Solutions

VANDERBILT SCHOOL OF ENGINEERING
Nashville, Tennessee | 2021-2022

OPTIMIZING
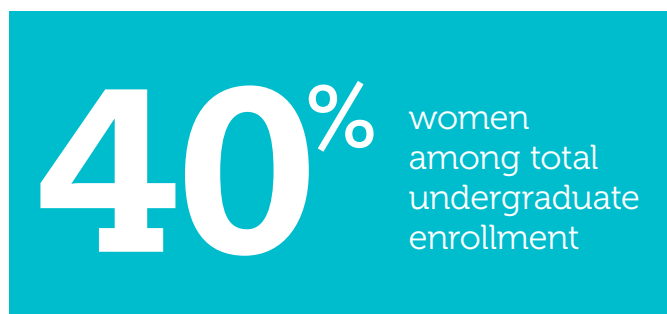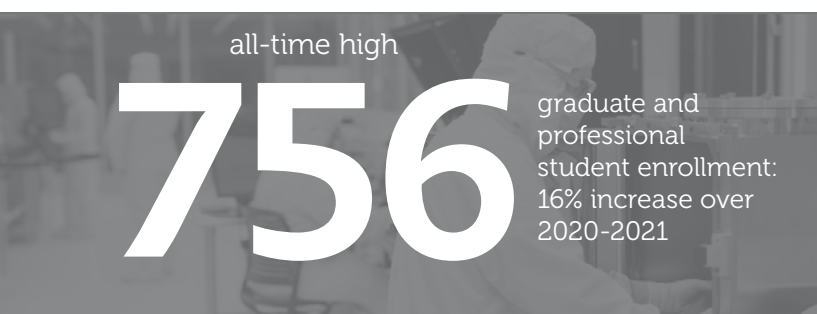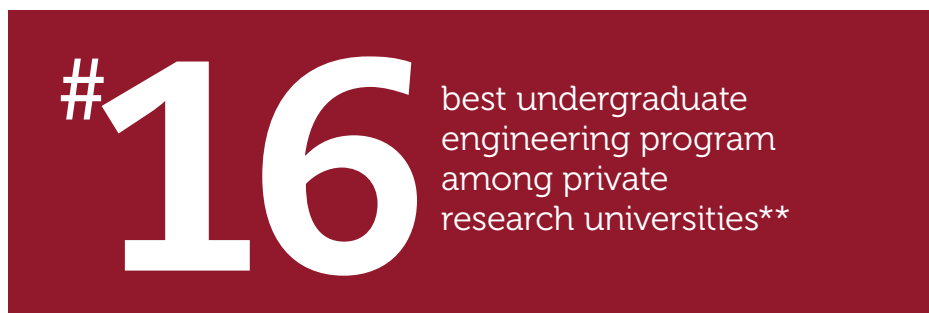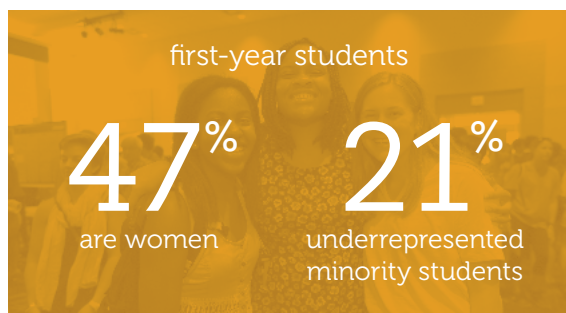inland waterway
freight capacity

ACHIEVING
Dual-band
optical processing

REFINING
Algae metabolism
for biofuels

Numbers of note

first-year students

47% are women

21% underrepresented minority students

#16 best undergraduate engineering program among private research universities**

90% of graduates have job offers before graduation*

all-time high

756 graduate and professional student enrollment: 16% increase over 2020-2021

40% women among total undergraduate enrollment

60% of undergrads participate in research projects outside the classroom

120 faculty honors from 36 societies

engineering undergraduates

32% have interned or studied abroad

16 institutes and centers

*U.S. citizen and permanent residents who sought employment (Class of 2021)
**US News and World Report, Sept. 2020

Solutions

INSIGHT ● INNOVATION ● IMPACT

6 From the Dean

The transformational force of computer science cannot be underestimated.
With CS becoming, in effect, a core competency, the School of Engineering
hired 10 new faculty members in the first year of a multi-year recruitment effort.

18 Surgery and Engineering

The first graduates of an immersive
clinical training program for engineering
PhD candidates are poised to influence
patient care, medical device development,
and engineering education.

32 Risk, Reliability, and Resilience

A case study of how markets that receive at least
some petroleum by river barges fared during the
Colonial Pipeline shutdown shows the potential of
inland waterways to increase supply chain security.

36 Cyber-Physical Systems

Before urban commuters take
to the skies, a multi-institution
team with Vanderbilt engineers
and funded by NASA will
develop and test the foundations
of safety management for
commercial, self-piloted air taxis.

Internship success fueled by coursework, mentors, career development emphasis

By Hannah Farley, Computer Science, '23

This past summer, I had the opportunity to work as a Technical Program Manager Intern at SiriusXM and Pandora. I spent the beginning of my 10-week program learning about the agile software development process, stakeholders in the software development lifecycle, and using Jira, a project management software.

When I shifted into the TPM role I assumed full responsibility for a particular set of app features. As a TPM, I coordinated with engineering leads, software engineers, product managers, and UX designers to schedule meetings and lead syncs. Additionally, I ran cross functional meetings, utilized the beta app to identify bugs and verify behavior, tracked project completion via Jira, presented to senior leadership, and participated in hallmarks of the agile process, such as scrum, feature grooming, triage, and sprint planning. My responsibilities as a TPM also led me to learn a new programming language, JQL (Jira Query Language.)

