also means looking beyond technical solutions to address the effects of a warmer world like advanced water resources management and coastal erosion protections. (Although Duke is working on all of these challenges, too.)

To address the wide range of impacts climate change will have on every nook and cranny of society, engineers and scientists need to move beyond technical collaborations aimed at keeping the change to a minimum. Thanks to the Climate Commitment, they're doing just that and working with new partners to help communities adapt to the unavoidable effects of climate change.

To get an idea of what that means, take a closer look at three projects that might not seem STEM-related on their face but are benefiting from these truly interdisciplinary collaborations.

RISK MANAGEMENT IN A RISKIER WORLD

It's been said that nothing ever gets done without some sort of insurance. Often cited as one of the oldest professions in the world, its history can be traced all the way back to 3,000 – 4,000 BCE. From Babylonian merchants to medieval English traders to modern corporations, the insurance industry has evolved and expanded throughout the ages. And as entire cities face new existential threats from extreme weather events occurring more frequently than ever before, insurers must find ways to mitigate their exposure to extreme losses while continuing to help communities rebuild.

"Insurance companies have a tremendous amount of computing power for climate modeling and prediction. They're doing even more than we can because of the resources they're putting into it," said Mark Borsuk, the James L. and Elizabeth M. Vincent Professor of Civil and Environmental Engineering at Duke. "What they need is new ideas and strategies that account for these challenges that can be tested at some capacity before being implemented at larger scales."

With these needs in mind, Borsuk recently launched Duke's Center for Risk Science Climate Resilience, or RESILE for short. The initiative looks to integrate data science and modeling, risk assessment and decision theory, and economic and policy analysis to develop actionable strategies to address climate risk.

Take personal property insurance, for example. As it works now, insurance is sold for an individual structure a year or two at a time, which makes incorporating the long-term risks associated with climate change impossible. That leaves insurance providers wary of taking on too much climate-related risk with only one option—backing out from coastal communities entirely. Dwindling suppliers combined with greater chances of extreme events are leading to price spikes, which many long-time residents with lower incomes can't afford.

What if, instead, property insurance was written at a neighborhood level, or even for an entire county? At these scales, financial liability risks over time and over many

Coastal communities, like Beaufort, North Carolina, shown here, must look for innovative ways to insure their infrastructure to adapt to growing risks. Photo by Avery Davis Lamb.

“**Insurance companies can’t meet together to talk about rates or they’d face collusion charges.** Having an initiative like RESILE allows us to be an impartial convener to think through these issues on a longer time scale than individual companies often do.” – **MARK BORSUK**

households could be better predicted, and communities could be incentivized to take climate resilience measures to obtain lower rates.

"This hasn't been done before, but we want to explore it because we think it has potential," Borsuk said. "It would also provide an opportunity to rethink the finance mechanisms and distributions of reimbursements, which has issues of equity around it, too."

Rather than sending out insurance adjusters to each individual home that sustains damage, Borsuk explained, predetermined payouts could be calculated for each individual home or structure based on metrics such as a river's water level or a storm's maximum sustained windspeed. Besides being more efficient, payouts would happen much more quickly. And whole neighborhoods could get a single payout to allocate in a much more informed way than insurance companies typically can.

"Insurance companies can't meet together to talk about rates or they'd face collusion charges," Borsuk noted. "Having an initiative like RESILE allows us to be an impartial convener to think through these issues on a longer time scale than individual companies often do."

The initiative kicked off this past February, when a group of experts from the insurance sector met with faculty from engineering, business, law, economics and environmental policy, as well as faculty from other schools across the country.

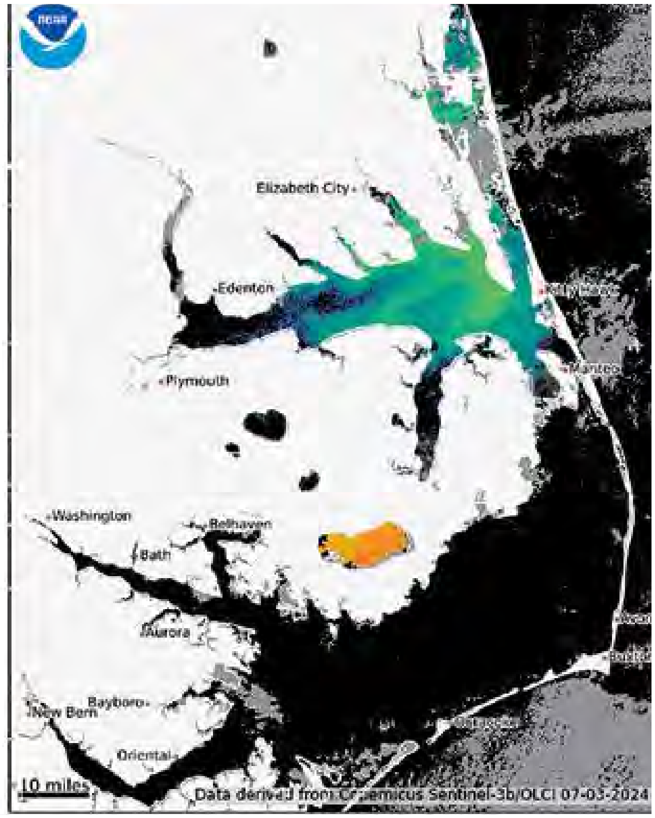
"Resilience is not simply rebuilding roads or rebuilding people's houses," said Frank Nutter, who served as president of the Reinsurance Association of America for more than three decades. "It's rebuilding the fabric of these communities."

CLIMATE CHANGE'S IMPACT ON RURAL HEALTH

It's been well established that urban areas have pockets where a lack of vegetation and permeable surfaces, along with many other factors, create "urban heat islands" where temperatures soar much higher than surrounding areas. While these heat islands often affect the residents with the fewest resources to take care of themselves, cities are beginning to put more resources toward helping their most vulnerable citizens.

But cities have resources to provide residents that rural areas usually don't. While rural communities may not experience the same heat island effects as cities, they are still being subjected to higher temperatures

(Left) Climate change is making green algal blooms much more common in certain areas of the country. (Right) A comparison of satellite images showing algal blooms at their low and high points just several days apart a few miles west of the Outer Banks.



each year. Researchers are beginning to find that this heat, combined with a lack of resources often provided by cities, is leading to mental health disparities and increased substance abuse.

"Climate change is not at the top of the list of concerns for residents of rural communities," said Devon Noonan, an associate professor in Duke University's School of Nursing. "But a growing body of literature is connecting substance abuse and mental health to heat, and heat is obviously a big issue in North Carolina."

In a new partnership with Marta Zaniolo, assistant professor of civil and environmental engineering at Duke, the team is working to see if they can use AI to predict heat thresholds that lead to an increase in overdoses and hospitalizations.

The project will start by gathering climate data like maximum daily and nightly temperatures, humidity and heat persistence as well as anonymized health data on hospital admissions and mortality data related to mental health and substance abuse. The researchers will then use advanced AI techniques to identify the climate variables that impact health outcomes the most and use them to build a bespoke model for early warning and intervention efforts.

Zaniolo has used this type of approach before for creating specific models for climate and crop failure. Issues of health outcomes, however, are obviously more complex. But the challenge is worth the effort.

"I believe that climate change and mental health are the defining challenges of our time, and the current generation of students at Duke overwhelmingly agrees," said Zaniolo. "These challenges are so encompassing that they break disciplinary silos, requiring researchers to collaborate across fields and think differently."

The researchers plan to put together a community advisory board to not only take their ideas and opinions into account when building the model, but also to translate their findings into actionable solutions for rural communities throughout eastern North Carolina.

Heat isn't the only health issue that climate change is bringing to the residents of North Carolina. It's also resulting in chronic exposures to Cyanobacterial harmful algal blooms, or CHABs for short. These blooms secrete a neurotoxin that likely contributes to the development of amyotrophic lateral sclerosis (ALS), an incurable neural disease that is more common in and around the Outer Banks than anywhere else in the state.

Armed with an array of new equipment ranging from algal bloom analyzers and high-resolution drones, a group of Duke Engineers is working with local health partners to better gauge the risks and warn communities


okout

"Climate change is not at the top of the list of concerns for residents of rural communities. But **a growing body of literature is connecting substance abuse and mental health to heat**, and heat is obviously a big issue in North Carolina." **– DEVON NOONAN**

Sarah Spiegler (NSOE CEM 2012) prepares a sailboat to take members of the Pastoral Care for Climate Change retreat out for a ride at the Duke Marine Lab. Photo by Lydia Sellers.

when blooms are at their highest. After receiving training on the new equipment, community teams will test waters where blooms have formed or are about to form based on satellite data and test for Cyanobacteria and their toxins.

"Healing estuarine ecosystems to reduce risk for neurodegenerative diseases is a paradigm shift," said Lisa Satterwhite, assistant research professor of civil and environmental engineering at Duke. "This project will empower coastal communities of eastern North Carolina to monitor their own water and build predictive models to safeguard health across the region."

PREACHING TO THE CHOIR

Growing up a Southern Baptist in Kansas, there were few people in Avery Davis Lamb's congregation who wanted to talk about the environment. But as a lover of both science and nature, he could never see the two as being separate given that nature is fundamentally God's creation.

"Maybe I'm weird, but I think it's fun to bring together environmental science and religion," said Lamb, who graduated from Duke in 2022 with dual master's degrees in divinity and environmental management.

Now the co-executive director of Creation Justice Ministries, Lamb is working with Elizabeth DeMattia, a research scientist and director of the Community Science Initiative at the Duke Marine Laboratory, and together they are connecting the two seemingly disparate professions. For the past three years, Lamb and DeMattia have connected ministry leaders with faculty from Duke's schools for divinity, the environment, public policy, business and nursing during a three-day retreat called "Pastoral Care for Climate Change." Hosted at the Duke Marine Laboratory in Beaufort, North Carolina, the event aims to discover approaches that address climate change that could empower Christian leaders to move

"**When pastors see that data**, they start to realize that what they do in terms of hospitality and community building makes a real difference, which brings more excitement toward that work. And you can tell that the scientists find emotional support from these connections as well."

— AVERY DAVIS LAMB

their congregations to action and advocacy.

"One of highlights for me is that this work recognizes the role of churches as central community spaces and how important these spaces are in energizing their members around issues of climate and justice," said DeMattia.

Each year, the experience looks to find ways to engage its participants through three key goals: connecting hope and action to give people agency; examining the role of storytelling to motivate congregations and create empathy; and developing a sense of place between people and their environments.

The scientists who attend share their research with ministry leaders, not so much to convince them that climate change is real—although that is a topic that gets a fair amount of attention—but to share information that they can take back to their congregation. "The interaction between faculty in the Divinity School and those within the STEM disciplines allows the work that we do with congregations to be practically grounded," said Wylin Wilson, assistant professor of theological ethics at Duke. "Providing hope that speaks to the practical reality of congregations gives faith leaders and congregations confidence in the continued relevance of their faith." And in at least one case, that exchange of knowledge was taken to another level. Allen Brimer, pastor at the Church of Reconciliation in Chapel Hill, NC, invited each and every

A clergy member contemplates the day's lessons at sunset (left), participants in the Pastoral Care for Climate Change retreat gather together on the shore in Beaufort, North Carolina (top right), and Avery Davis Lamb speaks to the group (bottom right). Photos by Lydia Sellers.

one of them to give the same presentation to his congregation after having heard them at the retreat in 2023.

"There was something refreshing that the numbers and data and explanations brought home for me," Brimer said. "I was struck by the straightforward numbers and explanations of the creative scientific solutions they're working on to curb these massive challenges."

But the retreat is by no means a one-way street. The faith leaders and divinity faculty are working to give the researchers something to take back with them, too—hope.

That is where the organizers believe the most meaningful experiences lie for the environmental scientists. And not some sort of blind hope rooted in mysticism, but hope that is rooted in history and religious scripts in a way that can break their cycle of focusing only on what's wrong with the world.

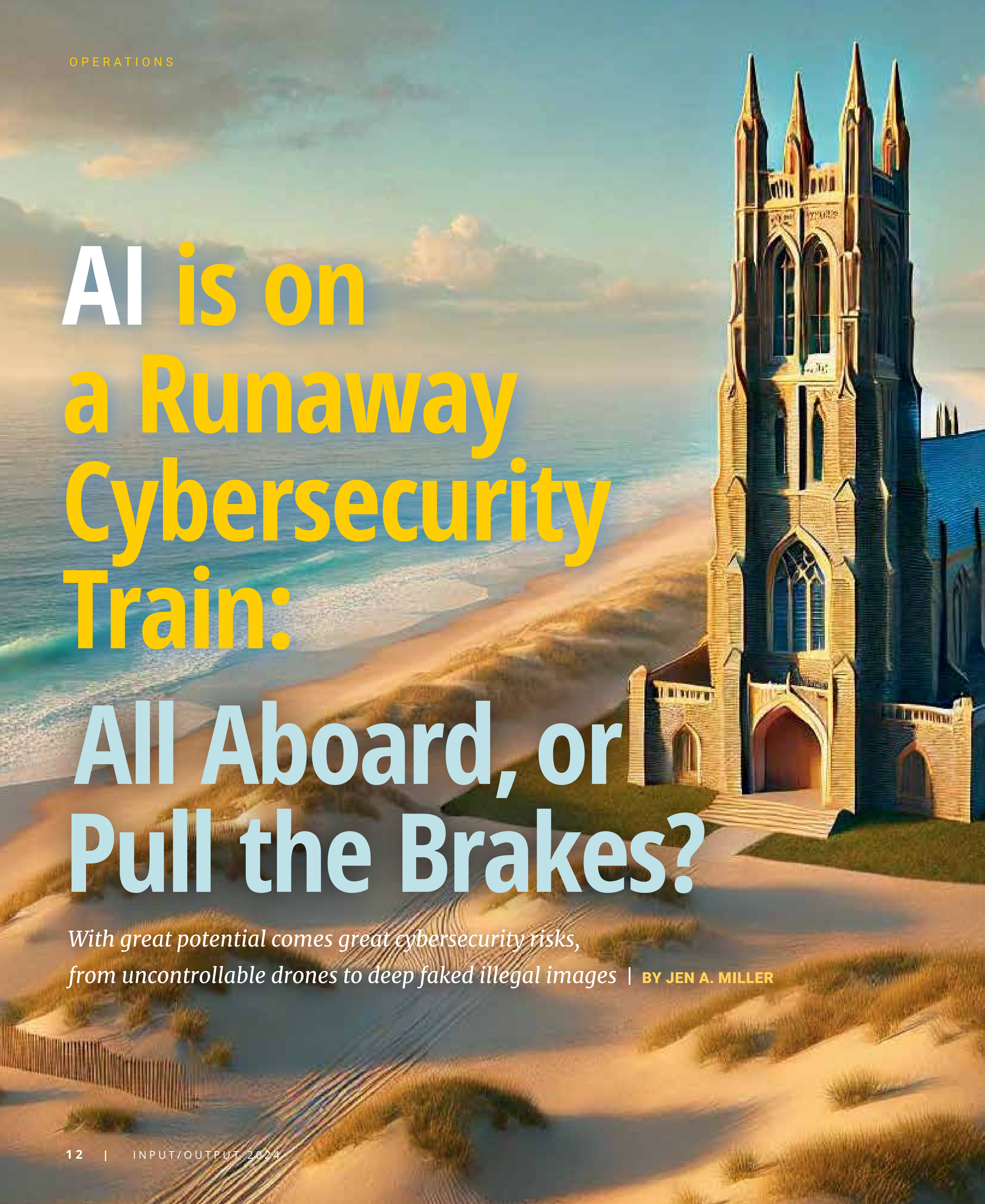
"What came up again and again was that the scientists working on the front lines were in pain, and I found myself really wanting to reach out to them," said Lisa Mullens, a transitional pastor currently at John Calvin Presbyterian Church in Salisbury, NC. "These incredible people must find ways to care for themselves because it can get lonely, and whatever we can do to encourage one another is critical."

And at the end of the day, perhaps hope is what these three-day excursions are all about. Not convincing people that climate change is real or finding new ways to present the latest climate model predictions, but connecting to each other and building communities that are resilient and reliable to one another no matter what may come.

"Pastors are encouraged by the respect that climate scientists have for the grassroots work of building social networks," said Jerusha Neal, assistant professor of homiletics at Duke. "Seeing data about the differences these communal connections make to equitable recovery efforts is deeply empowering. And scientists are encouraged to find community partners that have committed to this work over the long-haul."

Research has shown time and again that churches play a crucial role in helping communities and individuals bounce back after disasters. Whether it be a fire, hurricane or flooding, connections between people are the biggest predictors for how a group will come through a crisis.

"When pastors see that data, they start to realize that what they do in terms of hospitality and community building makes a real difference, which brings more excitement toward that work," said Lamb. "And you can tell that the scientists find emotional support from these connections as well. I feel like it's a perfect example of not just offering expertise from Duke to the community, but the community offering something back as well." ■



AI is on a Runaway Cybersecurity Train: All Aboard, or Pull the Brakes?

With great potential comes great cybersecurity risks, from uncontrollable drones to deep faked illegal images | **BY JEN A. MILLER**

DALLE artificial intelligence reimagines what the Duke Chapel might look like if it were positioned more like Mont Saint-Michel on North Carolina's Outer Banks.

WHEN CHARLEY KNEIFEL HEARD that a colleague had been training an AI to narrate video in his own voice, it gave him pause. He could easily see the benefits his colleague was after. "It's really useful if you're doing voiceovers from scripts," he said.

But this "cool" potential also raised alarms. Because while this use of AI was "good," it could also be flipped around. A cybercriminal could use the same approach to trick voice recognition systems or create a targeted phishing attack. "It's a really cool thing that bleeds over into something else."

As the chief technology officer of Duke's Office of Information Technology (OIT), Kneifel's job isn't to be the fun police when it comes to exploring the possibilities of large language models (LLMs) and generative AI. But it is his job to recognize the potential risks and threats these burgeoning technologies introduce. Spoofing someone's voice or image. Scraping terabytes of data from across the internet to perfect socially engineered attacks. Corrupting the AI itself with malicious code to return incorrect, wrong or even dangerous results.

"It's a little bit of an arms race," said Alexander Merck, an information security architect at Duke's OIT, who works with Kneifel. "We have the same tools at our disposal...and these tools are going to provide some really novel ways of handling vulnerabilities and threats."

Who will win out? It depends on how the race is run, and if legislative and legal actions will tilt AI away from the dark side.

THE PROMISE OF GENERATIVE AI, CURDLED

Turning AI into a weapon is not an idle threat. IBM's X-Force Threat Intelligence 2024 report found over 800,000 references to emerging generative AI technology on illicit and dark web forums last year. Generative AI has already been used to create politically charged deepfake images surrounding the wars in Gaza and Ukraine.

Concerns about generative AI being used to disrupt elections is also sky-high. According to Crowdstrike, a cybersecurity technology firm, more than 42% of the

Watermarks invisible to the human eye can fool AI trying to mimic an artistic style. Each row above shows two examples of a famous artist's paintings, followed by a piece created in that style by AI (left) and then a style of painting the watermark intends to fool AI into seeing instead, followed by AI's thwarted reproduction attempts (right).

> **"We're working to build more secure guardrails and more secure safety mechanisms."** — NEIL GONG

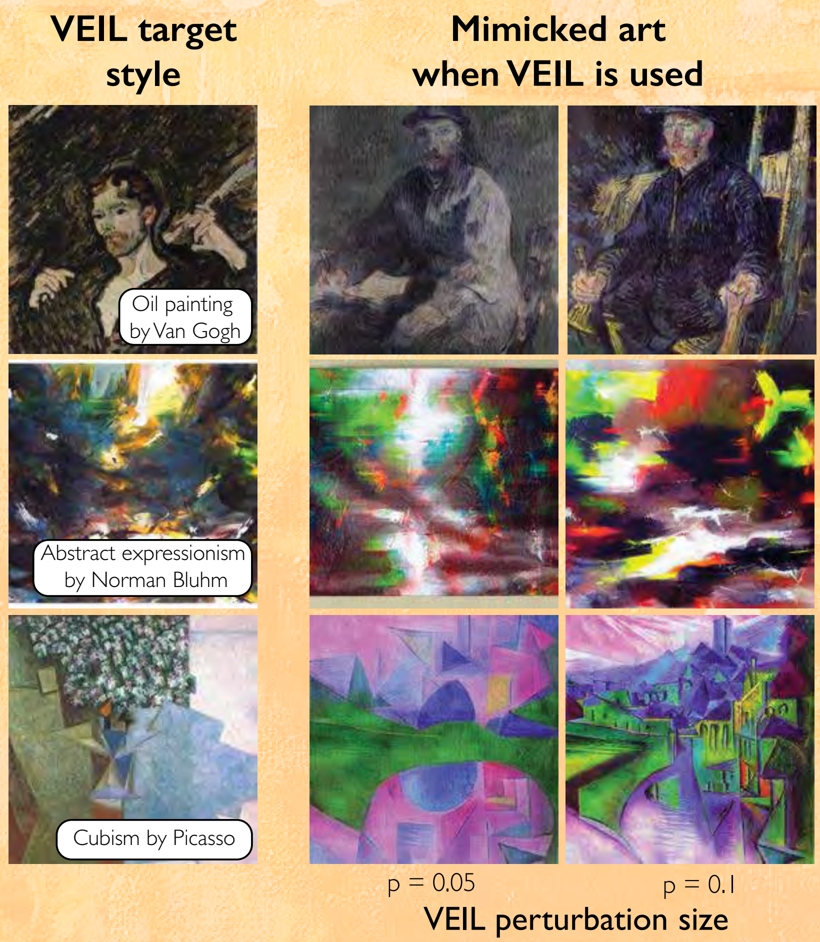
global population will be voting in presidential, parliamentary and/or general elections this year. If someone can create deepfake videos of celebrities to try to sell products, as happened to Jennifer Aniston, Taylor Swift and Selena Gomez, then what's to stop them from creating a fake video of a presidential candidate?

Or if fake videos don't scare you, how about hijacking physical AI systems to create havoc and harm on your city's streets? "With their increasing levels of autonomy, systems like cars and drones are pushing humans more and more out of the loop," said Miroslav Pajic, the Dickinson Family Associate Professor of Electrical and Computer Engineering at Duke. "Which means these systems are more vulnerable to AI attacks."

Pajic's research focuses on how these types of devices and equipment operate in contested environments, like war zones, and what kind of safety guarantees can be created. That's vital, since the radar used by autonomous vehicles or drones, including those used by the world's militaries, can be disrupted to make other objects and vehicles disappear. Connectivity can also be stopped altogether.

"I can't stop a drone for five seconds to figure out whether you are a malicious agent or not," Pajic said. "I need to figure those things out on the fly—am I hitting a house or not a real house? These kinds of real-time decisions are really important."

The good news is that these types of systems already require more robust security than standard machine learning components used to make or read



an image, for example. "But if your vehicle makes correct decisions 97% of the time and wrong ones 3% of the time, someone is probably going to get hurt," he said.

And it's not just devices that rely on machine learning to operate; Duke researchers have also shown that AI-enabled security measures can also be easily overcome. "Somewhat surprisingly, we found it's not that hard," said Michael Reiter, the James B. Duke Distinguished Professor of Computer Science and Electrical and Computer Engineering at Duke.

In a 2019 study, researchers designed eyeglass frames that enabled a wearer to impersonate someone else and were difficult to distinguish from regular eyeglasses for sale on the Internet. Some of the frames were on the more colorful side, but weren't that flashy and didn't cover a person's face—"not like crazy, big, Elton John eyeglasses," Reiter said. But even these basic frames fooled facial recognition software, creating questions as to whether or not AI-enabled biometric security is practical in real life.

While being able to hack things like cars and biometric scanners is still theoretical, AI is causing real harms right now, as it's being used to make toxic, harmful and unsafe images, said Neil Gong, assistant professor of electrical and computer engineering at Duke. For example, generative AI is creating child sex abuse materials and pornographic images of real people that are being distributed as a kind of "revenge porn." Recently, high school students in New Jersey and California were caught making and sharing nude deepfakes of their classmates.

"It's inappropriate information, some of which violates the law, and it can do tremendous harm to people's mental health," Gong said. "And as of right now, the safety mechanisms on the programs that create these images are not robust or secure enough. An attacker can slightly modify their request and the generative AI will generate harmful content."

EFFORTS TO REIGN AI BACK IN

While stopping the runaway train that is AI is not going to be an easy task, the cybersecurity world isn't just sitting idly by.

"We're working to build more secure guardrails and

more secure safety mechanisms," Gong said.

In October 2023, the White House released an executive order that includes a battery of directives aimed at reigning in AI. For example, in accordance with the Defense Production Act, developers of AI systems must share their safety test results and other critical information with the U.S. government. The National Institute of Standards and Technology has also been tasked with developing standards, tools and tests to help ensure that AI systems are safe, secure

Would Blue Devils and Tar Heels ever be friends? Only in a deepfake created by AI.

"This space still needs a lot of research, but research alone is not going to be enough. The law always comes after the new technology." — NEIL GONG

and trustworthy. Agencies that fund life-science projects are also creating standards for biological synthesis screening, to protect against the risks of using AI to engineer dangerous biological materials.

The executive order also gives directives on how AI can be used to better the life of American citizens as well as directives aimed at AI-enabled fraud, protecting Americans' privacy and keeping bias out of AI models.

Cybersecurity professionals are looking at how to use AI to create better defenses as well. "There's two sides of this coin. We're going to see attacks that are leveraging generative AI, but we're also going to get tools that leverage it ourselves," said Nick Tripp, interim chief information security officer at Duke's OIT. "Having LLMs and machine learning combing through our alerts data is going to be really important for us." That way, they can use LLMs to keep pace with the quickly accelerating number of automated attacks.

"It's a little bit of an arms race, much like everything else in security," Merck of OIT said. "There are going to be a lot of new attacks coming out of these tools, but there's also going to be some really novel ways of handling alert data or identifying vulnerabilities and threats."

LEGISLATION AND LAWSUITS

The good guys are trying to stop the bad guys from using AI, but they're starting from behind. "This space still needs a lot of research, but research alone is not going to be enough," said Gong. That means legislation. "The law always comes after the new technology," he said.

Ten states, including California, Florida, Georgia, Hawaii, Illinois, Minnesota, New York, South Dakota, Texas and Virginia, have enacted penalties for the creation and distribution of AI-generated deepfakes. Lawsuits, or at least the potential for them, are also in play.

In May, actress Scarlett Johansson threatened a lawsuit and called for legislation after she alleged OpenAI copied her voice for their ChatGPT's voice mode named "Sky." In a statement, Johansson, who voiced a computer operating system in the movie *Her*, said this happened after she told OpenAI CEO's Sam Altman no—twice—when he asked if they could use her voice.

"In a time when we are all grappling with deepfakes and the protection of our own likeness, our own work, our own identities, I believe these are questions that deserve absolute clarity. I look forward to resolution in the form of transparency and the passage of appropriate legislation to help ensure that individual rights are protected," she said in her statement.

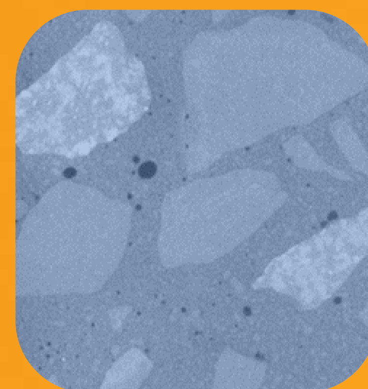
"What she's doing is not all that different than what other artists and publishers have attempted to keep their work from being used as training fodder for AI," said Emily Wenger, assistant professor of electrical and computer and engineering at Duke. For example, digital watermarking, which embeds information into images that AI will pick up, is one such tactic being used to foil AI scrapers. Wenger herself was named one of Forbes 30 Under 30 for her work on Glaze, a tool designed to protect artists from their work being sucked up by AI without their consent.

But Johansson—and other celebrities—have a much bigger platform, and are drawing attention to the real issues surrounding AI.

"Maybe now that a very big name is caught in this net, more resources will be devoted to figuring out proper legislation or guidelines," Wenger said. "It feels a little like how fake porn has been a problem ever since deepfakes got somewhat believable...but it took Taylor Swift being targeted for the world to realize how big the problem really was."

Like with other new technologies, AI isn't all good or all bad, but people making decisions about how to use them will ultimately determine how they become woven into our daily lives. "We have the balancing act," said Kneifel of OIT. "We have to help [people] make deliberate choices, I don't want to say in an easy fashion, but at least understanding the tradeoffs." ■

Engineering the Acceptance of Climate Change **Solutions**



No matter how clean our technologies become, people must be persuaded to use them to make a difference

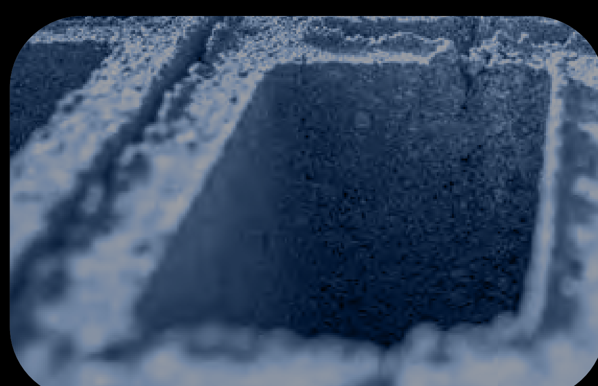
By JEN A. MILLER

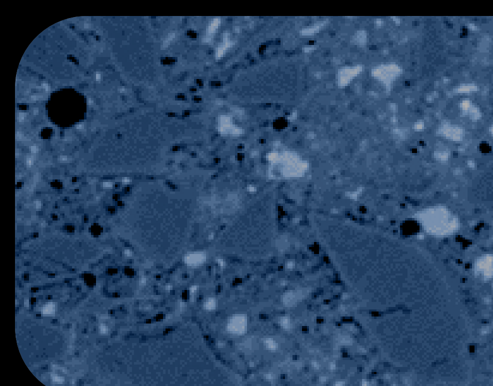
OUR BUILDINGS ARE FILTHY—and not just in terms of whether they're tidied by cleaning crews or not. According to the UN's Global Status Report for Building and Construction, energy demand and emissions from the building and construction sector make up 20% of global emissions. In 2022, these divisions accounted for 37% of global operational energy and process-related emissions. Energy consumption also reached 132 exajoules, which accounts for more than a third of global demand.

Its carbon footprint is still growing, too. While a one percent increase from 2021 to 2022 may seem small, that one percent is equal to 10 million more cars circling the Earth's equator, according to the UN's report.

Changing how we build things is just one challenge when it comes to addressing a climate-changed world. Not only are some of the most commonly used materials CO2 belchers, but getting people on board with emerging technologies may be an even harder feat than engineering the new solutions.

Concrete itself may be a solid material, but it's also a lens through which we can view the myriad of challenges facing society's ability to adapt to climate change.





"For a lot of engineers, the job is just to do the design. You're not supposed to ask questions. You do your design and you walk away. We can't operate that way."

— SARA OLIVER

Concrete manufacturing facilities (top right) are terrible for the environment, using up enormous amounts of fossil fuels and emitting carbon dioxide to sustain our cities' ever-expanding footprints (left).

A CARBON-HEAVY, POPULAR BUILDING MATERIAL

In many ways, concrete is an ideal building material. It's cheap to make, easy to use, durable against intense weather and fire, and can be drummed up just about anywhere. With more than 30 billion tons of concrete consumed each year, it's one of the world's most popular building materials for a reason. It just works.

It's also become an environmental disaster. About 8% of human-caused global CO_2 emissions come from concrete production, according to a report from the Royal Institute of International Affairs. Beyond its production, there's also transportation energy required, as it is often prefabricated off site. And outside of energy concerns, concrete production also takes up an estimated 10% of industrial water use.

Laura Dalton, assistant professor of civil and environmental engineering at Duke, doesn't like to call concrete "dirty" because, she said, "Technically speaking, it's extremely sustainable. The issue is that we produce so much of it. Anything produced at that large of a scale is going to have some footprint associated with it."

Concrete is made by cooking limestone and clay to 1450 degrees Celsius (2640 degrees Fahrenheit), a temperature that requires burning a massive amount of fossil fuels. Building large structures with concrete also usually requires the use of rebar, typically made from steel, to reinforce it. Steel also has a "really terrible CO_2 footprint," Dalton added.

But unlike concrete itself, the ways in which we produce it and the ingredients we use are not set in stone. Progress on these fronts is being made, and if a solution is created—and widely adopted—it could allow our society's ever-expanding physical footprint to leave behind a much smaller environmental one.

ENGINEERING A BETTER CONCRETE SOLUTION

Research into how to cope with concrete-related carbon is moving in several different directions, Dalton said. One is accelerated carbonation. Buildings will naturally sequester carbon over time, but it's a slow process, and a building may only suck back in about 10% of what was put out to make it. Companies like Mutual Materials have created a process where CO_2 is injected back into fresh concrete, where it's converted into a solid mineral. The process both gets rid of CO_2 and makes concrete materials stronger.

Another approach is to make the ingredients used in concrete greener. Research teams are working on making "living cement materials," where algae creates the limestone used in concrete through a

"You can only replace so many ingredients and still get a useable product." — LAURA DALTON

process similar to how coral grows its own limestone-like exoskeleton. Scientists have also been experimenting with other supplementary materials that can be put into concrete, including fly ash, which is a byproduct from burning coal. This line of research is not new, Dalton said, but it has its limits. "You can only replace so many ingredients and still get a useable product," she said.

While these lines of research are helpful, in her opinion, the most promising work is coming out of two start-ups: Sublime Systems, which started at MIT; and Brimstone, which grew out of Caltech. "They're getting at the source of the problem," Dalton said.

They're doing so by disrupting it. Right now, cement is typically made by mining materials like limestone, clay and gypsum, and then grinding it up in to a fine powder. It's then heated to 1450 degrees Celcius in a cement kiln to break down the material's chemical bonds to create new compounds. The new material, called clinker, is then ground down again, mixed with gypsum, and voilà: you have portland cement.

Both Sublime Systems's and Brimstone's tactic is to make cement with calcium-rich rocks instead of limestone, which accounts for 60% of the CO_2 from making portland cement. This removes the primary source of carbon from the problem. Sublime Systems takes this a step further by using an electric chemical process to break and reform those bonds, skipping the need for a kiln altogether and removing the remaining source of the CO_2 problem.

Some new technologies that have been developed to address climate change, like solar panels and electric cars, are becoming commonplace. But better concrete, and other decarbonized building materials, are not yet at that tipping point, said Dalton. Both Sublime Systems and Brimstone are relatively young start-ups and have not yet reached commercial success. "That's really going to come back to policy and a point where economic considerations will have to give way to environmental ones," she said.

THE CHALLENGE OF IMPLEMENTING CHANGE

Even when an alternative, greener product works, not everyone jumps on board to adopt it. That's an especially tricky issue with concrete. When something has worked just fine for a long period of time, it's hard to see a reason to switch things up.

"We as people are used to doing things the way we do them," said Sara Oliver, director of Duke's Climate and Sustainability Engineering Master's Program. When it comes to infrastructure, especially big structures like bridges and buildings, "people are used to seeing them look a

certain way." Why would someone change if it's been working, especially when it's what people feel comfortable and safe with?

Part of the problem is that engineers tend to be siloed off into their own entities instead of mixing with and collaborating with other experts—and, in many cases, their end users. One of Oliver's first jobs as an engineer was working on a highway project being designed using decades-old traffic data. When she pointed this out, she was told that wasn't her job and to focus on her task only. "For a lot of engineers, the job is just to do the design. You're not supposed to ask questions. You do your design and you walk away," she said.

When it comes to climate and sustainability, however, "we can't operate that way," Oliver added. The end user, whether it's a government contractor looking to use decarbonized concrete or an ocean-front community that's being told the federal government is going to build a seawall, must be part of the conversation. Decarbonized concrete may be as strong or even stronger than what's being used right now, but that doesn't mean people will believe statistics in a report; because if the old way works, why take the risk? "You need to bring those people along. You need to understand what their priorities and needs are when determining the risk profile as you're designing a solution," she said.

THE STUBBORNNESS OF CHANGE

Getting large groups of people on board with change will always be a challenge, especially as such issues are often pulled into muddy political waters. When New York banned pollution-spewing natural gas stoves in most new construction homes and buildings, the backlash was so strong that similar projects in other states failed. And other states went even further, passing bans on such ultimatums, including Florida, where 92% of homes already had electric ovens anyway, according to the U.S. Energy Information Administration.

While some of this pushback against climate change solutions is rooted in politics, a lot of

Exeter Great Dam in Exeter, New Hampshire before the dam's removal (2002) and after its removal in 2016. Credit: NOAA.

it comes from a fundamental fear of change, the unknown and what's involved in making big moves. "It's thinking through how many current practices do you have to change to incorporate the new one?" said Rick Larrick, the Hanes Corporate Foundation Professor at the Duke Fuqua School of Business.

"If all your current systems are organized to make this way of doing something work, sticking in something new is not as simple as it seems," he said. "That becomes a very rational reason why people are slow to adopt to what seems to be, on the surface, a really good new way of doing things. But there are real costs of transitioning and integrating."

Government investment can help, as is happening in building and construction, including in concrete. In the U.S., federal, state and local governments buy about half the concrete cast and poured. "Buy Clean" programs led by the federal government and 12 state governments are designed to use purchasing power to give a boost to cleaner and less carbon-intensive building materials and processes. The 2021 Infrastructure Investment and Jobs Act also earmarked $97 billion in funding to the U.S. Department of Energy to expand its existing pathways while also creating new ones for federal investments in research and development, demonstration, and deployment programs.

Putting money behind these efforts helps, as does redefining what the cost of carbon actually means. European countries have been pushing ahead with concrete alternatives, including 3D printed concrete. In February, a 6,600 sq.-ft, 3D-printed data center opened in Germany, the largest 3D-printed building in Europe so far. That's possible in part because of how they value—or devalue—carbon, said Larrick. "They put a higher price on carbon," which makes reducing its production more financially justifiable. "There's also a basic desire to show that you're acting on values shared by your voters and consumers," he added, which is part of the "cost" to speed up a transition.