Separately, I coordinated with another intern to develop a standard, optimized system for tracking progress and presenting it to senior leadership. Our mentors and managers, who recognized us as fresh eyes, explained the issue, its downstream implications, what they had tried before, and what an ideal solution would achieve. Through research, interviews, collaboration, gap analysis, and trial and error we developed a solution that met the requirements. The following weeks were spent presenting our solution to senior management and holding informational sessions to help existing teams implement it.

More than a few Vanderbilt experiences prepared me for this internship. The most notable is the overarching premise of my engineering education: problem solving. Vanderbilt School of Engineering's emphasis on the development of problem-solving skills equipped me to meet every challenge with poise and enthusiasm. This attitude allowed me to take on additional responsibilities and contribute in ways with lasting and meaningful impact.

From a technical perspective, my computer science classes focused on coding primed me to learn a new programming language swiftly and comfortably. My engineering management courses, specifically Applied Behavioral Science, helped me expand soft skills necessary to succeed in an engineering management role.

My experience at Vanderbilt also has been marked by the support I've received from people as well as organizations. As a Clark Scholar, I entered Vanderbilt with an automatic network of over 40 people who were invested in my success. In fact, before my internship interview, a fellow Clark Scholar spent hours helping me prepare and assuring me I would do great. Not only did I find mentorship from older Clark Scholars, I also found a great mentor in our faculty adviser, who consistently provided valuable feedback, advice, and guidance.

Still, I would have never even been at SiriusXM and Pandora if not for Vanderbilt's emphasis on career development and internships. Soft skills and programming know-how are well and good, but they must be put to use! Education is cumulative, and my time at Vanderbilt allowed me to seize this opportunity, learn a great deal from it, and excel in my position.

Clinical observation adds rigor, real-world design constraints to BME graduate studies

By Eric Tang, PhD candidate
Department of Biomedical Engineering

Photo credit

It was midsummer as I stood out on the docks, dehydrated, covered in mosquito bites, but still motivated to complete my project, which involved constructing a raft to hold blue crabs while studying their development. By the end of my time at a marine lab, I had a makeshift raft built from spare plywood and inflatable tubes, though half of my blue crabs had escaped. While some might see this as a failure, I still view the process as a foundational experience that foreshadowed the ups and downs of doctoral research.

As I continued my undergraduate studies, my interests shifted toward the medical aspects of my major, biomedical engineering. I joined another lab and began work on a project to develop a handheld probe to image circulating tumor cells in patients with melanoma. I was introduced to the rigorous design constraints of translational research, which made the project significantly more challenging—but simultaneously more rewarding— than designing a raft for blue crabs.

In coming to the Vanderbilt School of Engineering for graduate studies, I wanted to continue translational work, which led me to join the Diagnostic Imaging and Image-Guided Interventions Laboratory under Dr. Kenny Tao, assistant professor of biomedical engineering. My current project focuses on developing image-guidance tools to improve visualization of ophthalmic microsurgery in hopes of improving surgical outcomes for patients who have lost vision though diseases such as diabetic retinopathy and macular degeneration. Through a collaboration with the Vanderbilt Institute for Surgery and Engineering, I joined the T32 training program, which bridges the gap between the engineering and clinical sides of translational research with clinical observation. I shadowed Dr. Shriji Patel, an ophthalmologist and retina specialist at VUMC, obtaining first-hand experience of patient care.

My experiences in the clinic and operating room have helped me better understand the limitations of current technology and the potential to improve patient care. Ophthalmic surgery, for instance, is conventionally performed under a 2D microscope. However, procedures such as epiretinal membrane peels involve the manipulation of fine ocular tissues that are only tens-to-hundreds of microns thick. My own research, which involves providing 3D visualization of these surgical maneuvers, can offer depth-guided feedback for surgeons and potentially help verify completion of surgical goals.

More importantly, my observation has challenged my way of thinking about my own project. Engineering design itself has many technical challenges, and clinical translation and implementation of technology raises additional barriers, including cost, ease-of-use, and integration into surgical workflow. We also must be able to account for case variability, changes in the surgical environment, and patient and disease differences. With the guidance of mentors in the T32 training program, I have been able to think more broadly and critically about my project, and I intend to maintain a close collaboration with them to bring a fresh perspective as I continue my research.

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COMMERCIAL IMPACT

Widely used software tops 1,000 academic licenses

A software tool for metabolic analysis developed by a Vanderbilt chemical engineer has passed 1,000 total academic licenses and is the most licensed software on the university's online licensing and e-commerce platform.

Additionally, it was the third highest revenue generator on the platform, VU e-Innovations, for 2020. About 20 total commercial licenses have been sold since INCA was released. In 2020, a total of 125 licenses, the bulk of them academic, were sold.

INCA, or Isotopomer Network Compartmental Analysis, enables researchers to model data from metabolic tracer studies and quantify the flow of labeled atoms inside living cells. The information provided by INCA can help to better understand metabolic diseases and improve the productivity of cell-based bioprocesses.

"We developed it to serve our own research needs," said Jamey Young, professor of chemical and biomolecular engineering. "We were investigating the metabolism of tumor cells, how they use nutrients to grow and survive. We needed better software tools to make sense of the data we were collecting in the lab."

INCA, which was released in 2014 as part of the Young Lab's Metabolic Flux Analysis suite, automates flux analysis of isotope tracer experiments, which has become an essential component of metabolic engineering research. The most common metabolic tracer is carbon-13. Researchers feed cells with a labeled nutrient, and the carbon-13 can be detected through mass spectronomy as it is metabolized.