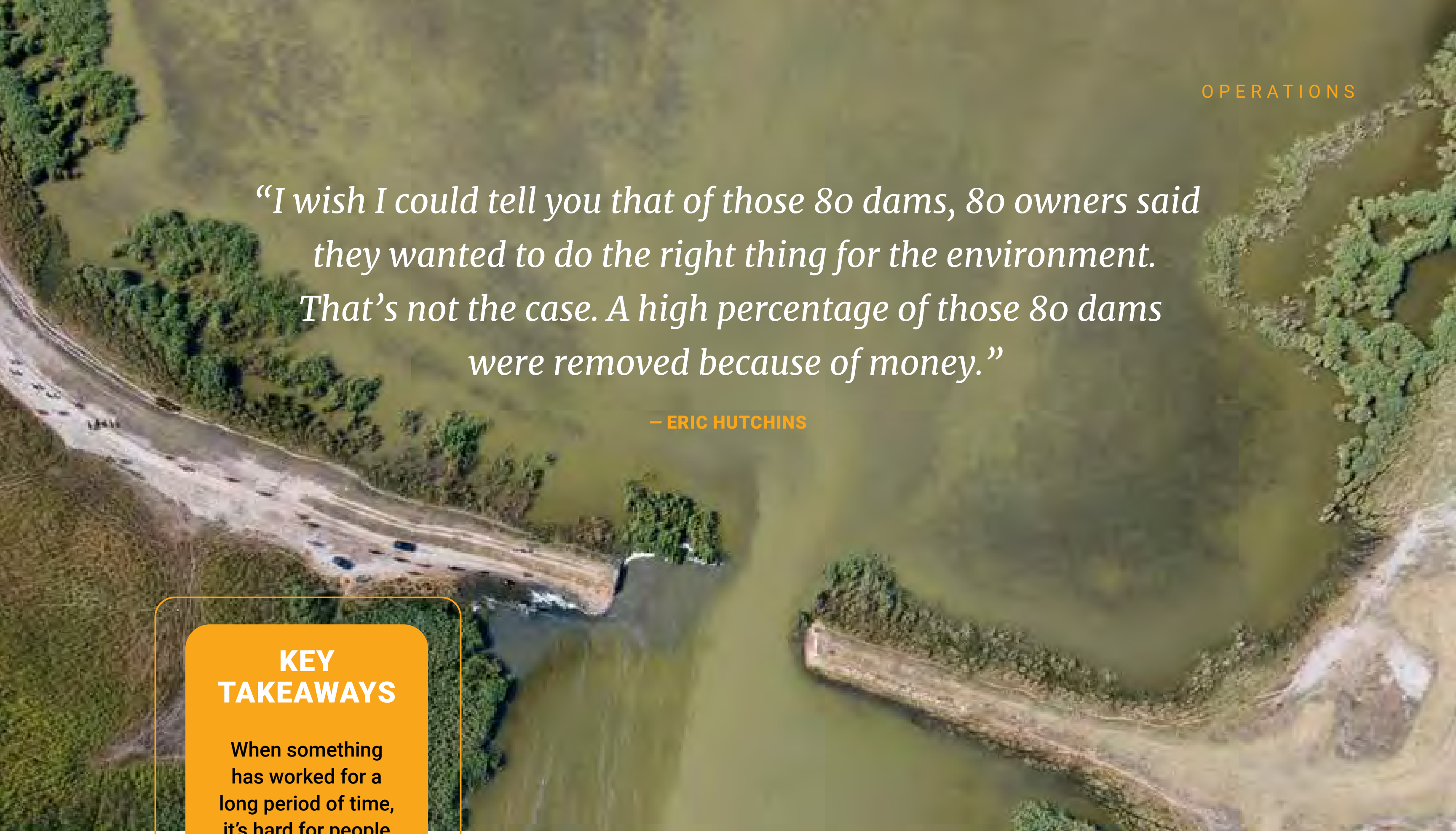
INCENTIVIZING COMMUNITY MEMBERS TO ENACT CHANGE

Getting people to accept change, especially when it comes to climate, is difficult, but it has been working in one sector: dams, and the removal of them. What were once usually built for power, sometimes for small mills that no longer exist, are now dangerously falling apart and damaging fish populations and river health.

In 2023, 80 dams came down across the country, according to American Rivers. Overall, 1,160 miles of river have been reconnected for the benefit of river fish and wildlife.

That doesn't mean everyone in these communities just hopped on board. Eric Hutchins, fisheries biologist at the NOAA Restoration Center, has been working on dam removal projects for nearly 40 years. "They all balk," he said, of every municipality he's approached about taking down their dam.

Part of that is inertia. Most often, dam removal



> *"I wish I could tell you that of those 80 dams, 80 owners said they wanted to do the right thing for the environment. That's not the case. A high percentage of those 80 dams were removed because of money."*
>
> **— ERIC HUTCHINS**

Aerial view of the Cogîlnic River in Ukraine after it was freed from its dams.

KEY TAKEAWAYS

- When something has worked for a long period of time, it's hard for people to see a reason to switch things up
- Understand users' priorities and needs to determine the risk profile of the solution you are designing
- Large-scale changes often require government intervention in either law or finance (or both)
- Working with local communities to understand benefits can help move the needle

wasn't on a community's radar. "In most towns, they're just kind of like a curb on the side of the road," he said. "Until there's an issue, it's not an issue," like when someone drowns or the dam is due for a costly repair.

When working with a community, Hutchins starts by striving to understand their feelings about the dam. "I respect that they like a dam socially and functionally in their memory," he said. "Ecologically, I know that a free-flowing river is nicer, but there's a lot of value in a pond behind my house."

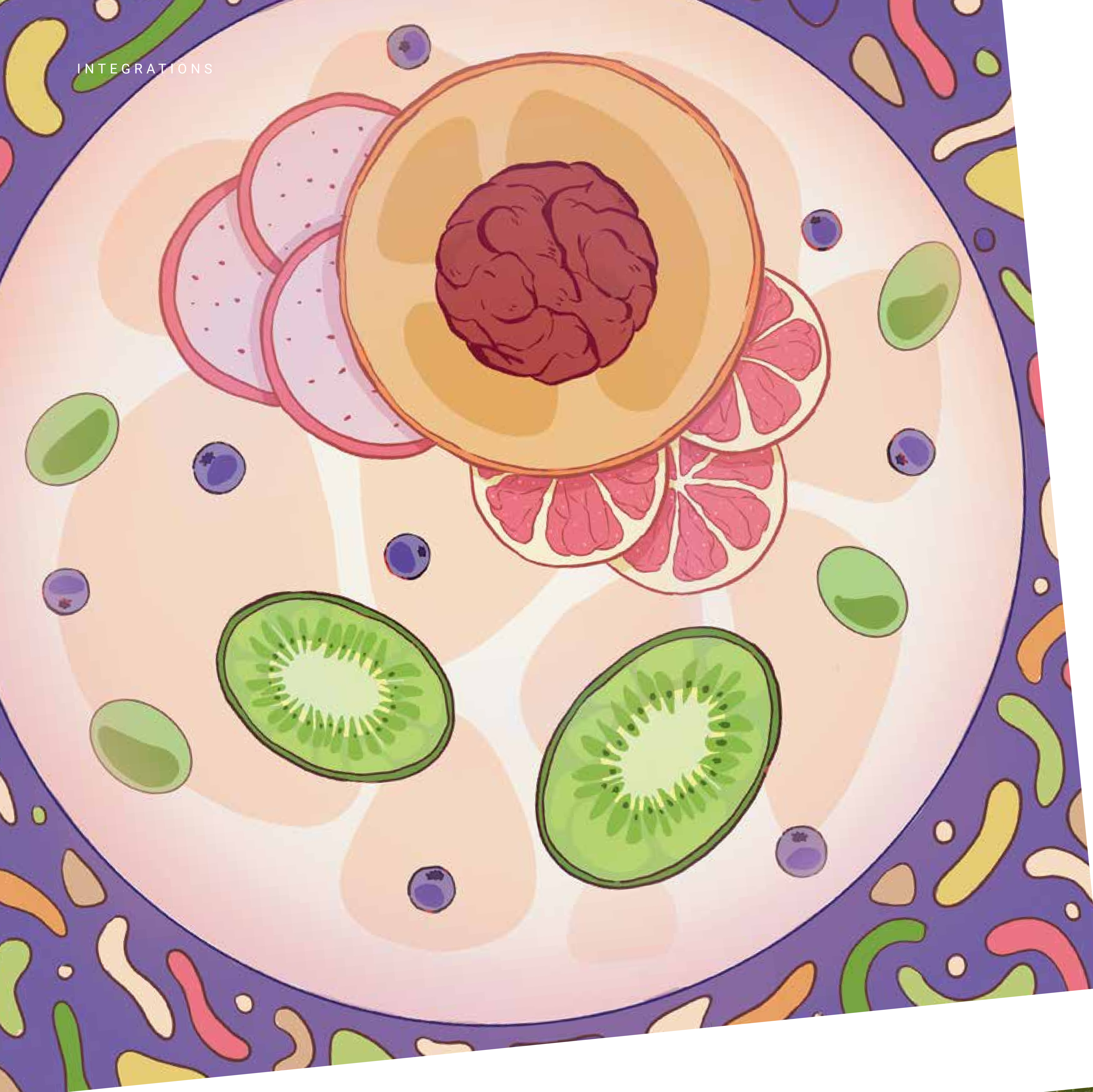
He then looks for common ground in these values and what a dam removal project would mean. "You may have better fishing here in your river, nobody will die anymore due to safety issues, and there won't be flooding around the dam," he said.

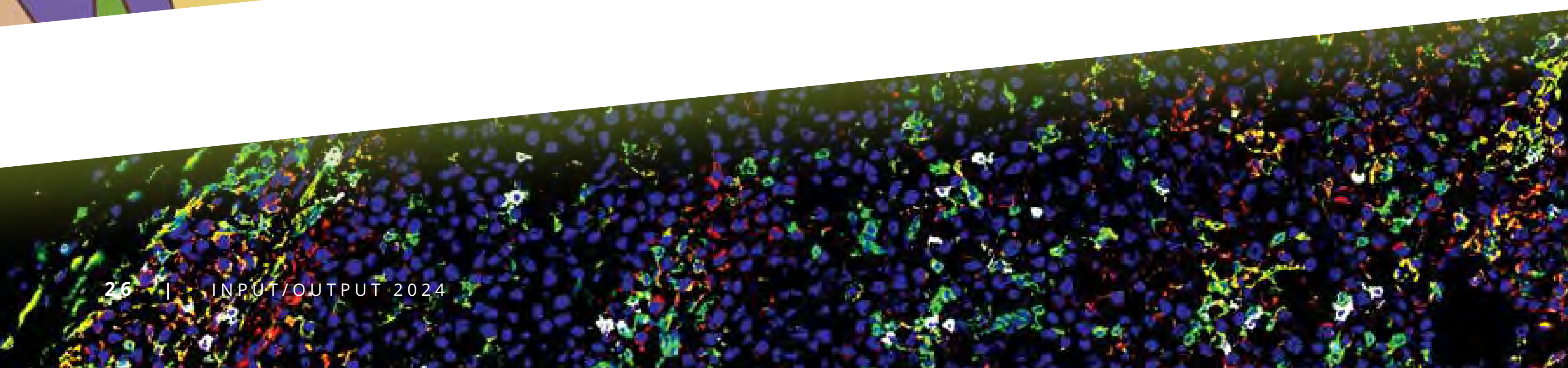
As important as this work is, the financial aspect is what usually pushes towns forward when a structure is deemed unsafe and would need millions of dollars to repair and maintain. "I wish I could tell you that of those 80 dams, 80 owners said they wanted to do the right thing for the environment. That's not the case," he said. "A high percentage of those 80 dams were removed because of money."

In his time working for NOAA, he's seen minds change as the effects of climate change become more apparent, prompting people to try something new, even if it feels uncomfortable—even if it still seems harder to make a change than stand pat.

The combined forces of finance and environmental justice could move the needle for building methods and materials, even if the financial part needs to take a bigger role, as it has for dam removal and the uptick in adoption of other technologies like solar panels, e-bikes and electric cars. Someone who doesn't "believe" in climate change might make the switch if it's just cheaper to do so.

"When I define sustainability, it's a balance among equitable, environmental and economical practices," said Dalton. "That's how you really get at solving a global problem." ■



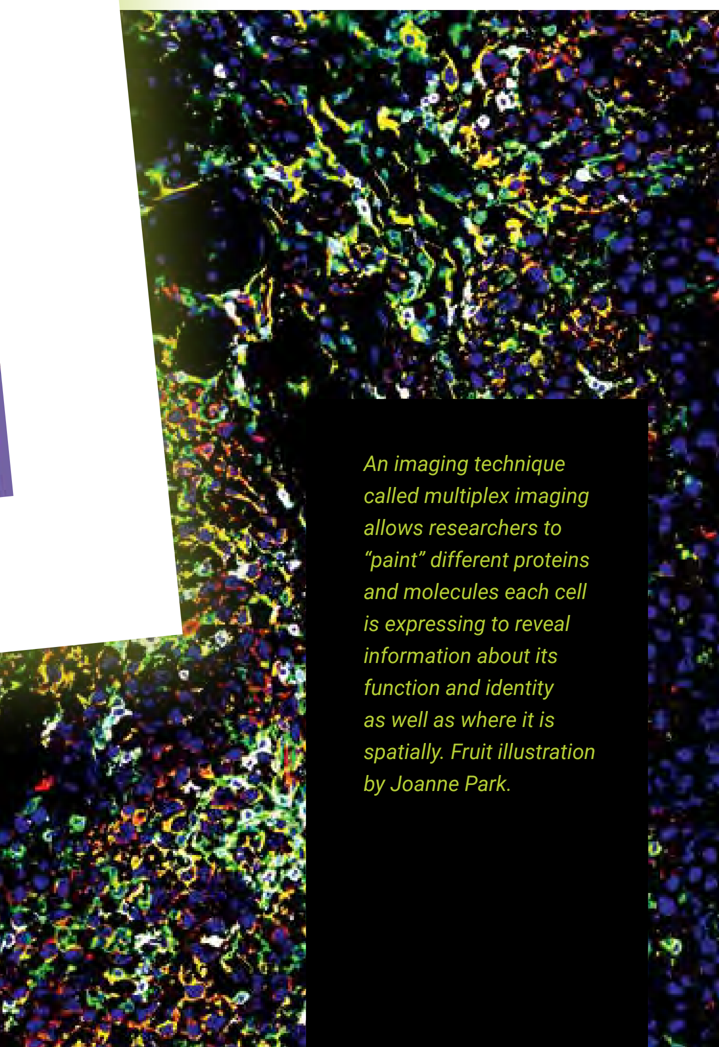


A Genomic Medicine Story

(With Only a Little CRISPR)

While the Nobel-winning genome-editing technology CRISPR holds great promise, Duke's Center for Advanced Genomic Technologies is putting some eggs in other baskets

By ALISSA KOCER



An imaging technique called multiplex imaging allows researchers to "paint" different proteins and molecules each cell is expressing to reveal information about its function and identity as well as where it is spatially. Fruit illustration by Joanne Park.

GENOMIC TECHNOLOGIES are transforming our understanding of biology and medicine, enabling the precise manipulation and comprehensive analysis of genetic material. Duke University is investing in the development and use of genomic technologies through the Center for Advanced Genomic Technologies (CAGT), supported by the Pratt School of Engineering, the Trinity School of Arts & Sciences, and the Duke University School of Medicine.

CAGT launched in the fall of 2019. Under the direction of Charles Gersbach, the John W. Strohbehn Distinguished Professor of Biomedical Engineering, it is focused on developing and applying cutting-edge genomic technologies to address critical biomedical questions and advance human health.

Perhaps the best known of these genomic technologies is CRISPR, which, in the last 12 years, has been revolutionary for both biomedical research and medicine and has shown promise in helping to treat and potentially even cure a wide range of genetic disorders, such as cystic fibrosis, sickle cell anemia, muscular dystrophy and more.

CRISPR's discovery, though, is just the beginning of a field that continues to expand. "There is a misconception that CRISPR is transformative because of gene editing. While that is true, it's potential is much wider," Gersbach said. "CRISPR is transformative because of the ability to precisely target these molecular machines to specific regions of the genome. Gene editing is one basic operation these machines can perform on our genome, but there are many other ways to control genome structure and function that CRISPR technology enables."

CAGT focuses its efforts on epigenomics of disease, gene regulation, drug responses to gene regulation, genome engineering technologies, and genome structure and function. While CRISPR gets a lot of attention, it is only one of many genomic technologies the center is pursuing in the hopes of speeding up science innovation and pushing the boundaries of what is possible to revolutionize the way we treat multiple conditions, including cancer.

Although their approaches are different, John Hickey and Emma Chory, both assistant professors of biomedical engineering at Duke, have a common goal: develop better, more effective ways to deliver chimeric antigen receptor (CAR) T-cell therapy using genomic technologies.

CAR T-cell therapy isn't a new idea. It's a way to use a person's own T cells—a type of white blood cell—to fight cancer by changing them in the lab so they can find and destroy cancer cells. However, it doesn't work for all people or all types of tumors. For example, CAR T-cell therapy works best in liquid tumors, like leukemias, while solid tumors like sarcomas, carcinomas and lymphomas are harder to penetrate, making CAR T therapy less responsive.

A PICTURE IS WORTH A THOUSAND DATA POINTS

Hickey is using spatial relationships and computational strategies to better understand how solid tumors are organized so he can figure out better ways to attack them.

Using an imaging technique called multiplex imaging, Hickey can add DNA barcodes to antibodies that recognize specific molecules. This allows him to make as many unique combinations of DNA barcodes as needed, and

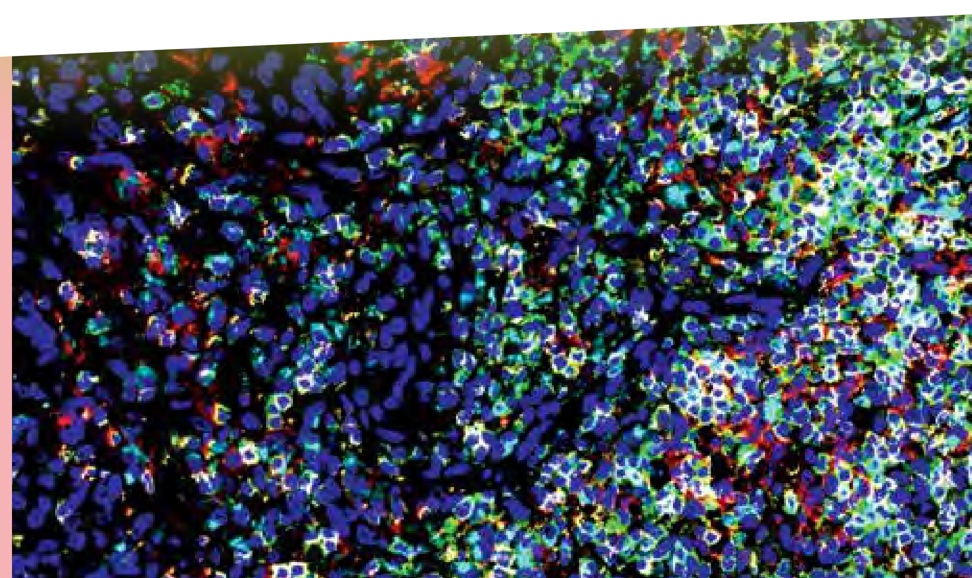
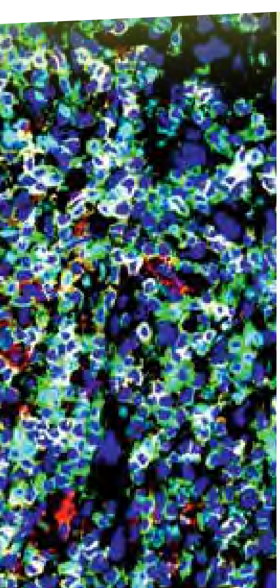


Illustration by Joanne Park.

> "But essentially, what that's doing is taking a beautiful fruit platter, throwing it all together and getting a fruit smoothie." **— JOHN HICKEY**



the antibodies act as a paint to differentiate as many proteins and molecules each cell is expressing as needed, which can provide information about its function and identity as well as where it is spatially.

Previously, researchers could only take cells, mash them up, harvest the RNA or DNA, and sequence it. "But essentially, what that's doing," Hickey said, "is taking a beautiful fruit platter, throwing it all together and getting a fruit smoothie." When single cell technology came along, they were able to isolate each cell and characterize it, like isolating a piece of fruit on that fruit platter. What Hickey can do, though, is look at the fruit platter, see what fruit is next to what, and gain a better understanding of the relationships between the fruit.

Then, using computational methods, Hickey can figure out the relationships between cells at different scales, like protein-protein or cell-cell interactions.

Recently, the Hickey lab used two different cell therapies in a mouse model with solid tumors. When they took the tumors out, they wanted to see why one cell therapy worked better than another. "What we found was that both cell therapies created similar cell proportions," Hickey said. "The number of cells was relatively similar, but the organization of the tumors was different."

In the cell therapy that worked well, the T-cells were able to get into the tumor and cause tumor inflammation, which stopped the tumor from growing. It also secreted inflammatory cytokines that recruited other immune cells close to them to create a boundary around the tumor. And while there are still some questions to be answered, Hickey said that it appeared that the T-cells were fighting for a while, then leaving to rest before returning. "It provides a large environment to improve tumor killing," he said.

The other tumor, with the less effective therapy, didn't have large areas of immune cells next to them and were more broken up. T-cells also created both anti-inflammatory and inflammatory molecules, which was less effective. Without Hickey's technology, he would not have been able to see the spatial relationships nor determine why one treatment worked better than the other.