Young plans to release a major software update later this year. INCA, which is MATLAB-based, is further distinguished as the first publicly available software package that can analyze both steady-state and dynamic labeling experiments. The latter are especially relevant to photosynthetic organisms and cell cultures that metabolize the tracer very slowly.

Air quality startup advances to VentureWell

An indoor air quality monitoring startup founded by a PhD student in computer science is the first Vanderbilt University team to be accepted into VentureWell, winning a stage 2 grant.

Tim Darrah, who also is a NASA fellow, grew Intelligent Systems through the Wond'ry, Vanderbilt's Innovation Center. The company is developing software technology that uses internet-connected sensor devices and deep learning algorithms to monitor HVAC systems and identify indoor air quality problems.

Through Wond'ry's Post Launch program, Darrah connected with experts in entrepreneurship who also helped his team successfully compete in the NSF Innovation Corps program. He said working with mentors and advisers at the Wond'ry gave him and his co-founders a chance to think through the details and nuances essential to a growing business.

Teddy Dinker, MBA '20, serves as the company's chief revenue officer, and Kenneth Konam, an undergraduate student in chemical engineering, and Diego Manzanas-Lopez, an electrical engineering PhD student, joined the team as well.

At Vanderbilt, Darrah's research focus is in cyber-physical systems and the development and application of algorithms handling prognostics and health management and decision-making for aerospace vehicles. He has worked on research projects in these areas sponsored by the Office of Naval Research, Department of Defense and NASA. Darrah is a U.S. Army veteran and served in Afghanistan.

VentureWell, formerly known as the National Collegiate Inventors and Innovators Alliance, funds and trains faculty and student innovators to create successful, socially beneficial businesses.
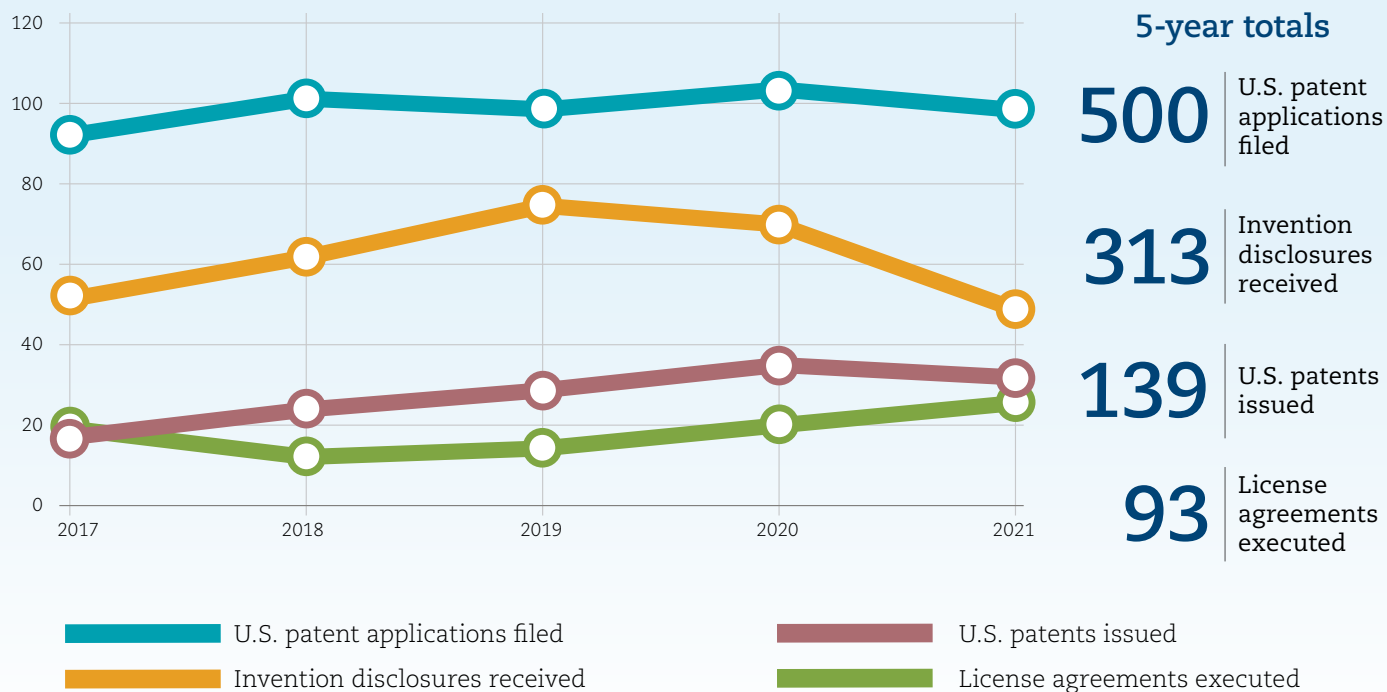
Most Recent Fiscal Year

99 U.S. patent applications filed

49 Invention disclosures received

139 U.S. patents issued

93 License agreements executed

5-year totals

500	U.S. patent applications filed
313	Invention disclosures received
139	U.S. patents issued
93	License agreements executed

Legend:
— U.S. patent applications filed
— Invention disclosures received
— U.S. patents issued
— License agreements executed

(Chart x-axis: 2017, 2018, 2019, 2020, 2021; y-axis: 0 to 120)

Vanderbilt climbs in NAI ranking

The National Academy of Inventors and the Intellectual Property Owners Association has ranked Vanderbilt University 35th among top 100 worldwide universities granted U.S. utility patents in 2020.

This is up one spot from 2019. The list was compiled using data obtained from the U.S. Patent and Trademark Office during the 2020 calendar year.

It was a record-setting year for Vanderbilt faculty and the Center for Technology Transfer and Commercialization. In FY20 alone, CTTC facilitated 1,057 material transfer agreements, 94 licensing transactions, 33 investor pitches and five startup opportunities; issued 76 U.S. patents and evaluated 168 invention disclosures across 63 distinct departments, divisions,

institutes and centers. The faculty working with CTTC on commercializing their research spans the School of Engineering, School of Nursing, College of Arts and Science, School of Medicine Basic Sciences, Peabody College of Education and Human Development, and School of Medicine Clinical Sciences.

"Despite all the challenges of the pandemic, we had a tremendous year in 2020 thanks to the innovative thinking that is the hallmark of our Vanderbilt community and the dedication of the CTTC team," said Vice Provost for Research Padma Raghavan. "Our position on this list is a reminder that the Vanderbilt research community has a key role in shaping our world for the better."

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$7,429,010 | Revenue generated from VUSE technologies in five years

These figures were provided by Vanderbilt's Center for Technology Transfer and Commercialization for the most recent fiscal year (July 1, 2020 through June 30, 2021).

21st Century literacy

School positioned for new interdisciplinary partnerships and evolution of computing

by Philippe Fauchet
Bruce and Bridgitt Evans Dean of Engineering

Once a domain of room-sized mainframes and esoteric databases, computer science is everywhere and part of everything. Basic understanding of it has become, in effect, a 21st Century competency.

The World Wide Web launched as a public domain less than 30 years ago. Your smartphone has more than 100,000 times the processing power of the computer that helped land U.S. astronauts on the moon. The global digital payments industry is expected to top $6.6 trillion this year. Computing technology has exploded in terms of performance and exceeded all imagination in creating value.

Moore's Law predicts that processor speed and overall processing performance double every two years. Yes, it may be on shaky ground, because in pushing the very definitions of computation and processing, artificial intelligence, quantum computing, and nanobiology may prove Moore's Law irrelevant. The pace of growth with these new technologies, at least in the short term, will outstrip anything Intel cofounder Gordon Moore envisioned.

The School of Engineering is embracing this transformation. In an ever-changing technological world, we must adapt not only to stay relevant but also to lead in generating new kinds of knowledge with new kinds of partnerships. Twenty years ago, our Electrical and Computer Engineering and Computer Science programs were combined to focus on collaborations and strategic growth. This past summer we "re-created" them as two separate departments that must be allowed to grow in their own ways and capitalize on new forms of collaboration.

These partnerships will be with each other, with researchers throughout Vanderbilt, and with engineers and scientists at other organizations. To this end, we embarked late last year on a massive, multi-year faculty recruitment push. Destination Vanderbilt: Computer Science will add at least 20 new tenured and tenure-track positions in addition to existing hiring plans across all our engineering departments. These new CS hires are in four strategic areas:

- Autonomous and Intelligent Human-AI-Machine Systems and Urban Environments;
- Cybersecurity and Resilience;
- Computing and AI for Health, Medicine, and Surgery; and
- Design of Next Generation Systems, Structures, Materials, and Manufacturing.

In the first of three years, we hired 10 new CS professors with specialties ranging from quantum computing to computer vision, cyber-physical systems, autonomous vehicles, machine learning, medical robotics, and game theory. Additionally, we hired four faculty members in three other departments. You will meet all of them on pages 8 and 9.

The new CS and ECE departments will build on their areas of excellence as well as evolve with new core competencies. This arrangement also accommodates for forecasts in enrollment growth and the ever-increasing interest in computer science from non-engineering students.

ECE will focus on four strategic areas based on its faculty's established national and international recognition: electronic devices, circuits, and computing hardware; design and analysis of digital devices integrated with physical systems; signal and image processing, communications, computer vision, and control systems;

and photonics and optoelectronics. In fact, this work has been underway for years. With deep industry connections, the Institute for Space and Defense Electronics is the world's largest and most recognized university-facing radiation effects institute. Vanderbilt Institute of Nanoscale Science and Engineering, often in collaboration with Oak Ridge National Laboratory and other institutions, is creating new materials and solutions to problems long considered unsolvable.

These disciplines are inherently interdisciplinary. Consider a few examples from the pages of this issue of *SOLUTIONS*:

- An AI platform that invigorates education with narrative scenarios optimized for individual learners as well as groups,

- A breakthrough using light to transmit data at two separate infrared ranges—at the same time, in the same device,

- An algorithm that corrects for image distortions in brain MRIs to give researchers a more accurate picture of neurological pathways, and

- A system using sensors, drones, point-of-collection diagnostics, and newly imagined data streams to predict emergent biological threats such as West Nile virus.

Research supported by the Data Science Institute has a broad reach as well: deep learning methods for automating recognition of symbols on ancient pottery in Peru; natural language processing to render church records of enslaved peoples written in Spanish and Portuguese; machine learning to establish indicators and potential interventions in so-called diseases of despair, which contribute to higher midlife mortality in the U.S.

These latest projects span education, medical imaging, epidemiology, archaeology, history, and psychology and public health. Large efforts also are underway to improve mobility, urban quality of life, and personal and public safety.

With our new faculty, computer science will be more accessible to a wider range of Vanderbilt students seeking education in data science, cybersecurity, system architecture, and other computing-related areas required for career success and advancement in the world of today…and of tomorrow.

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Meet the new faculty

Ten CS faculty join school in first year of Destination Vanderbilt

Ten of the 14 new professors Vanderbilt University School of Engineering has hired are computer science faculty members recruited during the first year of Destination Vanderbilt: Computer Science.

Eight of the new faculty are in tenured or tenure-track positions. Two are professors of the practice and will help balance the teaching load in a rapidly growing department.

Destination CS is part of Destination Vanderbilt, a $100 million university excellence initiative to recruit new faculty launched in December 2020. The multi-year recruitment and hiring process in computer science will add at least 20 tenured and tenure-track positions at the Assistant, Associate, and Full Professor levels.