SPEEDING UP EVOLUTION

Emma Chory's research takes a slightly different approach: integrating robotics with evolutionary biology.

Chory uses protein engineering to develop drugs, understand how genetic elements work, and answer basic questions about evolution and the genetic underpinnings of cancer.

"Cancer is the biggest gene regulatory question that encompasses the three main focuses of our lab: therapeutics, genetic elements and understanding evolution," Chory said. "Fundamentally, cancer consists of cells that are genetically diverse and misregulated, competing within a mixed population—this is a fundamental aspect of evolution."

Using robots typically found only in pharmaceutical companies, Chory and her lab conduct experiments that would normally require large bioreactors to study how populations change over time. "With our custom robotics, we can test a thousand different experimental conditions with the same group of cells and see if some grow faster or if some might even die," Chory said. "We can hopefully use robotics to grow cell lines continuously with much more precision and gain deeper insights into their biological responses."

Currently, with CAR T-cell therapy, only one methodology is applied to growing the cells, but, as Chory notes, "sometimes those methodologies can make the cells stop growing such that they almost don't even work by the time you transplant them back into the patient."

Chory's robots can screen a lot of different drugs and can also screen the conditions to make the cell-based therapies. "So, if you think of the drug as being the patient's own cells," Chory said, "we could not just personalize the cell itself, but also the conditions under which we cultivate the cells to ensure the best outcomes when reintroduced into the patient." Her tools give her the ability to not only screen the types of cells but also the environments in which they grow. ■

"Fundamentally, cancer consists of cells that are genetically diverse and misregulated, competing within a mixed population—this is a fundamental aspect of evolution."

— EMMA CHORY

High-throughput robotics is allowing researchers to conduct many experiments at once in parallel to explore many different variables. Illustration by Joanne Park.


DUKE ENGINEERING
DESIGN
POD

Engineering Design Experiences While Designing Engineering Curricula

A closer look at the design experiences becoming more common in engineering schools across the country

By KEN KINGERY

A group of students receive instruction from Ann Saterbak in Duke Engineering's First-Year Design course in its inaugural year (2017). Photo by Les Todd.

IT'S BEEN OFTEN repeated that necessity is the mother of invention. But sometimes, solutions to needs nobody realizes even exist present themselves unbidden.

That's what happened at Rice University in the early 2010s. For decades, the campus had prepared student meals in a single, enormous facility to distribute to various food halls. When they decided to move to a more distributed meal preparation system, it left an industrial-sized building vacant.

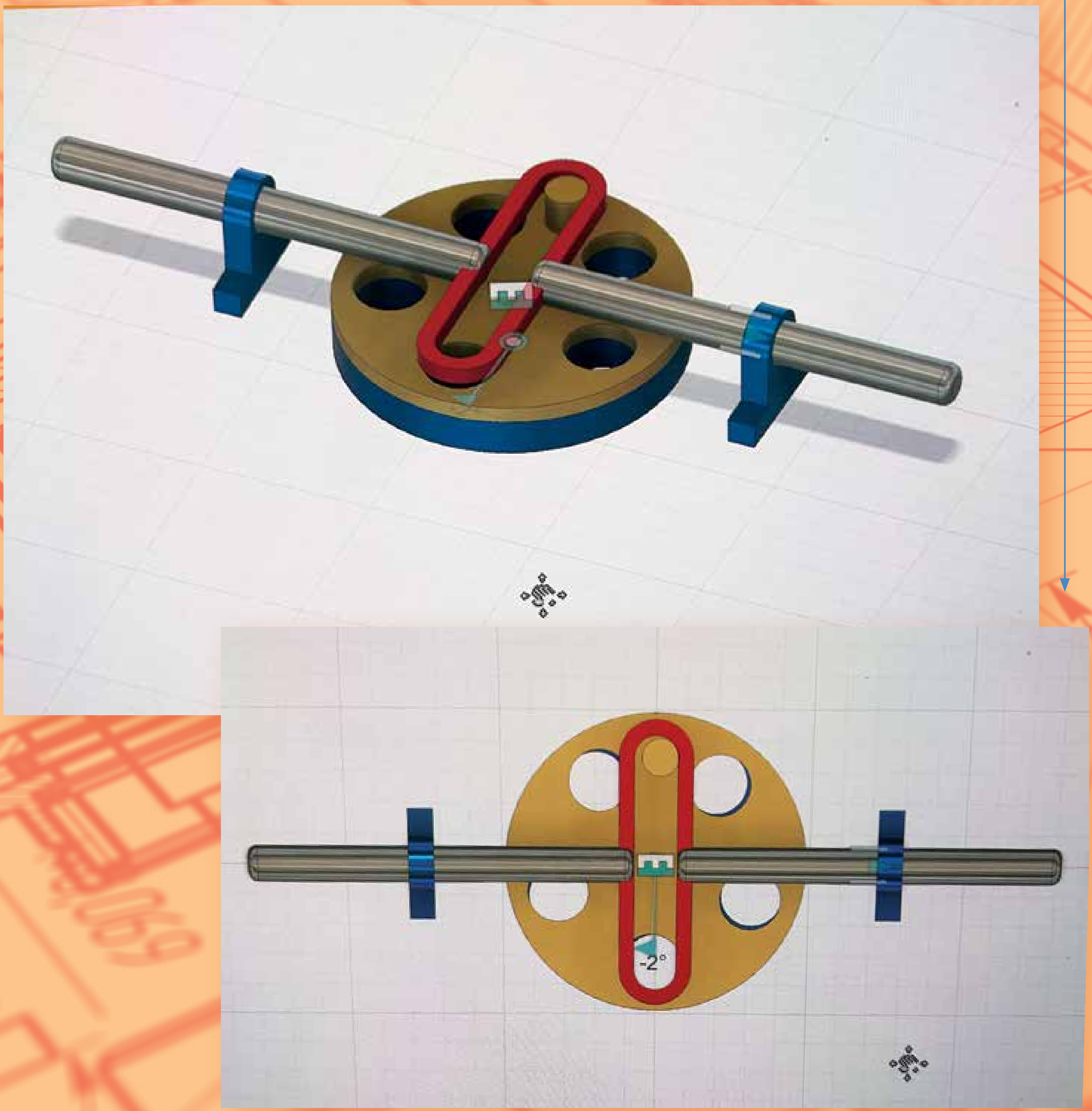
And Sallie Keller-McNulty, dean of the engineering school at the time, knew exactly what to do with it. She pounced on the opportunity to create a makerspace where senior design teams could work on a wide variety of projects alongside one another. Shared across departments and disciplines, it became an interdisciplinary haven for design work.

But Ann Saterbak, who had been teaching team project classes at the school since 1999, still felt like something was missing, and it didn't take long for her to realize what it was.

"It seemed like a natural thing to me to have first-year students working in the space, too," Saterbak said. "Their identity development as engineers was being farmed out to other departments through chemistry, physics, math and programming classes. I strongly believed we needed to be teaching engineering design courses in that first year."

Looking around the country and her education network, Saterbak created a first-year design engineering course with an eye toward what she believed to be exemplary programs, such as those at Northwestern University and Harvey Mudd College. After piloting the program for a couple of years and working out some kinks related to team size, project scope and working with clients, she built a strong program aimed at improving student retention and self-efficacy.

And then Duke Engineering convinced her to do it in Durham.



Student design project renderings from Duke Engineering's First-Year Design course.

Ann Saterbak took inspiration from several of the nation's top engineering design programs, including those at Northwestern University and Harvey Mudd College. Photo by Jim Wallace.

Hired as a professor of the practice of biomedical engineering in 2017, Saterbak wasted no time testing the waters at Duke. She quickly sought out partnerships with community organizations, located resources to create a makerspace and launched a pilot program with 60 students. It only took a year for the program to expand into a larger space and enroll the entire first-year class of about 400 students.

"Students are learning the engineering design process," Saterbak said. "What steps make sense, the importance of iteration, how testing informs redesign—those sorts of skills."

It's an idea that Harvey Mudd College jumped on perhaps before anybody else in the growing engineering design movement. The name most associated with Harvey Mudd's forward-thinking design curriculum is Clive Dym, who joined the school in 1991 as the inaugural holder of the Fletcher Jones Design Chair. Dym believed design was the distinguishing activity of the engineer, and that it did not require a foundation in the classical sciences such as chemistry, math and physics beforehand.

"Clive knew you could teach students design as a process early in their careers, and that it could be highly motivational for them," said Gordon Krauss, the current Fletcher Jones Professor of Engineering Design at Harvey Mudd. "They may not know how to calculate the strength of a beam or know how a material will behave, but when they come across those topics later in the curriculum, they think, 'Wow, this ties back into all that knowledge I'd wished I'd had back when I was working on that project.'"

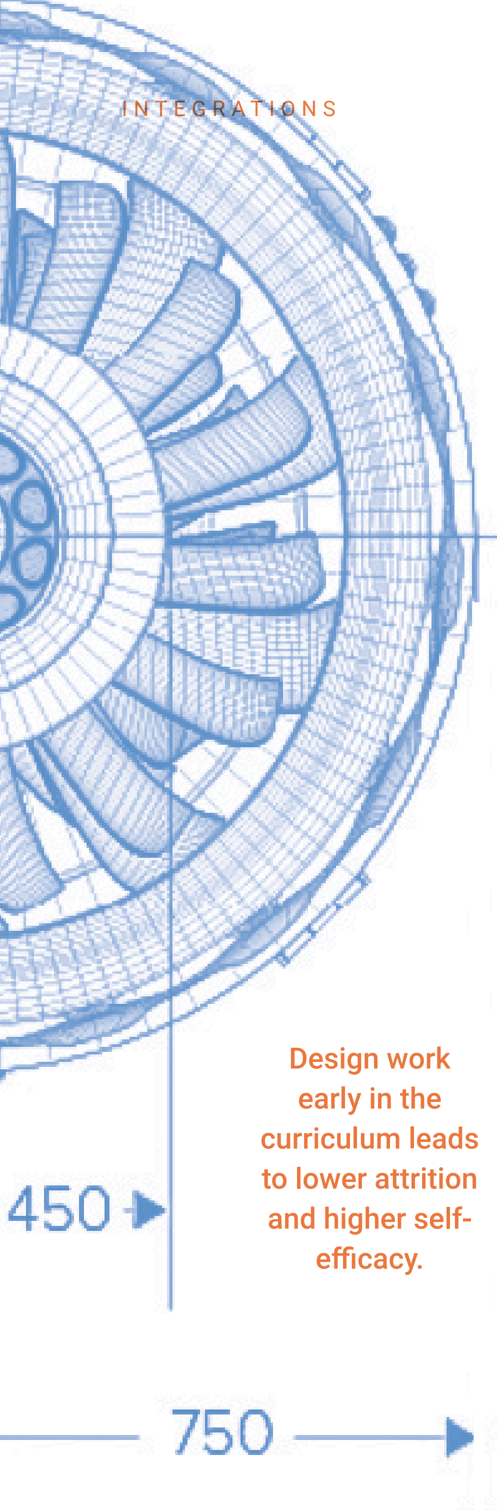
"They may not know how to calculate the strength of a beam or know how a material will behave, but when they come across those topics later in the curriculum, they think, ***'Wow, this ties back into all that knowledge I'd wished I'd had back when I was working on that project.'"*** **— GORDON KRAUSS**

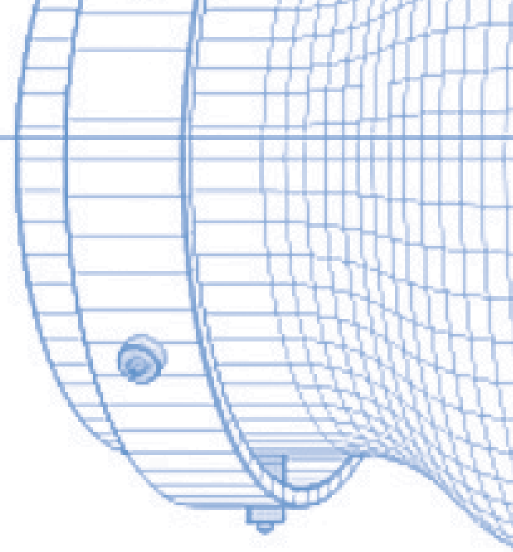
According to Krauss, Harvey Mudd's early team project-based engineering courses contribute to the low attrition within the department, though he suspects such interventions are more impactful at larger programs that traditionally have had higher rates. They'll even sometimes attract students from other members of The Claremont Colleges of which they are a part of. (Though majoring at HMC in engineering for such students has proved challenging).

That's a sentiment that Saterbak can relate to. After instituting it's First-Year Design program, the retention rates over the first four semesters increased by more than five percent, with underrepresented groups showing even higher retention. Students also self-reported a greater belief in themselves in the areas of engineering design and tinkering.

"There's still a belief in many programs that if 100 students come in, you're supposed to weed 50 of them out by graduation," Krauss said. "That's something I strongly disagree with. I think instead of weeding people out who can't do it, what we're actually doing is demotivating them. Just think of everything those students could contribute."

Part of the motivation in having these types of design experiences early in an educational career is likely tied to students actually being able to see themselves growing into an engineering role that appeals to them. And to be able to do that,





KEY TAKEAWAYS

Team-based design work does not require a foundation in the classical sciences, and can be implemented early in a student's career.

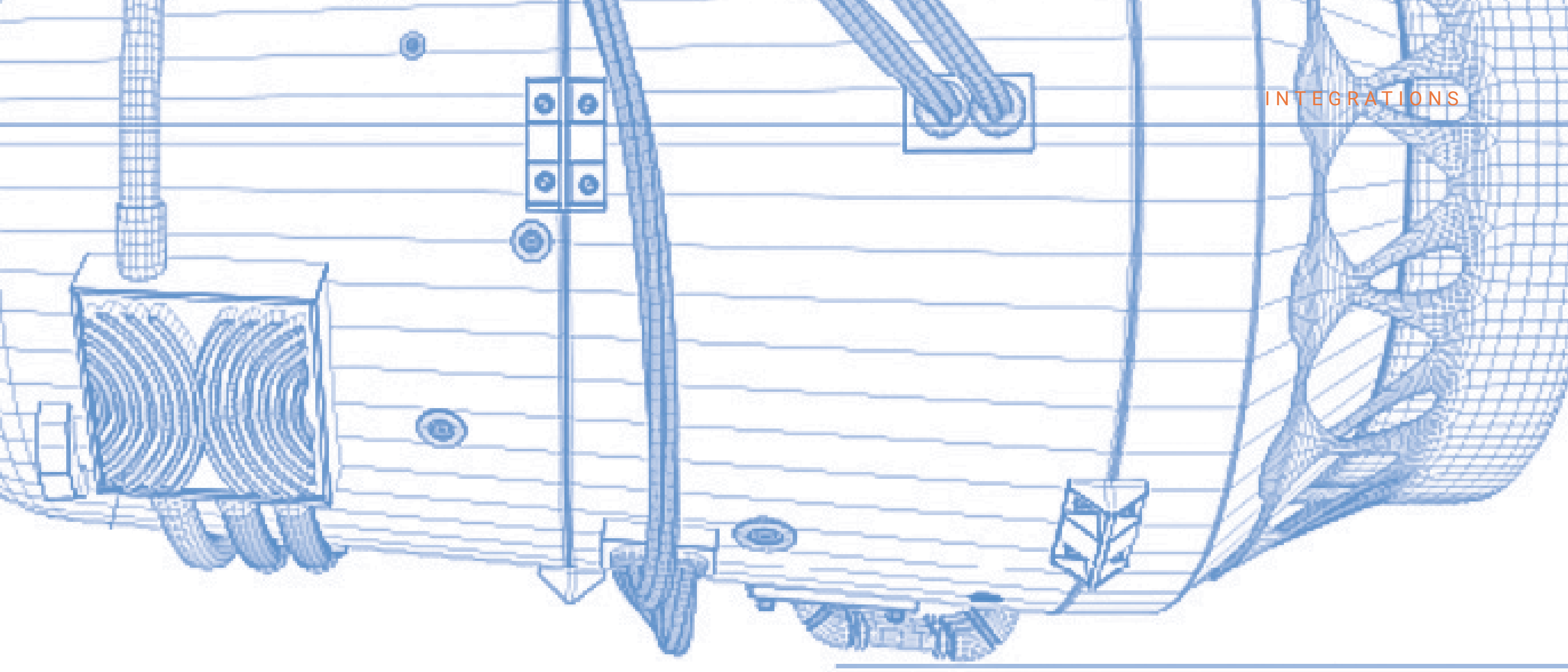
Hospitals and therapy practices can provide endless users with unique needs not addressed by commercial products.

Design work early in the curriculum leads to lower attrition and higher self-efficacy.

Industry partners can provide unique experiences and projects for seniors.

Cultivated senior design courses with external partners can be a more reliable source of training and education than internships.

Partnership with local organizations can provide students with a range of projects that can interest a variety of goals.



Saterbak notes, programs need to provide a variety of projects.

To accomplish this, Saterbak and her colleagues have spent years building relationships with a wide range of partners over the past seven years. They work with partners within Duke such as the Lemur Center and the libraries. They have several ongoing clients through local zoos and gardens, which often present a wide range of challenges for students to think through.

But perhaps their most fruitful colleagues in terms of sourcing projects come in the form of the Duke University School of Medicine and local organizations serving people with disabilities. Human health is a never-ending maze of options that work for some people but not others, while differently abled people often present truly unique challenges.

This is an approach used by Northwestern University as well.

"Health care providers often present a very rich source of people with high needs but not many commercial options to meet them," said Alex Birdwell, co-director of Northwestern's Design Thinking and Communication program. "While their specific problems might be uncommon, that one person has a huge opportunity to benefit from a student-created solution. And these interactions build empathy in students, who see the challenges first hand and also get to see the benefits of what they built first hand."

Even with a steady stream of projects being provided by consistent partners like the Shirley Ryan AbilityLab rehabilitation hospital and other Chicagoland health care organizations, sourcing enough projects is a challenge for Birdwell and his colleagues. Each of Northwestern's 500 first-year engineering students take the Design Thinking and Communication course—twice.

With 65-70 course sections taking place each year, Birdwell's team needs to source 60-70 projects from the community each year. And it has to deal with the problems of real people; real people who are willing to meet with students a few times during the course of the project.

Given how much teams need to work with one another and interact with their clients and the faculty, Northwestern also integrates a communications aspect. That makes sense, given that its Medill School of Journalism, Media and Integrated Marketing Communications is widely regarded as one of the best in the nation.

"That's one aspect of our design program that is somewhat unique, that we have two instructors in the classroom, one from engineering design and one from the Cook Family Writing Program, who weave their instruction together," said Birdwell. "But effective engineering requires effective communication, so we teach sharing information in multiple formats like speaking, graphical communications, making slides, giving presentations, designing posters. And it counts as a required English credit."

Northwestern's program, which began in the mid-90s as a pilot, has grown to encompass about 50 faculty members each term, split about 50/50 between engineering and communications. It is, as Birdwell put it, a rather large machine that requires a lot of people to make happen.

"It's definitely a lot of work to rescope 50 to 60 new projects every year," Saterbak echoed.

That time requirement is one of the reasons many engineering schools struggle to also provide design-focused projects through the middle of their curriculum. At Duke, efforts are being made to get sophomores and juniors into such projects through programs such as the Biomedical Engineering Design Fellows. There, each student designs, constructs and demonstrates a functional medical instrument based on a clinical need identified by a Duke University Medical Center clinician. Their devices are also tested and iterated on while students learn about the FDA medical device clearance process.

But programs such as these come with a cost, which is perhaps why implementing them can be such a challenge.

"When we add content or educational experience to a course or curriculum, it will typically displace some other important

A group of students in Duke's Design Pod iterate on their design project for the semester during First-Year Design's inaugural year (2017). Photo by Les Todd.

subject matter," said Krauss. "We strongly believe that incorporating design in the student experience enhances the ability to apply the engineering sciences and modeling course content."