The 10 new computer science faculty members are Jonathan Sprinkle, Yu Huang, David Hyde, Forrest Laine, Kevin Leach, Meiyi Ma, Soheil Kolouri, Jie Ying Wu, Shervin Hajiamini, and Peng "Dana" Zhang.

The other new faculty are Xiaoguang Dong in mechanical engineering; Andrea Locke and Marc C. Moore in biomedical engineering; and Ahmad F. Taha in civil and environmental engineering.

Jonathan Sprinkle, professor of computer science
- Autonomous vehicles, modeling, cyber-physical systems
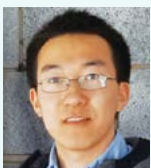- PhD in Electrical Engineering, Vanderbilt University, 2003
  Prior to joining Vanderbilt, Sprinkle was the Litton Industries John M. Leonis Distinguished Associate Professor with tenure and the Interim Director of the Transportation Research Institute at the University of Arizona.

Ahmad Taha, associate professor of civil and environmental engineering
- Dynamic networks and cyber-physical systems
- PhD in Electrical and Computer Engineering, Purdue University, 2015
  Prior to joining Vanderbilt, Taha was an assistant professor in electrical and computer engineering at the University of Texas at San Antonio.

Xioguang Dong, assistant professor of mechanical engineering
- Miniature robotics, soft robots, biomedical devices, magnetic actuation
- PhD in Mechanical Engineering, Carnegie Mellon University, 2019
  Prior to joining Vanderbilt, Dong was a postdoctoral researcher at the Max Planck Institute for Intelligent Systems.

Andrea Locke, assistant professor of biomedical engineering and assistant professor of chemistry
- Nano-biosensers, paper- and micro-fluid design, optical spectroscopy, analytical chemistry
- PhD in Biomedical Engineering, Texas A&M University, 2016
  Locke has been a postdoctoral scholar at the Vanderbilt Biophotonics Center and starts her new position in January 2022.
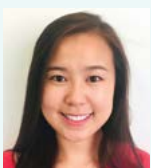
Yu Huang, assistant professor of computer science
- Software engineering and human factors
- PhD in Computer Science and Engineering, University of Michigan, 2021
  Huang will join Vanderbilt in January 2022. Her research interests are primarily at the intersection of software engineering and cognitive science.

David Hyde, assistant professor of computer science
- Computational physics, graphics, machine learning
- PhD in Computer Science, Stanford University, 2019
  Prior to joining Vanderbilt, Hyde was a postdoctoral scholar and an assistant adjunct professor in the mathematics department at UCLA.

Soheil Kolouri, assistant professor of computer science
- Machine learning and computer vision
- PhD in Biomedical Engineering, Carnegie Mellon University, 2015
  Prior to joining Vanderbilt, Kolouri was a Principal Machine Learning Scientist at HRL Laboratories, LLC, Malibu, California, focusing on aspects of deep learning.

Forrest Laine, assistant professor of computer science
- Computational game theory, numerical optimization, robust autonomy
- PhD in Electrical Engineering and Computer Science, UC Berkeley, 2021
 *Laine's primary interests are multi-agent interaction, multiple-object tracking, trajectory optimization, and robust machine learning.*

Kevin Leach, assistant professor of computer science
- Systems security and dependable autonomous systems
- PhD in Computer Science, University of Virginia, 2016
  Leach will join Vanderbilt in January 2022. He is a Senior Research Fellow in Computer Science and Engineering at the University of Michigan.
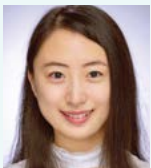
Meiyi Ma, assistant professor of computer science
- Machine learning, formal methods, cyber-physical systems
- PhD in Computer Science, University of Virginia, 2021
  Ma has developed novel formal logic-based learning frameworks to verify and guide deep learning models, as well as decision support systems for integrated IoT services in areas of smart cities and health care.

Jie Ying Wu, assistant professor of computer science
- Medical robotics and machine learning
- PhD in Computer Science, Johns Hopkins University, 2021
  Wu focuses on using machine learning techniques to transform surgical robots from a teleoperated tool to an intelligent assistant. She will join Vanderbilt in January 2022.

Marc Moore, associate professor of the practice of biomedical engineering
- Regenerative medicine, biomaterials and biomedical design
- PhD in Biomedical Engineering, University of Florida, 2013

Shervin Hajiamini, assistant professor of the practice of computer science
- Green engineering
- PhD in Computer Science, Washington State University, 2018

Dana Zhang, assistant professor of the practice of computer science
- Data Science and blockchains
- PhD in Computer Science, Vanderbilt University, 2018

NOTABLE

Mark Abkowitz, professor of civil and environmental engineering and director of the Vanderbilt Center for Environmental Management Studies, was appointed chair of the National Academy of Sciences committee on Extreme Weather and Climate Change Adaptation.

Bobby Bodenheimer was named Editor-in-Chief of *Transactions on Applied Perception*. His term as editor is Aug. 1, 2021, to July 31, 2024. He is professor of computer science, electrical engineering, and computer engineering.

Michael Goldfarb, H. Fort Flowers Professor of Mechanical Engineering, was elected as a fellow of the National Academy of Inventors, the highest professional distinction accorded solely to academic inventors.

University Professor **John C. Gore**, founding director of the Vanderbilt Institute of Imaging Science, was selected to give the Paul C. Lauterbur Lecture at the 2021 annual meeting of the International Society for Magnetic Resonance in Medicine.

Anita Mahadevan-Jansen, Orrin H. Ingram Professor of Engineering and professor of biomedical engineering, is president-elect of SPIE. She assumes the presidency in 2022.