According to Krauss, many previously believed that teaching design independently of other courses was appropriate with the expectation that students will seamlessly integrate all these aspects. In his experience, moving from understanding content to incorporating it in the design process is a big leap for many students, and they benefit from practicing design related applications.

It's an integration that many students eventually have to make regardless of how much practice they've had with the design process, as senior design capstone projects have long been a staple at many engineering schools. But as with emerging first-year design programs, there can be large differences between how different programs approach them.

At Harvey Mudd, for example, the "senior" design project actually encompasses three semesters, stretching back into the junior year. And rather than in the sunny confines of southern California, students are typically sent out to partners in industry and non-profit organizations. For example, one recent project saw students flying out to Malaysia to work on a windmill project. As with Northwestern's first-year program, this requires a lot of effort to source projects and find companies willing to sponsor them.

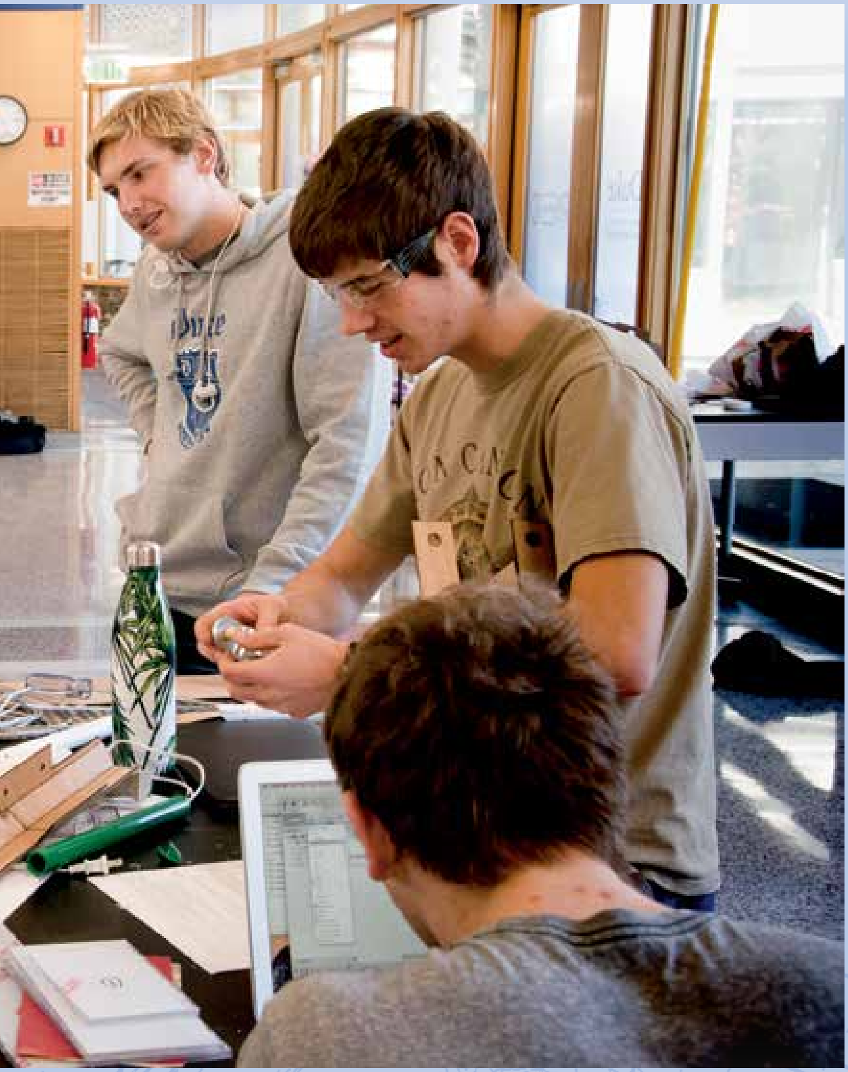
"Our students' tuition isn't funding these sorts of trips any more than other schools' tuitions are, so these have to be self-sustaining," Krauss said. "It's critical that we have a group that goes out and recruits projects by helping to make contact with industry partners who want to participate."

Krauss also stressed that this level of effort is not the only way to get students professional practice experience. Many schools rely on internships or co-ops during the school year to fill this role. But he also pointed out that internships can have all kinds of experiences, ranging from the opportunity to work on a long-term design project to having offices scramble to find a task for them each day.

At Duke, working with industry partners for senior design projects is not the norm, but it is a growing trend. One example can be found in the classroom of Rabih Younes, assistant professor of the practice of electrical and computer engineering.

Since 2020, Younes has brought in a handful of projects from Garmin International, which "brings GPS navigation and wearable technology to the automotive, aviation, marine, outdoor and fitness markets," and also has offices about 30 miles from Duke's campus. Each year, Garmin brings in a couple of open-ended ideas for projects that students could pursue, or students are also welcome to suggest their own ideas.

"Because the supporting team from Garmin understands the technicalities of what the students work on, besides the usual client meetings, students also meet virtually with them every other week to



receive technical support on their hardware and software systems," Younes said. "They're great at supporting our teams throughout the semester."

As one might expect, many students jump at the opportunity to work with professional engineers and designers. Last year, four out of the five teams in the class wanted to work with them, so Younes and the Garmin team had to go through a proposal round.

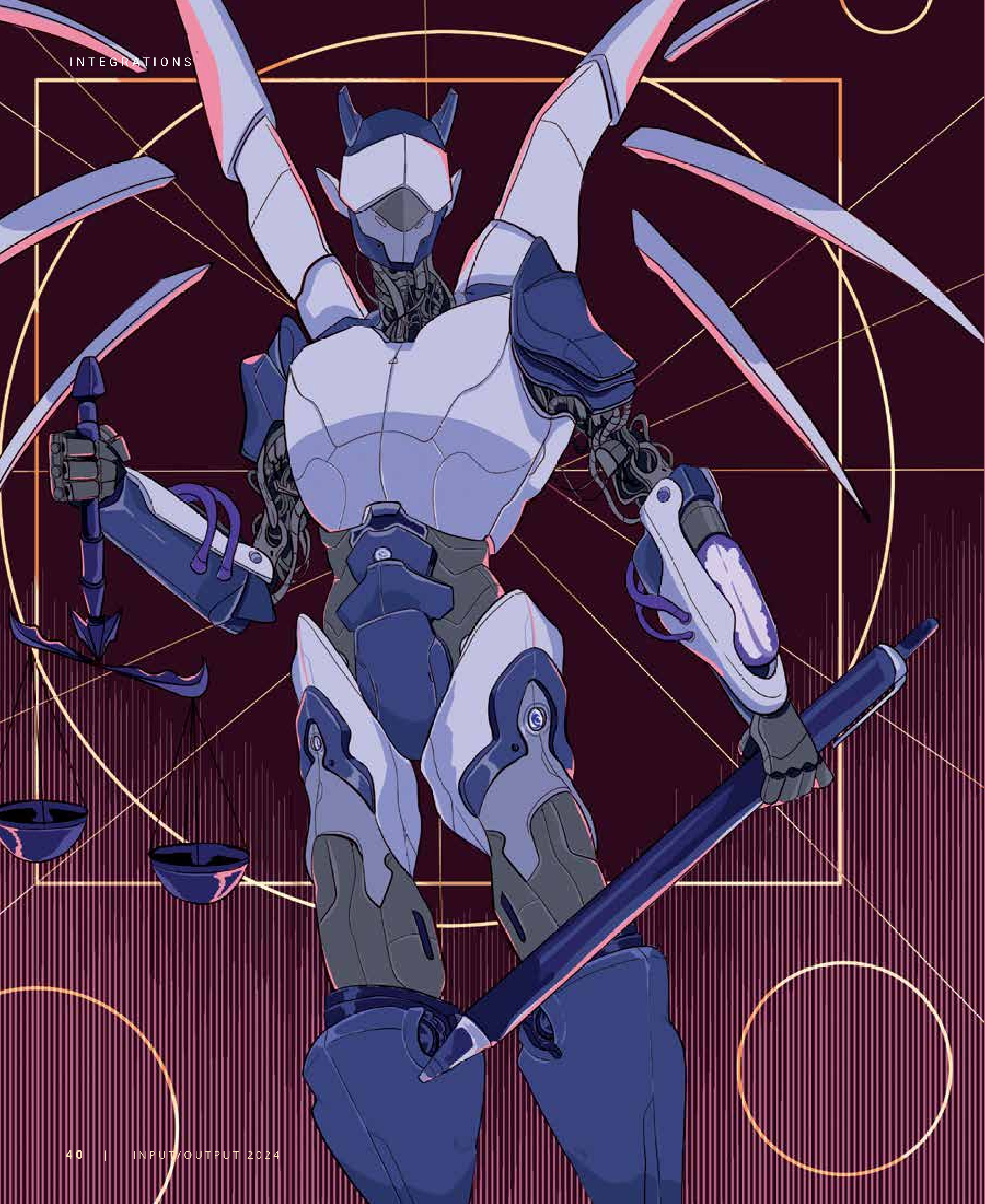
But even if students don't work with Garmin, there are still plenty of other exciting projects to work on. One recent example was an ankle bracelet to provide gait feedback to Parkinson's patients in a local physical therapy practice. Whatever the project, students practice designing and engineering a whole system that requires skills in hardware, software, human-computer interaction, 3D printing, prototyping and agile project management.

"No matter the client, it's a good experience for the students," Younes said. "They have to work through issues of misunderstandings and working with clients who don't know which instructions are easy to accomplish and which are impossible. But at the end of the class, they get very good at communicating with their peers and the clients."

And those misunderstandings and life lessons are crucial, because learning to design, to engineer, always requires failure. Founding faculty members of Harvey Mudd's Clinic Program, Jack Alford and M. Mack Gilkeson, thought the best way to expose students to such challenges was to give students a "clinical" experience similar to that which medical students receive.

"I gained the idea that engineering was like dancing," said Gilkeson during an interview about the history of Harvey Mudd's Clinic Program. "You don't learn it in a darkened lecture hall watching slides; you learn it by getting out on the dance floor and having your toes stepped on." ■

*"**It's critical that we have a group that goes out and recruits projects** by helping to make contact with industry partners who want to participate."* **– GORDON KRAUSS**



THE INCREASINGLY INESCAPABLE NEED TO INTEGRATE

Ethics

Engineers are facing more ethical dilemmas in their professional lives than ever before. Students need to be taught how to handle them

By MICHAELA MARTINEZ | Illustration by JOANNE PARK

IN 2019, Charles Gersbach was on a peaceful, if extremely long, flight from Durham, North Carolina to Hong Kong to speak at the 2nd International Summit on Human Genome Editing. He assumed the conference would be a helpful, if relatively uneventful, couple of days talking with and learning from colleagues.

He was wrong.

After turning on his phone after landing, the notifications came in a tidal wave of beeps and rings. While Gersbach was in the air, He Jiankui, a scientist at the Southern University of Science and Technology in Shenzhen, China, had announced that he had genetically modified the DNA of newborn twin girls named Lulu and Nana.

“My phone blew up with emails and phone calls from reporters looking for comments on the story,” said Gersbach, the John W. Strohbehn Distinguished Professor of Biomedical Engineering at Duke University. “He was scheduled to speak at the meeting, and when he took the stage there were more reporters in the room than scientists. The sound of the cameras clicking was deafening. I’ve never seen anything like it at a scientific meeting.”

During the conference, He explained that, when the twin girls were each a single embryo, he had used CRISPR to delete a key gene involved in HIV infection. Disrupting this single gene would—in theory—make the children immune to infection by HIV.

Using CRISPR to treat diseases isn’t a new idea, especially for illnesses like muscular dystrophy, Huntington’s disease and sickle cell anemia, where researchers have identified key genes. But this work involves altering cells that will not pass the genetic editing down to the patient’s children. By changing the genome in early-stage embryos, He also changed the DNA of the embryo’s future eggs or sperm—meaning the change would be inheritable for the twin’s children as well.

The work ignited a firestorm of controversy and anger from genome engineers, physicians and ethicists around the globe, who claimed that the project exposed the children to potential risks of off-target gene editing for no significant health benefit, especially when there are already safe and effective ways to protect people from HIV.

“In the moment, it was difficult to decipher

> **“It’s important that we recognize what can happen when these rapidly evolving tools are misused.”**
>
> **— CAMERON KIM**

what we were hearing,” Gersbach said. “There was a general feeling of disbelief and outrage. But there was also a realization that this was a monumental step in human intervention in our own biology.”

This is just one example of the many ethical dilemmas facing professional engineers in the 21st century. Creating AI that can teach itself; engineering robots that can chase people down; deciding where new sea walls are placed. It’s more essential now than ever before that students be prepared to think through the potential consequences of their decisions.

Duke Engineering recently hired Rich Eva as director of its new Character Forward program to specifically address this issue. With funding from Duke’s Undergraduate Program Enhancement Fund, the Lord Foundation and the Kern Entrepreneurial Engineering Network, he is leading an initiative to provide seed grants to modify courses or pilot ideas for co-curricular activities that can strengthen students’ understanding of these issues.

The need for this level of engagement is self-evident in the materials already being taught across the school.

The He Jiankui experiment and its fallout, for example, is one of several case studies students explore in Duke’s BME290: Ethics in Biomedical Engineering course. Led by Cameron Kim, a professor of the practice of biomedical engineering at Duke, the course helps ensure that engineering students have a strong foundational understanding of the different ethical guidelines that shape the biomedical and engineering fields. Armed with this knowledge, they examine topics ranging from AI in medicine to brain-computer interfaces to discuss and debate the ethical merits and challenges of new and emerging technologies.

“We could always discuss challenges from 30 years ago and learn from them, but I want these students to be forward-thinking,” said Kim. “So many of these technologies are evolving and changing in ways that necessitate us talking about them now. It’s important that we recognize what can happen when these rapidly evolving tools are misused.”

CRISPR may be the poster child for this argument because its power to transform the fundamental code of what makes humans human is already so readily available.

“Gene editing is deceptively simple,” said Pranam Chatterjee, an assistant professor of biomedical engineering at Duke. With CRISPR, a Cas protein is bound to guide RNA that gives Cas directions to cut or alter DNA at a specific location, leading to changes in the DNA sequence.

“Having even an undergraduate-level knowledge of biology could essentially be enough for you to go in and edit pretty much any gene in almost any organism that you’d like,” said Chatterjee. “That ease has widened its use, but it’s also made it incredibly difficult to regulate people’s activity.”

THE START OF AN IMPORTANT CONVERSATION

Recognizing the widespread potential—and dangers—of this tool, the U.S. National Academy of Sciences and the National Academy of Medicine organized a multidisciplinary, international committee in 2017 to review the technology and make recommendations outlining its ethical uses in human genome editing.

While the committee agreed that gene therapy for non-reproductive cells could proceed under existing medical and ethical guidelines, they drew a much stronger line in the sand for CRISPR’s use in reproductive cells, decreeing that heritable human genome editing only be used to prevent a serious disease or condition, and only if there are no reasonable alternatives available.

"We've mitigated a lot of the safety issues with CRISPR in the years since its discovery, but it's still not the safest therapy to put in your body," said Chatterjee. "It comes from bacteria, so it can trigger an immune response, and it requires very expensive delivery strategies. It's not the right approach for 99% of things, but it is still the best, and sometimes only, option for a subset of diseases."

One such illness is sickle cell disease, a group of inherited blood disorders that affect 100,000 people in the U.S., and can cause severe pain, organ damage and microcirculation obstructions that can lead to disabilities and even death. Previously, the only long-lasting treatment was a bone marrow transplant, but in 2023, the FDA approved two non-hereditable gene therapies to treat patients 12 and older.

As these first FDA-approved trials begin to show results, Chatterjee is curious if researchers will push to use gene editing therapies for diseases that already have alternative treatment options. In those cases, he says, doctors and researchers who are today's students will have to look closer at the risks and benefits to using each therapy.

After all, the committee's decision in 2017 was intended to be the beginning of a conversation about the ethics of human gene editing—not the end of one. But for now, Chatterjee is firmly focused on what he can accomplish in the present in both his role as a scientist and as a professor.

"I think overall we haven't done a good enough job of preparing for the fact that so many people can use this tool," Chatterjee said. "There are people who have this capability, but how do we make sure they're going to use it the right way? And to do that, we need to incorporate ethics into any educational lesson we do with this technology. That's got to be a part of the conversation."

CHASING DOWN A RUNAWAY TRAIN

Another technology that is advancing ethical debates and is already surprisingly easy for people to use is AI. But rather than focusing on the implications of creating AI that could become self-aware and even outthink humans—which we'll get to later—many researchers are worried about how simpler decision-making algorithms are reaching their conclusions. After all, most are "black boxes" that do not show their work.

Cynthia Rudin wants to change that.

Rudin, the Gilbert, Louis, and Edward Lehrman Distinguished Professor of Computer Science, leads the Interpretable Machine Learning Lab at Duke. There, she develops machine learning algorithms with her students that help humans peer behind the curtain to see exactly how and why the AI made certain decisions in ways that are clear and easily accessible.

But as she's working to unlock and clarify the inner workings of the AI her lab builds, Rudin has kept a close—and concerned—eye on the technology as it's undergone explosive growth by those who don't mind a black box.

"AI technology is like a runaway train, and we're trying to chase it on foot," she said. "Very often, we don't train our computer scientists in the right topics. For instance, we don't train them in basic statistics, and we don't really train them in ethics. They've developed this technology without worrying about what it could be used for, and that's a problem."

One of Rudin's biggest concerns is how quickly and easily AI can generate misinformation that is taken and shared as fact. She's also wary about the proliferation of AI in facial recognition software, and how it can be used outside of highly regulated scenarios.

But Rudin is doing her best to push back. She serves on several government committees on AI to share her knowledge and concerns about the unregulated proliferation of these technologies. And while she's aware that many of her own students will go on to jobs in the big tech companies that help develop these technologies, Rudin is upfront about the existing ethical shortcomings they will need to address in these roles.

"Either I don't teach them, and they perpetuate these problems, or I do teach them about these issues and how to solve them," she said. "If my people are going to go into big tech, then at the very least they are going to know how and why these tools can be harmful."

For Rudin, this means probing the context surrounding the development of these tools. By understanding how and why they were initially created, students get a sense for how drastically tools they create can evolve and be used for sometimes unexpected purposes. For example, the vision systems in self-driving cars were trained using algorithms that can identify deer in images. Today, those same algorithms are used in facial recognition software.

"I also teach my students how to use interpretable machine learning algorithms and how to derive them in class so they can experiment with them against black box models," said Rudin. "They see first-hand that a lot of data doesn't require neural networks to achieve the

"I think it is essential for students to fully experience the robot design and control process so that they can not only understand the essential knowledge in robotics, but also identify the key challenges to tackle next."

— BOYUAN CHEN

highest performance. Not only can my students point this out, but they then know how to create interpretable algorithms to use instead of black boxes. That's very unusual, as most maching learning courses just teach that black box approach."

UNLOCKING A NEW WAY OF THINKING

Now, back to those sentient killer robot scenarios.

Boyuan Chen, an assistant professor of mechanical engineering and materials science, electrical and computer engineering, and computer science, and the leader of the General Robotics Lab at Duke, is very familiar with these types of science fiction storylines. But that doesn't stop him from working on robots that can learn, act and improve by perceiving and interacting with the complex world around them, just like a human child does.

"Ultimately, I hope that robots and machines can be equipped with high-level cognitive skills to assist people and unleash human creativity," he said (see page 64 in the magazine for more on his research).

But Chen isn't looking to make the prototype for the next Terminator or Westworld guide. On the contrary, he's actually concerned that there is a major gap between what the public thinks robots can do and what they actually can do. And that gap is perpetuated by societal needs to impress and obtain more funding or sell more products.

"In robotics, you can't publish a paper without a real robot video demo. But what people don't know is that many such video demos are cherry picked," Chen explained. "In a lot of cases, limitations with the systems may be buried in the paper's appendix, but they are left out of the main sections of the paper or do not even get mentioned. This practice gives students and the general public an incorrect perception of the field in terms of what we have actually achieved and cannot do yet."

In one of Chen's undergraduate classes, he tasks his students to build a legged robot from scratch. At the end of the semester, they hold a dancing and walking competition in front of the Duke Chapel. Students think it's a way to test their robots, when in fact it's a way to show that live demos don't work well. If that point doesn't immediately come across in the lab, it usually does when students take their machines to the stones outside the chapel. Suddenly the robots can barely walk with the friction on the new surface, even if they were working somewhere else before.

"When they make a summary of the project, nearly 80% of the video is students documenting about how various unexpected challenges and failures happened and how they overcame them," explained Chen. "I think it is essential for students to fully experience the robot design and control process so that they can not only understand the essential knowledge in robotics, but also identify the key challenges to tackle next. Documenting the entire process teaches the students how they can communicate complex technologies to general audiences, and that makes the development process much more transparent."

As students progress through these classes loaded with ethical dilemmas, they often learn that there often isn't a stark "good" or "bad" answer. Instead, the lessons from their readings, case studies, class discussions and real-life experiences help them learn how to articulate their thoughts, concerns and decisions about different technologies and their uses.

"It felt like this class unlocked a new way of thinking for me that I haven't experienced in any other class I've taken at Duke," says Morgan Sindle, a senior in biomedical engineering at Duke who took Kim's ethics class in the spring of 2023. "Being able to look at problems with the perspectives I've gained from this class feels like a skill that's just as necessary as the engineering skills I've learned at Duke."

This is common feedback from students, which can

> **"Very often, we don't train our computer scientists in the right topics. For instance, we don't train them in basic statistics, and we don't really train them in ethics. They've developed this technology without worrying about what it could be used for, and that's a problem."**
>
> **— CYNTHIA RUDIN**

also be seen in takeaways from Ethics in Robotics, another robotics course at Duke in which a series of speakers from industry and academia talk about ethical topics in the field of robotics and automation.

"One of the examples we talked about is how pulse oximeters work better on some skin colors than others," said Allison Taub, a recent Duke graduate who double-majored in mechanical engineering and computer science. "It's interesting to learn about all of the ways these new technologies impact society and talk through all the nuances involved. We've had a lot of great speakers, so it's been great to get a deep dive into so many different fields."

"Very few things are black and white, and there's a lot of grey area," said Siobhan Oca, a professor of the practice of mechanical engineering and materials science at Duke, who teaches the class. "But we need to have these conversations and be able to hold ourselves and our technology accountable."

"What we do as engineers doesn't occur in a societal, ethical or legal vacuum," added Kim. "We need classes where we can challenge our students to think about the possible impacts of the work we do as engineers, and think not only about our current challenges, but also the future ethical challenges we may face as these technologies evolve." ■

Four Duke Engineering faculty members have gone all-in on their entrepreneurial adventures, bringing back tips and advice to share with others. From left to right: Ken Gall, Aaron Franklin, Ashutosh Chilkoti, Sonia Grego. Photo by Alex Mousan Sanchez.

THE HARD-EARNED LESSONS OF

Academic Entrepreneurs

Faculty entrepreneurs from Duke Engineering share their experiences of what it takes to spin a startup out of a university

By FEDOR KOSSAKOVSKI

WHEN YOU HEAR the word "startup," what do you think of? Is it the stereotypical image of a lone founder or two in their parents' garage, dropping out of college with nothing but passion, a bit of seed money, and a wild dream to "make the world a better place?" A Steve Jobs or a Mark Zuckerberg?

Of course, that does happen—but the lone dropout founder approach is more myth than reality, and there are many ways to go about building a startup in the modern world.

A growing type of founder profile is the faculty founder. Though it is not new—Genentech, the first biotech company, was a startup co-founded in 1976 by UCSF biochemist Herbert Boyer—academics are spinning more and more companies out of their labs.

Following the money really showcases this trend. According to analysis by Global University Venturing, the number and amount of financings for university startups globally in the past decade has doubled. At its peak in 2021, before economic headwinds put a damper on the whole market, university startups around the world raised $41 billion.

This trend, and some lessons that can be learned from it, can be found in the microcosm of Duke's startup activities.

"Interest in entrepreneurship among Duke faculty has increased dramatically since the 2010s," said Robin Rasor, associate vice president for translation and commercialization at Duke. "We've been lucky to attract some top-notch researchers who also have managed to be very successful at spinning out companies."

Rasor's office has helped Duke academics launch dozens of companies in recent years, with more than 120 active startups raising over $1.7 billion in capital over the past five alone. Eighteen have had successful exits in that same timeframe.

> “If you have technology that goes in different application areas, set up different companies—lesson number one.”
>
> — ASHUTOSH CHILKOTI

These startups are more than just numbers, however: They’re stories of struggle and success from unique academic founders who have learned many lessons along the way.

“Every university technology and startup is unique, but they all face some similar challenges,” said Jeff Welch, director of Duke New Ventures. “The two main challenges are: How do we build the right team and how do we raise enough money to create recognizable value?”

How academic entrepreneurs work through these challenges with their startups varies, too.

“There’s a continuum of involvement,” said Rasor. “Some professors are very hands-on throughout, while others are there at the very beginning but quickly pass off the torch to graduating PhD students or other professional management.”

THE LIGHT TOUCH MODEL

“My model is to start quietly,” said Ashutosh Chilkoti, the Alan L. Kaganov Professor of Biomedical Engineering. “I like to do the value creation in my lab.”

Incubating technologies stealthily in the lab lets Chilkoti more freely explore possible applications for his technologies, which focus on bespoke polymers engineered for various biotech uses. Chilkoti has spun five companies out of his lab: Sentilus, PhaseBio Pharmaceuticals and Isolere Bio, which all had successful exits; inSoma Bio, which is currently in progress; and Gateway Bio, which is still in stealth mode.

“If you have technology that goes in different application areas, set up different companies—lesson number one,” said Chilkoti.

PhaseBio, Isolere, and inSoma are all based around a platform called elastin-like polypeptides (ELPs), a biopolymer that transitions from liquid to an elastic solid when the temperature rises.

He’s speaking from painful experience. Originally, all intellectual property for ELPs was licensed to PhaseBio, but they were focused on only one use case: drug delivery. PhaseBio was doing well and went public in 2018, but it hit economic headwinds, and a poorly-structured debt financing tanked the company.

This was a decade after Chilkoti had much of anything to do with the company, since he adheres to the “light touch” model of spinning out a company. He was able, however, to claw back the intellectual property for other applications.

Graduate students play a critical role in Chilkoti's light touch brand of academic entrepreneurship. Technology applications are usually championed in the lab by grad students and postdocs, who then become the leaders of the spinout, like PhD graduates Kelli Luginbuhl steering Isolere and Stefan Roberts helming inSoma. Chilkoti advises the companies but is not part of their C-suite level teams.

"The fun is that I learn from them," said Chilkoti. "Soon, they're way more sophisticated about some of the business things. So, it keeps me intellectually engaged."

THE INVOLVED ADVISOR MODEL

"I consider myself a low-to-moderate entrepreneurially engaged faculty member," said Aaron Franklin, the Addy Professor of Electrical and Computer Engineering.

About seven years ago, his lab developed a sensor technology to better measure the thickness of car tires. They spun out a company, Tyrata, and Franklin joined the team as chief technology officer.

"That came at a significant cost that I," he chuckled, "sort of knowingly took on. But things are always a little different than what you may initially anticipate them to be in terms of time commitment and mental balancing."

He doesn't regret it, though, and credits a six-year CTO stint until the company's acquisition in late 2023 as a great learning experience. A key takeaway from Franklin's journey for academic founders, especially first-time founders like himself: up your communication game.

"Love it or hate it, it is a reality that you can have the most impactful scientific results in history, but if you do not message that well and get it to the right audience and put it together in the right fashion, it will have minimal impact," said Franklin.

That sentiment was echoed by Ken Gall, professor of mechanical engineering and materials science, who Franklin described as someone who "lives, breathes, sleeps and eats entrepreneurship."

Gall compared the difference in touting the technical findings of a paper published about a technology versus saying the same technology was implanted in 10,000 patients and made a difference in peoples' lives. One grabs the attention of an investor—and nobody needs to be told which one.

"It's hard to sell basic science to investors," said Gall. And it is very different from selling your work to a research grant committee.

"With a grant, you're laying out this meticulous plan that's reviewed behind the scenes and then they just tell you yes or no in a review document. With an investor, you talk face-to-face, and they give you a very small window to teach them why they should put their money in. And then they want their money back plus some."

Gall would know—as a serial entrepreneur specializing in implantable medical devices, he's had many of those conversations. When asked to list all the startups he's been involved with, Gall had to refer to his notes. He counted ten, with several successful exits including Vertera Spine, MedShape and InnAVasc.

Gall has several startups cooking now, but his most involved pursuit is as a board member and leader at restor3d, a 3D-printed orthopedic implant startup that recently closed a $70 million financing round. Over the years, he's figured out how to juggle professorial duties with his passion for entrepreneurship, but he concedes that it's no cakewalk.

"I think some people underestimate it," said Gall. "Sometimes, it's overwhelming."

He suggests riding the ebbs and flows of the academic calendar—for example, Gall is on a nine-month appointment, so his summers are more flexible—and maximizing your allotted consulting time for your startup activities. A sabbatical year may be a good option as well, he said. "That's a great way to test the waters."

THE ALL-IN MODEL

Some people, though, prefer to dive right in.

Sonia Grego, an associate research professor of electrical and computer engineering, had been working on a smart toilet technology with fellow research professor Brian Stoner and colleagues for a few years

"Love it or hate it, it is a reality that you can have the most impactful scientific results in history, but if you do not message that well and get it to the right audience and put it together in the right fashion, it will have minimal impact."

— AARON FRANKLIN

"The problems we encountered in trying to commercialize our materials drove all kinds of new basic science questions that we researched, received grants and published papers on. We didn't publish on devices, we published on the basic materials science."

— KEN GALL

approached them with interest in licensing the technology.

"We really did not sleep much," said Grego, recounting the team's late-night fretting over whether to license the technology to the manufacturer or to start their own business. After much discussion, especially with a group of Duke alumni advisors, who offered some pre-seed money for a startup, Grego and team founded Coprata in 2021.

The team has been prototyping and pivoting their technology over the past few years, gathering customer feedback and ramping up pilot studies.

"It's been full immersion and fundraising," said Grego. "We're building the plane as we fly it."

Grego's model of entrepreneurship is at the highest level of involvement, as she recently assumed the role of chief executive officer.

"My lesson here, and the challenge, is that nobody cares about the company as much as I do," said Grego. "And as a scientific founder for this space, I'm the one that knows the problem best, that can speak with clinical partners to identify the needs, that can shape the tech into a solution."

Grego highlights hiring challenges as something academics should be prepared for if they're thinking of doing a startup. When she posts an opening in her lab, Grego says she gets many great candidates. For her young startup? Not so much.

"Not everyone is comfortable with the demands and risks of a startup environment," said Grego. "Finding a good fit is important and may take time."

The hiring process, the business jargon, the endless fundraising. Grego has been picking up all these skills and more in what she characterizes as a steep but highly rewarding learning curve. For support, she leans on people she trusts: Stoner, one of her co-founders and an academic collaborator for over 20 years; a team of skilled engineers and experienced advisors that she has attracted; and the ecosystem of Duke entrepreneurial experts.

"We are in the thick of it," said Grego. After a beat, she added with a laugh, "And on the cusp of greatness, of course!"

BUILDING FOR THE FUTURE

Launching a university spinout used to be a lonely experience. "I was on an island," reminisces Gall of his earlier entrepreneurial ventures as a nontenured assistant professor.

Nowadays, universities like Duke provide much more support for their academic entrepreneurs. Serial entrepreneurs like Gall and Chilkoti have helped to build out more programs while in departmental leadership positions, such as the Duke Engineering Entrepreneurship Program and the Duke BRiDGE incubator. And more alumni are engaged, either directly with faculty founders

"We are in the thick of it, and on the cusp of greatness, of course!"

— SONIA GREGO

Photo by Angela Brockelsby.

or through organizations like Duke Capital Partners.

But it's important not to forget that you are, first and foremost, an academic.

"Do the best science," said Chilkoti. "Then, if your science leads to something that could be commercialized, don't be afraid to go for it."

That commercialization can lead to all kinds of new interesting basic science back at the university.

"The problems we encountered in trying to commercialize our materials drove all kinds of new basic science questions that we researched, received grants and published papers on," said Gall. "We didn't publish on devices, we published on the basic materials science."

First-time founders like Franklin and Grego have benefitted from the growth in entrepreneurial culture and community at Duke, learning from those with more experience and supporting each other through the rollercoaster ride of startup life, whichever model they choose to follow.

"For Duke Engineering and for Duke overall, there's an impressive precedence of success that is exemplary of having really good support arms in place," said Franklin.

"This has been an amazing experience," said Grego. "I understand now why people are serial entrepreneurs." ■

Faculty on Social Media: Friend or Foe?

¿Por qué no los dos?

By MICHAELA MARTINEZ

IN ONE OF THE MOST POPULAR videos on Roarke Horstmeyer's YouTube channel, he explains the difference between an analog microscope and a digital microscope in less than 12 seconds.

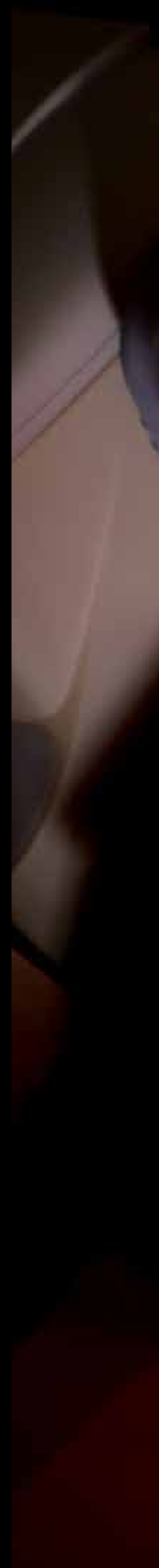
"This is an analog microscope," Horstmeyer says, gesturing to a standard—if sleek—simple microscope.

Then he pulls out his iPhone and plops the camera lens against that same microscope's eye piece. "And this is a digital microscope."

An assistant professor of biomedical engineering at Duke University, Horstmeyer develops microscopes, cameras and computer algorithms for applications ranging from detecting neural activity deep within tissue to studying the behavior of model organisms like zebrafish. But in his free time, he's been steadily building up a social media presence—specifically on YouTube and TikTok.

"I wanted to find a new way to get people engaged with my lab and show the work that we can accomplish with the imaging tools we make," said Horstmeyer. "But it always surprises me which videos find an audience, because they aren't always the clips I spend a lot of time on."

The topics in his videos are as varied as the imaging tools he makes. In one, Horstmeyer demonstrates how floating optics tables help ensure that experiments stay stable. In another, he zooms in on zebrafish embryos to



Social media and the ability to reach millions of people isn't going anywhere. Is its juice worth the squeeze for busy faculty and researchers? Photo by Alex Mousan Sanchez.


HBS
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VWR
BIOHAZARD
Autoclave Bag
Name:
Address:
VWR EU Cat. No. 129-1564
Size: 8 x 12 (200 x 305)
vwr.com

"THESE FACULTY ARE PURSUING PROJECTS THAT PROVIDE INCREDIBLE VALUE TO THE WORLD, BUT THEY NEED TO SHARE THAT KNOWLEDGE AND THOSE TOOLS AS BROADLY AS POSSIBLE. YOU CAN CURE CANCER, BUT YOU ALSO SHOULD MAKE SURE THE WORLD KNOWS YOU CAN CURE CANCER." - AARON DININ

Photo by Alex Mousan Sanchez.

show how the microscopes his lab develops can capture an unprecedented amount of detail. He even recorded a video to see if he could find any microscopic bugs in a slice of strawberry (thankfully, he did not).

Although Horstmeyer had previously dabbled in social media, he made a concerted effort to create more engaging content after participating in Duke Creator Lab's "Thought Leader Studio," led by Aaron Dinin, a faculty member in Duke's Innovation & Entrepreneurship program. Dinin previously made headlines for his innovative classes centered on social media and content production—dubbed "TikTok classes" by Duke students. When Jerry Lynch, the Vinik Dean of the Pratt School of Engineering, approached him about creating a class to help faculty build these same skills, Dinin jumped at the opportunity.

"These faculty are pursuing projects that provide incredible value to the world, but they need to share that knowledge and those tools as broadly as possible," said Dinin. "You can cure cancer, but you also should make sure the world knows you can cure cancer."

REACHING NEW AUDIENCES

Although researchers will often publish a paper and publicize it within their academic community, they don't usually make an attempt to share it with a wider audience. This is where Dinin believes social media can broaden the impact of their work.

"Bringing knowledge into the world should always be the primary goal," said Dinin. "No matter how popular a journal is, you're going to reach more people with a bad TikTok in 10 minutes than a journal could reach over a month. If your goal is to share your work with a broad audience, then you should also use tools that are actually able to reach that audience."

And the size of that audience is staggering. Today, more than five billion people around the globe use some form of social media. Roughly three billion people use Facebook. Instagram boasts more than 1.6 billion users. More than 1 billion people have LinkedIn profiles. X, the platform previously known as Twitter, reports 368 million monthly active users. And according to the Pew Research Center, roughly 170 million Americans use TikTok—just a portion of the more than 1.5 billion global users of the app.

That isn't to say that all faculty in Duke Engineering need to amass millions of followers. Instead, Dinin used the Thought Leaders program to help interested researchers develop a personal brand that would help them appeal to their targeted communities. From there, faculty learned how to create attention-grabbing content that could quickly attract and hold a viewer's mind, and what methods could help the all-powerful algorithms prioritize and highlight their work.

"At the end of the day, someone is going to talk about augmented reality headsets, and it could either be a 19-year-old who's using ChatGPT to make a script, or it could be Duke Professor Maria Gorlatova, who is one of the world's leading experts on the technology," Dinin said. "There is an audience inside those billions of users who want to learn about these topics, and if you're an expert, you should be thinking about how you can reach and engage with them."

But getting started is half the work.