Lloyd W. Massengill, professor of electrical and computer engineering, received the IEEE Nuclear and Plasma Science Society Radiation Effects Award at the 2021 International Nuclear and Space Radiation Effects Conference.

Michael Miga, Harvie Branscomb Professor and professor of biomedical engineering, was named a fellow of SPIE for achievements in technology-guided surgery and computational modeling for therapeutic and imaging applications.

Cynthia Paschal, senior associate dean for undergraduate education and associate professor of biomedical engineering and radiology and radiological sciences, was named a fellow of the American Institute for Medical and Biological Engineering. She also was appointed chair of the ABET Academic Advisory Committee.

Craig Philip, research professor of civil and environmental engineering, was appointed to the Transportation Research Board Executive Committee. He is director of the Vanderbilt Center for Transportation and Operational Resiliency.

Marjan Rafat, assistant professor of chemical and biomolecular engineering, received an award for young and innovative cancer researchers from the Concern Foundation, a cancer research nonprofit based in Los Angeles, California.

Cynthia Reinhart-King, Cornelius Vanderbilt Professor of Engineering and professor of biomedical engineering, is the new president-elect of the Biomedical Engineering Society. She assumes the presidency in 2022.

Ronald Schrimpf, Orrin H. Ingram Professor of Engineering and Director, Institute for Space and Defense Electronics, received the 2021 IEEE Nuclear and Plasma Sciences Merit Award. He is a professor of electrical engineering.

Lori Troxel, professor of the practice of civil and environmental engineering, was one of two recipients nationwide of the 2021 American Society of Civil Engineers' Outstanding Faculty Advisor Award.

Christopher J. Wiernicki, BE '80, was elected to the U.S. National Academy of Engineering for innovative leadership in the design, engineering, and operation of ships and offshore structures. He is president and CEO of ABS and a member of the School of Engineering Board of Visitors.

Chuchuan Hong, **Lauren Buck**, and **Riqiang Gao** received the inaugural C.F. Chen Best Paper Awards, in electrical engineering, computer science, and translational research, respectively. The $5,000 awards recognize top journal articles for which a graduate student is first author. A gift from May Juan Chen, BA '68, and Chun Fu "CF" Chen, PhD '68, created the awards program.

Mayna Nguyen, a biomedical engineering graduate student, and computer science graduate student **Preston Robinette** received 2021 National Defense Science and Engineering Graduate Fellowships. The DOD-funded fellowships are supported by the Air Force Research Laboratory.

Hoang-Dung Tran, PhD '20, received the 2021 IEEE Technical Committee on Cyber-Physical Systems Outstanding Dissertation Award.

New endowments will provide additional support for rising faculty talent. The faculty fellowships were created with gifts from Sally Baker Hopkins, BE '78, and David L. Hopkins, Caroline and Jack P. Williams Jr., BE '86, and Laura J. and William W. Hoy Jr., BA '64. The university matched the donations.

A **Vanderbilt Computer Science** team won an IBM-sponsored challenge at the 2020 Neural Information Processing Systems Conference. The team's natural language processing model that took a description in English and converted it to its corresponding Bash syntax, a Unix command language, took top honors.

10

Emily Mueting

At the top

Two Vanderbilt biomedical engineers to lead prestigious academic societies

Two outstanding scholars in the same Vanderbilt engineering department have been elected presidents of distinguished academic societies. Anita Mahadevan-Jansen is president elect of SPIE, the international society for optics and photonics that serves 257,000 constituents from 173 countries. Cynthia Reinhart-King is president elect of the Biomedical Engineering Society, the professional home for biomedical engineering and bioengineering that serves more than 5,000 members.

Mahadevan-Jansen is an acknowledged leader in biomedical photonics. She is the Orrin H. Ingram Professor of Engineering, professor of biomedical engineering, and director of the Biophotonics Center at Vanderbilt. Reinhart-King is a trailblazing cancer researcher and leader in bioengineering. She is a Cornelius Vanderbilt Professor of Engineering, a professor of biomedical engineering, and director of the department's graduate studies.

"The appointments of Anita and Cynthia to lead eminent professional societies reflect the significant contributions they are making in their respective fields of engineering. To have both as faculty in the same department is remarkable!" said Philippe M. Fauchet, Bruce and Bridgitt Evans Dean of Engineering. "Their vision, leadership, and experience certainly will not only serve their colleagues around the world, but also

further enhance the mentorship of our students and the 'lead by example' philosophy we embrace as a school."

Mahadevan-Jansen's technical interests include biophotonics, optical spectroscopy, and imaging for disease detection, neurophotonics, cancer diagnosis, optical guidance of surgery, and clinical translation of optical technologies.

"I am reassured by the support of the optics and photonics community and I am excited to serve the society," said Mahadevan-Jansen, a SPIE Fellow.

Reinhart-King, a BMES fellow, is a cellular bioengineer whose seminal work on extracellular matrices has contributed to a breakthrough in understanding tumor formation. The citations of her cellular bioengineering research number in the thousands.

"I am drawn to building consensus, and I am not afraid to explore new ideas to arrive at a better outcome," Reinhart-King said. "We also are in a terrific window of having robust membership, with many BMES members who are eager to get involved with the society's activities, and a national lens on science and scientists."

Mahadevan-Jansen and Reinhart-King will serve as presidents-elect in 2021 and as the societies' presidents in 2022.

Engineering Neighborhoods

The Vanderbilt University School of Engineering has nine core areas of impact in which faculty, staff, students, and outside researchers provide insight, drive innovation, and create solutions. The neighborhood concept aptly describes as well as defines our distinctive culture of collaboration.

Neighborhoods celebrate and leverage our commitment to transinstitutionality, collaboration, and cross-pollination both within and beyond the traditional walls of departments, schools, institutions, and disciplines.