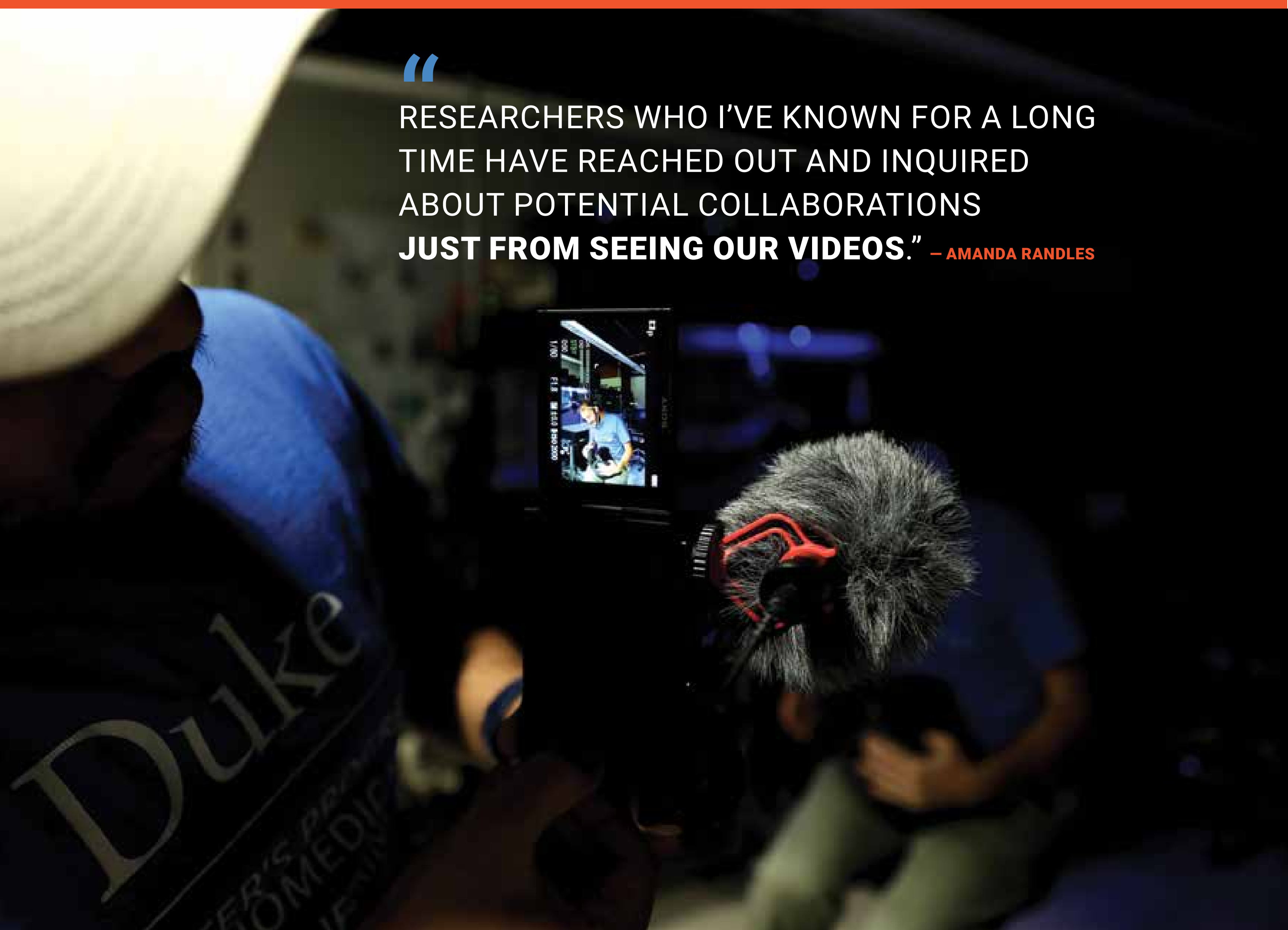
Ken Brown, the Michael J. Fitzpatrick Distinguished Professor of Engineering, had previously used Twitter/X to share research papers, student news from his lab in the electrical and computer engineering department, and job openings. Even he admits that these initial posts were done to appease his program director rather than out of a genuine interest in cultivating a social media presence. But as he began to post more, Brown discovered a quantum computing niche within the larger "Academic Twitter" world.

"We swapped papers, asked questions and interacted with one another like we were at a conference. Some science even got done!" Brown said. "I think because it was such a specific community, I was able to bring more personality into my profile. I was posting quantum computing memes, and when I shared a paper, I would include follow-up tweets that explained key points about the work. The more effort I made to show the scientist behind the profile, the more followers I gained."

Horstmeyer noticed something similar happening as he started making more videos. Now, he estimates that he spends at least four hours a week making content. It's a significant chunk of time when you consider that he's also teaching classes, grading papers, assisting his graduate students and doing his best to maintain a work-life balance. But when asked if he thinks the clips are worth the time and effort, Horstmeyer's answer is immediate.

Definitely.

"I've had people working in optics or even who are just interested in the field reach out to me because they saw one of my videos and thought it was fun and they wanted to know more about what we do," he said. "It's also been an easy conversation starter at conferences. Students will introduce themselves and say they found



“RESEARCHERS WHO I’VE KNOWN FOR A LONG TIME HAVE REACHED OUT AND INQUIRED ABOUT POTENTIAL COLLABORATIONS **JUST FROM SEEING OUR VIDEOS.**” **— AMANDA RANDLES**

Roarke Horstmeyer estimates that he spends four hours a week making content for social media. It's time that he firmly believes is well spent. Photos by Michaela Martinez.

out about my lab because one of my videos appeared in their YouTube Shorts or on TikTok."

"Researchers who I've known for a long time have reached out and inquired about potential collaborations just from seeing our videos," said Amanda Randles, the Alfred Winborne and Victoria Stover Mordecai Associate Professor of Biomedical Sciences at Duke. Randles and her lab use high-performance computational tools to create simulations that model blood flow and the movement of cancerous cells through the body. While this work had already garnered Randles significant attention in both biomedical and computational circles, Dinin helped her and her team learn how to package their research into short, palatable videos.

"I keep track of my social media on a spreadsheet, and you can see a significant spike in followers and interactions each time we post a video," she said. "It's made us think about more ways we can present our work. We're thinking of how we can make short videos to summarize new research papers, and I'm already making content for our newly launched Center for Computational Medicine."

Faculty aren't the only ones seeing the benefit from a more engaged social media presence. One of Brown's postdoctoral fellows contacted him about joining the lab specifically because they saw his job advertisement on X. Daniel Shapiro, a biomedcial engineering PhD student at Duke, finds that it's sometimes easier—and faster—to connect with faculty, researchers in industry and even potential investors on platforms like X or LinkedIn.

"You can have the smallest interaction, like a comment on a post, but there is a greater likelihood that you'll be seen and noticed on that platform than one of the thousand people in their inbox every day," he said. "I'm interested in going the entrepreneurial route after graduation, and these sites are incredibly useful to get your foot in the door."

ONLINE EXPOSURE—FOR BETTER AND FOR WORSE

Shapiro has been able to use social media platforms to find fellowships, network with scientists and entrepreneurs, and keep track of publications that relate to his research. But he's also taken precautionary measures to ensure he doesn't spend too much time in the virtual world.

"I don't have the apps on my phone because it's so easy to sit down and scroll for hours and hours. The apps are engineered to keep your attention," said Shapiro. "The most successful people are often elevated by the algorithms, so you see them a lot. It's very easy to get stuck comparing yourself and worrying about your accomplishments. You need to remind yourself when to take a step back."

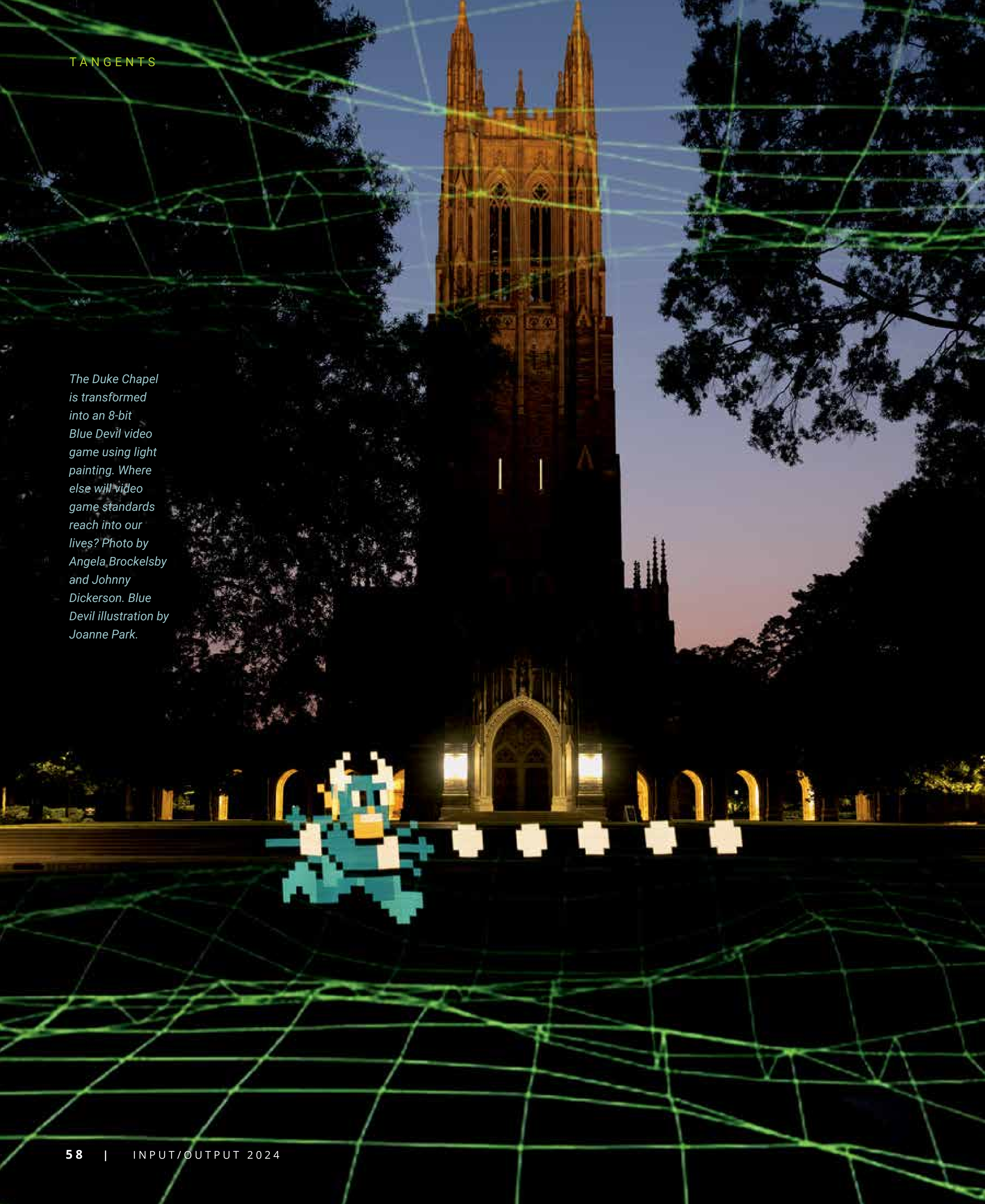
"There are two things that I try to protect at all times—my time and attention," echoed Brown. It's this mantra that recently led him to take a step back from X. He still plans to post his research papers and job openings, but he wants to otherwise limit his engagement with the site, at least for the time being.

"The quantum community that was on X basically crashed when the platform changed leadership in 2022, and the sad thing for me is that I haven't seen anything take its place," Brown said. "Our community was very diverse, but as X underwent changes, the platform felt like it got much more antagonistic."

Brown isn't wrong. According to data collected from the University of Southern California and the University of California, Los Angeles, the daily use of hateful speech nearly doubled after Twitter was sold in 2022. Many who fled X have since landed on LinkedIn and Threads, a platform that spun out through Instagram, but some communities are cautiously returning to X as it stabilizes.

Dinin fully recognizes the problems associated with social media platforms and their role in the ever-growing spread of misinformation. But these issues, he says, make it even more important for experts to effectively take advantage of these applications.

"It isn't for us to say whether these platforms are good or bad. Social media isn't going away, so we need to learn how to operate these tools, even with these constraints," he said. "You can draw a straight line from the printing press to Walt Whitman writing poems and editorials to YouTube and TikTok. It's just the next iteration of publication, and once you recognize that, you can recognize the opportunities we have at our fingertips." ■



The Duke Chapel is transformed into an 8-bit Blue Devil video game using light painting. Where else will video game standards reach into our lives? Photo by Angela Brockelsby and Johnny Dickerson. Blue Devil illustration by Joanne Park.

Leveling Up Our Game

With more game studios finding a home in North Carolina's Research Triangle, augmented and virtual realities growing in scope, and video game design reaching more diverse audiences, it's time we start understanding the medium beyond its tropes and stereotypes

By JAMAL MICHEL

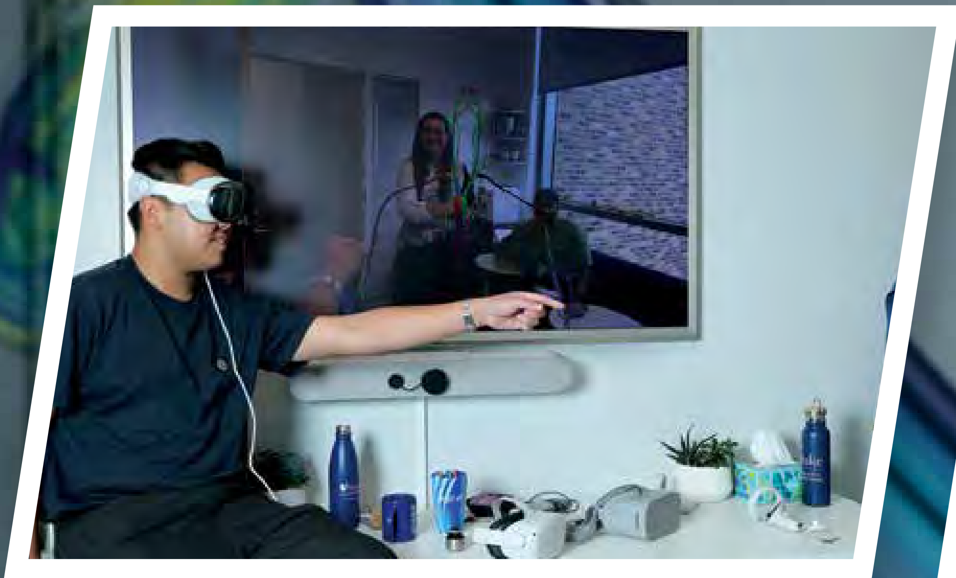
THE FILM AND MUSIC industries boasted some of their most commercially successful blockbusters in recent years, together raking in nearly $63 billion globally in 2023. Popular film franchises and timeless artists help propel these spaces to critical acclaim, but another, younger industry is making its own massive gains in the background.

It might come as a surprise, but the gaming industry earned nearly $184 billion in 2023 alone and shows no signs of slowing down in relevance or reach. From Ms. Pac-Man and Pong to Fortnite and Halo, this not-so-quiet-anymore industry has been steadily amassing revenue outpacing the film and music industries. Despite the commercial success, games have often been stereotyped as child's play with little to offer beyond their pixels.

But don't tell the growing professional industry behind video game design and development that.

More universities are offering programs tailored to students looking to study video games as well as building spaces for them to play and compete in the gaming arena competitively. Esports, as it's known in professional gaming, has seen a rise in recent years due to the highly competitive online scene, with teams from the U.S. and across the globe vying for millions of dollars in tournament winnings.

Academic researchers have been breaking down the social and cultural implications of digital representation in games. A video game series like *Call of Duty* can be scrutinized for its depictions of war, as well as others like *Metal Gear Solid* and *Mass Effect* that tackle themes of international espionage and free will.



85% OF U.S. TEENS *say they play video games, and* **ABOUT 4 IN 10** *do so daily.*

— PEW RESEARCH

Graduate students in the laboratory of Amanda Randles experiment with the Apple Vision Pro to perfect interactions and visuals that will allow doctors to make better-informed decisions about cardiac surgeries. Photos by Alex Mousan Sanchez.

Video games have transformed in their presentation and delivery, and the technology bringing these images to life has only improved.

PLAYING TO WIN, IN CLASS

Though the utility of something like video games may seem confined to the 3D space where bragging rights are up for grabs, game design offers a deeper look at how the digital space reflects the world around us. Teachers and educators use the game space as a launching point for deeper conversations about the design process.

Tools like the cross-platform engine Unity or the open source, interactive story creator Twine allow novice and expert game designers to engage with the development space more closely.

And that has opened the door for academic programs especially.

For instance, Duke University's newest graduate program combines engineering and gaming to produce an immersive experience for students through a hands-on learning environment. "Our students are placed into small teams, or studios, for the entire program," said Ernesto Escobar, executive director of Duke's Game Design, Development & Innovation Master's Program. "We're very excited about that—they'll be working as their own small studio to develop a game and make it ready for publication."

About 27 students will be joining the new program, making its launch one of the biggest at Duke Engineering. Escobar says this is the perfect opportunity to build relationships with other institutions in the region using video games to create bridges. "We'd love to plan game jams together with other programs in the state and also start thinking about ways to engage students earlier in their academic pursuits," he shared.

For Escobar, reaching students who are interested in the subject even before they consider graduate school or college is crucial for involving more diverse thinkers. A growing lack of resources across underserved communities makes connecting with those prospective students a challenge.

"One of our plans for the future is to go to middle schools and high schools to engage with these students as early as possible," he said. "That is the most important time to motivate and inspire and activate those students to go forward into technical careers and to maybe even consider graduate school."

Escobar also knows that for many, it's all about risk. The industry has recently seen a string of layoffs and studio closures as companies adjust to economic strains. "Parents of students interested in gaming may also have a perception of this risk," he said. "But there is a lot to be optimistic about in this space—there are a lot of different opportunities available in development and even in entrepreneurship."

Through the two-year graduate program, students will get to interact with AAA and independent studios as well as build a strong professional portfolio to be a competitive asset in the workforce. It's a chance to engage with video games in a multidisciplinary capacity while collaborating in one of the country's hotbeds for development.

And that means taking gaming beyond a form of entertainment.

Duke Engineering is uniquely situated between a network of interdisciplinary resources, and Escobar hopes to tap into that same network to bring game design into different arenas.

"We have very strong ties with the gaming industry in general, but we want to engage with other units at

Duke," he explained. "The medical field, for instance, is incredibly strong here, so getting to work closely with doctors, nurses, and physical therapists would present new opportunities."

A DIFFERENT KIND OF REALITY

The virtual world isn't entirely new to biomedical researchers at the university. Amanda Randles, the Alfred Winborne and Victoria Stover Mordecai Associate Professor of Biomedical Sciences, uses 3D printing in her classes alongside augmented reality and simulation to do virtual surgery.

And they surprisingly achieve this in one of the more unlikely places: Unity.

"Doing it on that platform is hugely important for students because there isn't much they need to code," Randles said. "They can go in, drop a shunt, perform the surgery virtually, and not have to worry about the complex aspects of the design."

Randles also teaches a parallel computing for biomedical simulation course that offers students the chance to focus on specific projects.

"A large focus of our research is on making 3D patient-specific blood flow simulations," she shared. "It involves fluid dynamic software through large scale parallel computing."

The conventional example in this case is, if someone has a narrowing lesion in their coronary artery, then

“We have very strong ties with the gaming industry in general, but we want to engage with other units at Duke. The medical field, for instance, is incredibly strong here, so getting to work closely with doctors, nurses, and physical therapists would present new opportunities.” **— ERNESTO ESCOBAR**

Augmented realtiy is already making complex procedures such as mechanical repairs easier for novices to handle themselves.

doctors will need to decide whether a stent is needed using a guided wire that measures pressure.

“In our work, we create 3D virtual models that can run blood flow simulations and virtually measure that pressure instead,” Randles explained.

This “digital twin” makes it so that everything can be accomplished noninvasively, highlighting the power of a tool like Unity when applied to other professional industries. And Randles takes it further—the ability to customize the virtual space allows students to engage with any number of possible surgery scenarios.

“If students are trying to assess what the right intervention is for a pediatric patient, which shunt should they pick?” she said. “In class, they can then modify the geometry to represent whatever surgery they need to try out and run the flow simulation, so that even before they ever step into the operating room, they can experiment with several different options and treatment plans.”

This approach mimics a clinician’s interaction, allowing students to test different options virtually before they’re even in an operating room.

Getting that crucial data back to doctors is how video game design aids in the visualization process, too. Randles says they work with petabytes of data—that’s one million times larger than a gigabyte. Advanced 3D modeling makes disseminating information more accessible, and the same tools that bring animated figures to life in the gaming world are also being used to relay massive amounts of information to medical professionals.

For Randles, key collaborations help make these goals possible. “We work with the Argonne National Laboratory for visualization—students have worked directly with them to help us not only figure out the best tools to connect with but also improve those tools and build on them to create new ones,” she shared.

Randles says that these 3D tools can become trends that change quickly over time, but her focus is using surveys to understand how useful these resources actually are.

“It’s not just a tool to show off when people come to the lab,” she explained. “What we’re really trying to understand is, when is it going to be useful for doctors or healthcare workers?”

What video game design and development offers goes well beyond entertainment. Graphics processing units, or GPUs, were made with games in mind at their inception, but researchers like Randles have taken advantage of their abilities to enhance even the medical space. “Even beyond GPUs, we’re going to make use of everything that’s been developed for gaming to improve computational modeling for health care,” she said.

“I feel like it’s a natural shift in our area—we’re building on this powerful tool that also happens to come from video games.” ■

IMAGINING THE Robots of Tomorrow

Duke researchers are pursuing robots that learn like humans, help perform delicate surgeries and look after manned space crews

By JAMAL MICHEL

TWENTIETH-CENTURY FILM and television are chock full of depictions of robots that tell a deeper story about the relationship humans have with technology. From the fears stoked by Cold War era advances in tech, to space travel amplified through the aid of droids and cyborgs, society has had a lot to say about the power of robots.

And we've been especially obsessive about cautionary tales. In the 1980s, Arnold Schwarzenegger's famous killer cyborg in *The Terminator* told of a future in peril due to advances in artificial intelligence. The 2008 Disney Pixar film *WALL-E* told the story of a solitary robot left to clean up an uninhabitable planet Earth after humans failed to preserve it.

As bleak as some of the stories are, it's not all bad.

Some takes in science fiction have shown just how far advances in areas like biomedical engineering could go because of robotics. For instance, the world of Wakanda, the fictional afrofuturist country set in sub-Saharan Africa in the Marvel universe, has scientists who have managed to create technology that is controlled through neurological commands. The biomedical engineers of Wakanda have even been able to build virtually indestructible prosthetics using rare minerals.

Not all of us, however, have access to space-age metals that don't degrade. At Duke, researchers are trying to figure out just how practical robots can become in our everyday lives.

And it starts by asking the right questions.

Dan Buckland is one of many Duke faculty members pushing the limits of what is currently capable through robotics, especially in the surgery and health care spaces. Photo by Eamon Queeney.

1

How do we build general purpose robots?

For Boyuan Chen, the answer goes beyond focusing on a singular application. As an assistant professor in the Thomas Lord Department of Mechanical Engineering and Materials Science (MEMS), and Duke's Departments of Electrical and Computer Engineering (ECE) and Computer Science, Chen's research is more than just the study of robotics. His specific interests are in developing "society-centered generalist robots" that learn and improve through dynamic interactions with the world, aiming to address significant questions in our society.

"One unique aspect of my research is to seek concrete but fundamental principles that can power the development of intelligent machines for diverse domains and applications," Chen explained, as he guided me through a winding corridor of robotics labs at the university. "Through our work, we study the science of embodied intelligence to answer what are the basic ingredients that we can bake into machines such that they have the capacity to learn and evolve over time."

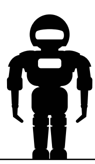
Chen is the director of Duke General Robotics Lab, which is broadly interested in both the hardware and software development of AI-enabled robotics. This combination may cover fields like robot learning, perception, machine learning and human-AI teaming.

The hope is that, through this dynamic engagement, these robots would ultimately acquire high-level cognitive skills by themselves to work alongside humans as our partners or teammates. Chen upends the conventional approach to thinking about artificial intelligence by instead realizing that machine intelligence has to have a "body and brain."

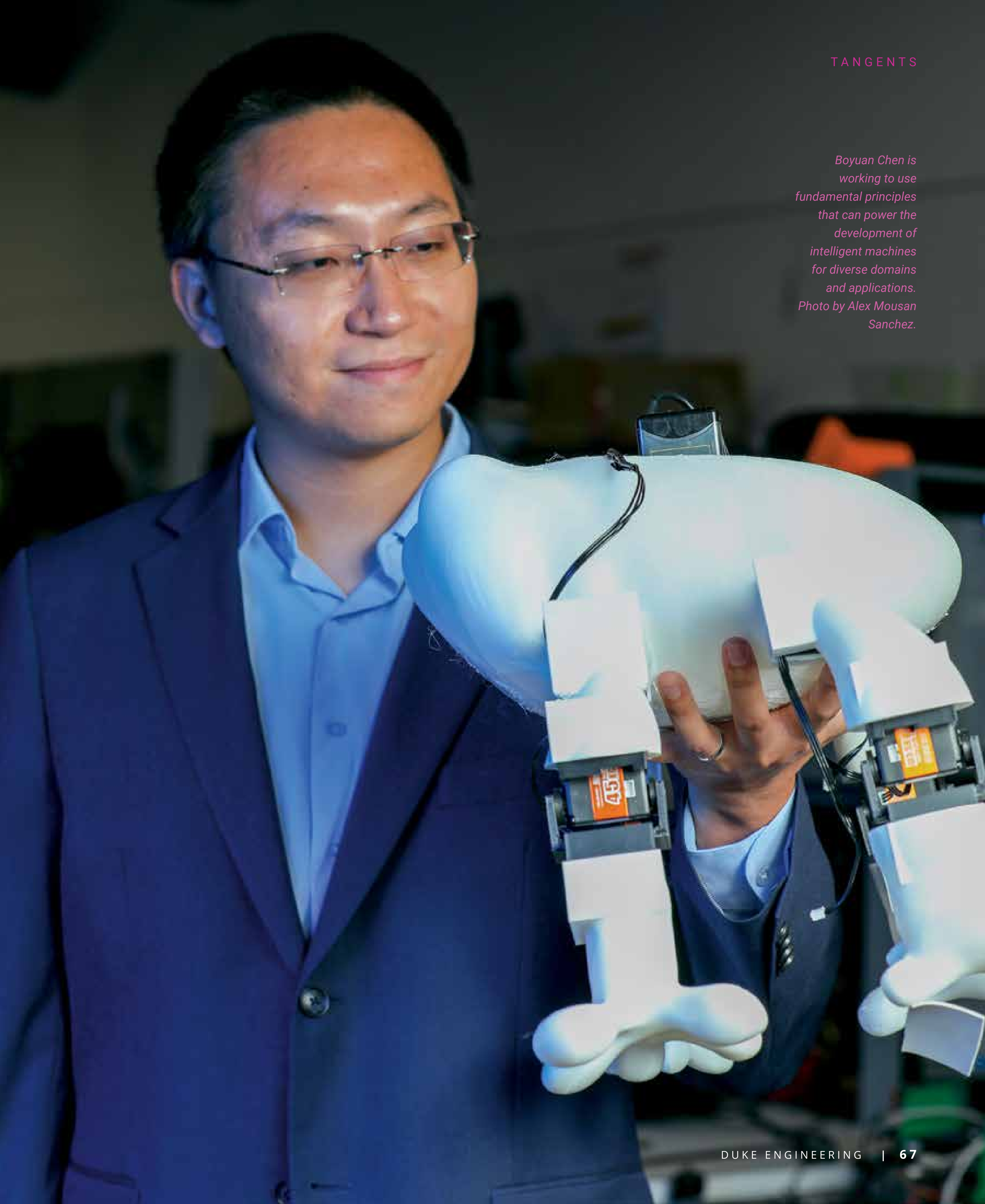
From mechanical systems to software and algorithms, Chen says the connective tissue—the "Holy Grail" of all of this—is adaptation. "You have to build mechanical systems with sensors around them, but you also have to look at software, which we call the brain, and its algorithms, for example, to build out a substantial perception system."

Though a relatively general term, adaptation in Chen's eyes should not be constrained to a narrow domain. Oftentimes people may think adaptation only refers to the way humans do it—we see data sets, perform tasks in various environments, and adapt where and when necessary. When we enter a new environment, we can quickly pick up new skills or adapt to that new environment, like learning to balance on icy surfaces.

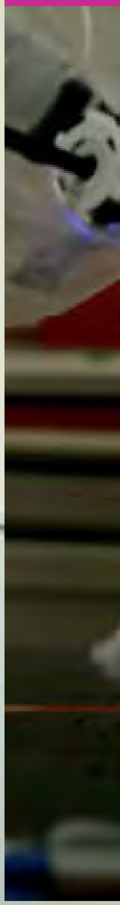
Chen takes this a step further, understanding that we can pass on this adaptation skill to robotic systems. "They may not have the same sensing system humans have, but robots with different body forms and configurations may be able to acquire the same skills," Chen explained.



"Through our work, we study the science of embodied intelligence to answer what are the basic ingredients that we can bake into machines such that they have the capacity to learn and evolve over time. **– BOYUAN CHEN**



Boyuan Chen is working to use fundamental principles that can power the development of intelligent machines for diverse domains and applications. Photo by Alex Mousan Sanchez.



2

Can robotics improve the already impressive abilities of our finest surgeons?

Duke's National Science Foundation Traineeship in the Advancement of Surgical Technologies (TAST) program is training graduate students with that very goal in mind.

TAST combines multiple disciplines to design advanced surgical technologies that consider provider, societal, end-user and patient needs in their development and testing. The program provides a pathway for graduate students in engineering and computer science to design fundamentally new technologies to advance medical practice.

"The reason why medical robotics is so important is because, when you want to do anything with medicine, it gets increasingly more complex and nuanced," said Siobhan Oca, assistant professor of the practice in MEMS, who has been instrumental in designing the new curriculum alongside fellow

Photos by Miranda Volborth.

"The reason why medical robotics is so important is because, when you want to do anything with medicine, it gets increasingly more complex and nuanced." **— SIOBHAN OCA**

MEMS professor Brian Mann. One of the strengths of TAST is the opportunity to collaborate with the breadth of medical faculty at Duke.

Through this traineeship, fellows engage in research goals that build collaborative relationships while developing professional skills through focused group activities. And to augment the program, multiple certificates in robotics have been implemented for students to engage with these convergent fields.

The Surgical Education and Activities Lab (SEAL) is another resource with medical robotics in mind. This lab is a state-of-the-art surgical simulation center designed to provide advanced and innovative training in a risk-free environment. Oca says preparing students for industry is a significant feature that shouldn't be overlooked.

"Conversations about what the industry offers and is looking for really empower students to think about where they can be part of the robotics workforce in a thoughtful way," Oca shared. "You are looking at jobs in particular that are focused on advanced degrees and skills that come from focused research training."

Exposing students to these diverse experiences enables them to pursue their specialized interests and offers more career opportunities to create the robo-surgeons currently relegated to science fiction.

Students and teachers in the Surgical Education and Activities Lab get hands-on experience with today's most advanced surgical robotics tools.

"There are plenty of things humans do in an emergency room, ambulance, healthcare system or even a spaceship that can be automated."

— DAN BUCKLAND

Photo by Eamon Queeney.

3

Can robots help us reach for the stars?

Scientists and physicians at Duke led by Dan Buckland, assistant professor of emergency medicine, are developing technology for NASA that looks at improving the health and performance of astronauts on exploration missions.

"From a robotics standpoint, what I look at is automation and, by extension, what it's going to look like on these exploration missions," Buckland shared. "I also try to understand how automation in exploration impacts human health and performance in particular." Buckland also leads the Duke Acute Care Technology Lab (DACTL), where they research developing technology for the diagnosis and treatment of acute diseases using data science and robotics methods.

Buckland connects these various areas of focus by investigating automation in safety-critical systems, which are systems that, if they fail, will result in loss of life or limb. "There are plenty of things humans do in an emergency room, ambulance, health care system or even a spaceship that can be automated," Buckland explained.

Discussions about AI are frequently confined to people interacting with devices or computers, but he notes that it becomes robotics when automation in a computational world impacts people without someone facilitating that connection. "I only have so many people or so much space," Buckland said. "Robotics allows me to deliver care remotely and at a bigger scale."

"Duke has several biomedical engineering courses that focus on clinical problems through a biomedical engineering lens," Buckland explained. "TAST and its focus on mechanical engineering methods provides a unique perspective that starts with an engineering and automation approach to health problems, instead of clinical problems searching for engineering solutions."

This kind of medical engineering is different in that it distributes competencies across disciplines. Going into a hospital, Buckland says he is one of a select few doctors who also have expertise in engineering.

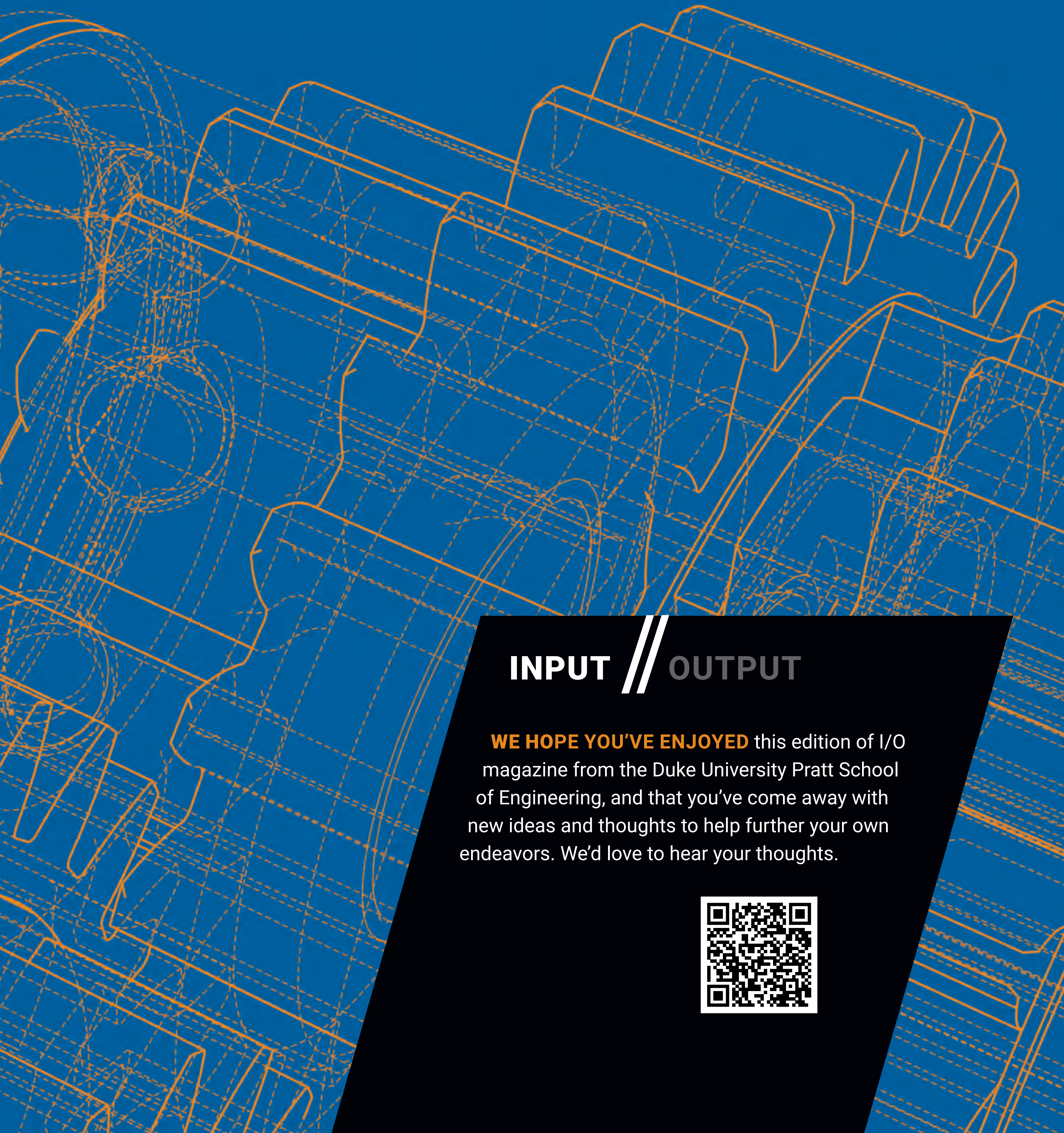
"I'd say one of my goals is to help students become valuable contributors in both fields. You may not go to a hospital looking for the best engineer or an engineering school for the best doctor, but it's the kind of guidance

Photo by Eamon Queeney.

we offer students looking to master this dual profession," Buckland said.

Cross-professional collaboration typifies how robotics at Duke is transforming the field. The TAST program, the university's robotics lab and the extensive course offerings equip incoming graduate students with the tools needed to navigate multiple disciplines, all while existing at the intersection of medicine and robotics.

"One of the benefits of Duke is its geography," Buckland said. "The medical school and the engineering school stare at each other from across the street. The faculty in both go to the same coffee shops and cafeterias, even the same sandwich shops. But what we're doing is working continuously to bridge that gap so that we're closer than just across the street at the end of the day." ■



INPUT // OUTPUT

WE HOPE YOU'VE ENJOYED this edition of I/O magazine from the Duke University Pratt School of Engineering, and that you've come away with new ideas and thoughts to help further your own endeavors. We'd love to hear your thoughts.

INPUT / OUTPUT

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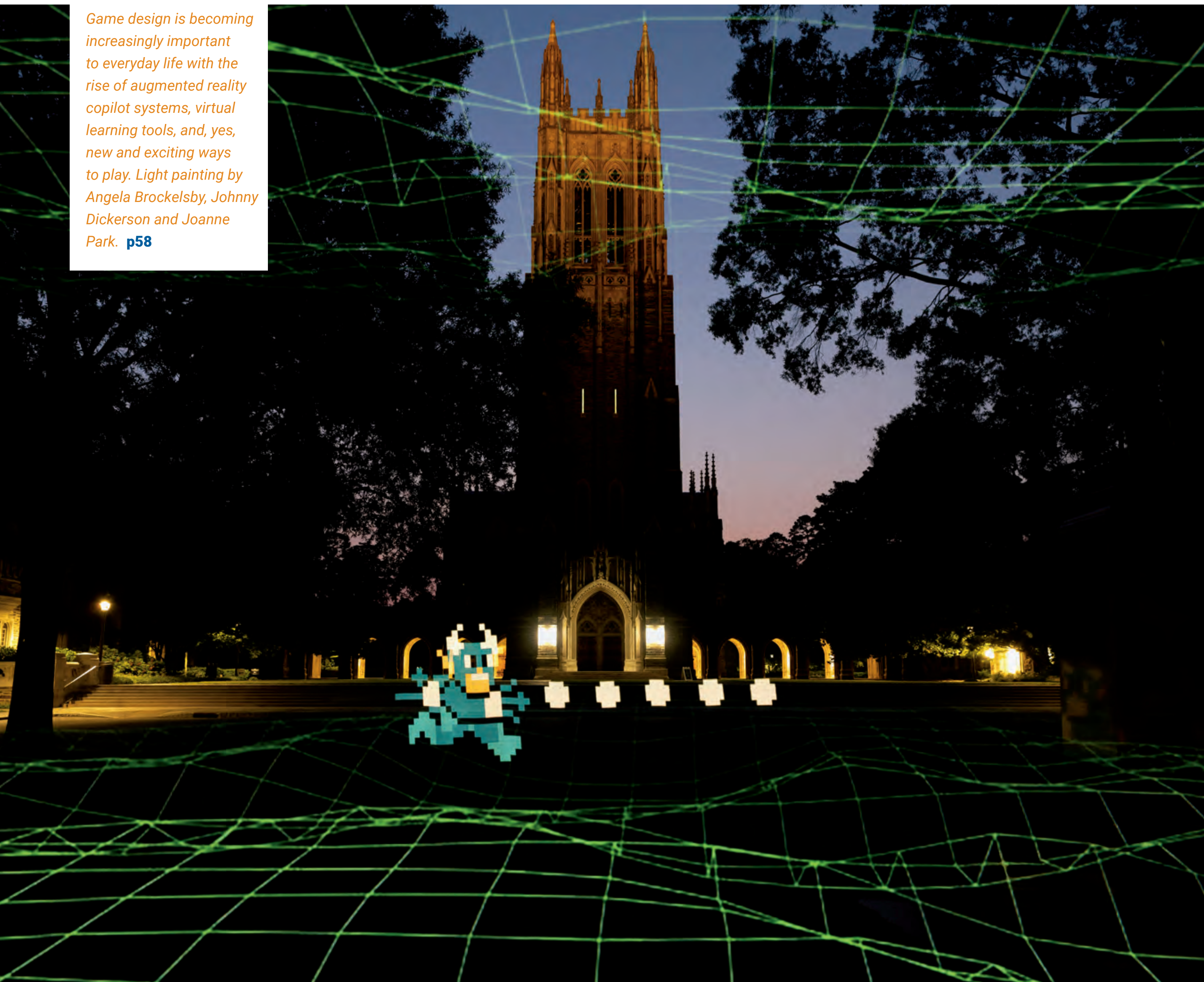

Game design is becoming increasingly important to everyday life with the rise of augmented reality copilot systems, virtual learning tools, and, yes, new and exciting ways to play. Light painting by Angela Brockelsby, Johnny Dickerson and Joanne Park. **p58**