Rehabilitation Engineering develops mechanics and robotics to help restore lost physical and cognitive functions.

page 14

Cyber-Physical Systems technology develops processes, protocols, networking, and technology needed for the seamless and secure integration of cyber (software) and physical (hardware, networks, and users) systems.

page 36

Regenerative Medicine involves understanding behavior of unhealthy and healthy cells at a molecular level and development of methods to disrupt disease processes, as well as drug delivery, drug efficacy, and tissue engineering.

page 24

12

VANDERBILT SCHOOL OF ENGINEERING

Risk, Reliability and Resilience
advances risk quantification; improves predictability; increases reliability of systems, infrastructure and materials; and creates technology and materials with more resilience.

page 32

Nanoscience and Nanotechnology
concerns the discovery and application of how materials and processes behave on the nanoscale in diverse areas of engineering, science and health care.

page 16

Energy and Natural Resources
targets transformative research to enable sustainable resource and energy conservation, production, and recovery.

page 29

Biomedical Imaging and Biophotonics
uses physical phenomena such as magnetic fields, radiation, and light to aid diagnoses and treatments of disease and dysfunction.

page 26

Big Data Science and Engineering
develops tools and processes to harvest and leverage knowledge from data sets too large and complex for traditional software to handle and often involves predictive or user behavior analytics.

page 22

Surgery and Engineering
concentrates on the collaborative efforts of engineers and surgical experts to create, develop, implement, and evaluate technology, methods, and tools that improve patient outcomes and experiences.

page 18

13

Taking a load off

Army Futures Command backs soft exoskeleton development

Ongoing academic–military–commercial collaboration wins first Pathfinder Project award

Soldiers often carry 100 or more pounds in water, food, batteries, gear and more. Those in logistics and sustainment roles may also bend and lift heavy objects hundreds of times a day.

The extra weight and repetitive lifting come at a cost, and back injuries are a big one. The U.S. Army Public Health Center estimates an annual count of nearly 100,000 back overuse injuries, conditions that degrade the health, effectiveness, and readiness of soldiers.

To help improve the health of soldiers and the success of missions, the Army has turned to a Vanderbilt mechanical engineering professor and colleagues who developed a soft exoskeleton, or exosuit, to reduce back strain for warehouse workers. Through the Army Research Laboratory and the Civil-Military Innovation Institute, the Army Futures Command has invested $1.2 million in development of a soldier-inspired exosuit. It marks the agency's first Pathfinder Project award.

Pathfinder will support the work of Associate Professor of Mechanical Engineering Karl Zelik, his lab members, industry collaborators, and soldiers of the 101st Airborne Division at Fort Campbell. The concept, known as the Soldier Assistive Bionic Exosuit for Resupply, or SABER, will expand on more than two years of informal design sprints, interviews, and field exercises between Zelik's team and soldiers of the 101st to understand their needs and support field artillery missions.

A big design challenge will be how to best integrate an exosuit with Army uniforms and gear. HeroWear, the startup Zelik co-founded, now mass manufactures the Apex exosuit, which is in use in logistics,

A Pathfinder award from Army Futures Command will support a collaboration between Vanderbilt mechanical engineers, industry partners, and soldiers of the 101st Airborne Division at Fort Campbell to develop an exosuit that will augment lifting capabilities and reduce back strain.

agriculture, construction, and retail worksites around the world. In nearly all cases, however, these civilian workers wear only a shirt and/or a t-shirt.

"Soldiers wear a lot of other gear, like protective body armor," Zelik said. "One design challenge is how to attach an exosuit without interfering with the other equipment?"

Additionally, soldiers need speed and agility during a far wider range of motions—running, crawling, jumping, rolling among them. "It takes exosuit design to another level," Zelik said.

The SABER team's ability to leverage lessons from prior Vanderbilt research and development and from HeroWear's translation of the exosuit technology to a commercially available product make it an ideal fit for the Pathfinder program.

Pathfinder supports collaborations between researchers and creative soldiers to rapidly innovate high-impact, research-based technologies with a path to commercialization and prompt acquisition of products by the Army.

The project is part of the Soldier-inspired Innovation Incubator in which Vanderbilt University and Vanderbilt University Medical Center researchers in engineering, education, neuroscience, emergency medicine, ophthalmology, management, and other domains partner with each other, as well as with soldiers and private industry.

Daniel F. Flowers Professor Doug Adams, who directs the incubator, called the university's partnership with Army "a once-in-a-generation opportunity to totally transform the Army's approach

to research and development and technology transition."

"We are building a new model for research and development that is soldier-inspired, that connects the researcher to the stakeholder in ways that heretofore have never been attempted and, most importantly, in ways that quickly provide transformative research-based technological solutions that advance national security interests and improve soldiers' lives," said Adams, who chairs the Department of Civil and Environmental Engineering. **V**

Above: Warehouse employees test out the Apex exosuit. The exosuit, or flexible exoskeleton, is also in use in the agricultural, retail, logistics, and military sectors. Photo courtesy of HeroWear

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Team achieves dual-band optical processing, advancing silicon photonics

A team led by Vanderbilt engineers has achieved the ability to transmit two different types of optical signals across a single chip at the same time.

The breakthrough heralds a potential dramatic increase in the volume of data a silicon chip can transmit over any period of time. With this work, the research team moved beyond theoretical models and demonstrated dual-band optical processing, a significant advance in silicon photonics.

Using patterned silicon to transmit optical signals uses less power without heating up or degrading the signal. Silicon photonics uses light rather than electrical signals to transmit data. The need for faster and expanded processing has all but outstripped the limits of adding more wire to smaller and smaller chips, which requires more power, creates more heat, and risks data integrity.

Still, doing more with the same chip has been challenging. Silicon waveguides provide the principle building block of on-chip photonics, confining light and routing it to functional optical components for signal processing. Different forms of light need different waveguides, but linear scaling to accommodate more waveguides would quickly surpass the available space of a silicon chip in the standard form factor.

"It has been difficult to combine near-infrared and mid-infrared transmission in the same device," said Mingze He, a Vanderbilt mechanical engineering PhD student and f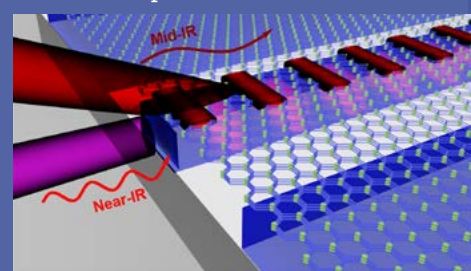irst author of the paper. "Guided Mid-IR and Near-IR Light within a Hybrid Hyperbolic-Material/Silicon Waveguide Heterostructure," was published online and in print in *Advanced Materials*.

Joshua Caldwell, associate professor of mechanical engineering, and Cornelius Vanderbilt Professor Sharon Weiss, professor of electrical engineering, led the team.

Two innovations—a novel approach and device geometry—allowed disparate frequencies of light to be guided within the same structure. Such frequency multiplexing is not new but the ability to expand the bandwidth within the same available space is.

Leveraging the infrared properties of hexagonal boron nitride, researchers devised a hybrid, hyperbolic-silicon photonic waveguide platform. The structure was demonstrated to guide long, mid-infrared wavelengths within nanoscale thickness slabs, with the optical modes following the path of the underlying silicon waveguide.

A novel approach and device geometry allow the guiding of disparate frequencies of light within the same structure, a significant advance in silicon photonics. Illustration: Caldwell lab

Mid-IR is widely used in the chemical and agricultural industries. Applications of near-IR include telecommunications and medical diagnostics.

First demonstration of a classic paradox effect bodes well for semiconductor development

Deyu Li, Professor of Mechanical Engineering

Nearly 70 years ago, the unexpected result of a numerical simulation sparked a chaos theory revolution in modern science and launched the study of nonlinear systems.

In 1953, Fermi, Pasta, Ulam, and Tsingou discovered an apparent paradox when investigating thermalization of mechanical vibration along a single atomic chain. Now, a research team led by Deyu Li, professor of mechanical engineering, and a former graduate student has produced the first experimental evidence of divergent thermal conductivity of aligned atomic chains, a direct consequence of that legendary numerical modeling, which is known as the FPUT paradox.
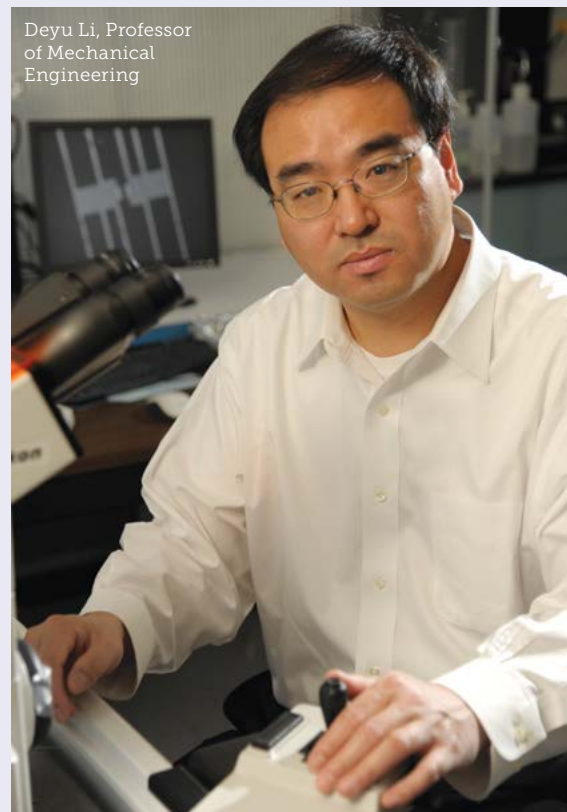
The groundbreaking work has significant implications for the development of more powerful electronics and other devices where relentless pressure for higher performance comes with a relentless escalation in heat loads. It points to a new route of creating a type of thermal superconductor with thermal conductivity values higher than that of any known materials.

Li and Lin Yang, PhD '19, now a postdoctoral research fellow at the Lawrence Berkeley National Laboratory, demonstrated experimentally that the thermal conductivity of a special kind of ultra-thin nanowires becomes divergent with the wire length. Their work, "Observation of superdiffusive phonon transport in aligned atomic chains," was published in the journal *Nature Nanotechnology*.

According to the FPUT paradox, the thermal conductivity of one-dimensional atomic chains would keep increasing with the chain length, which has been further demonstrated by numerous theoretical studies. However, until now, no experimental data had been obtained to prove the concept. In fact, the divergent thermal conductivity of one-dimensional atomic chains had been thought to be limited to academic interest because, in reality, achieving isolated single atomic chains of sufficient length has been almost impossible.

In their paper, Yang, Li and co-workers discovered that when the size of a quasi-one-dimensional $NbSe_3$ nanowire hits 26 nanometers, its thermal conductivity starts to increase sharply as the wire diameter further reduces. Such behavior is exactly opposite to the so-called classical size effect. They further showed that the thermal conductivity of diameter wires of less than 10nm becomes divergent with the wire length following a 1/3 power law length dependence, consistent with numerous theoretical predictions. The behavior violates the well-known Fourier heat conduction law and serves as the first observation of superdiffusive transport of one-dimensional phonons, which are discrete units or quantums of vibrational mechanical energy, in one-dimensional van der Waals crystal nanowires.
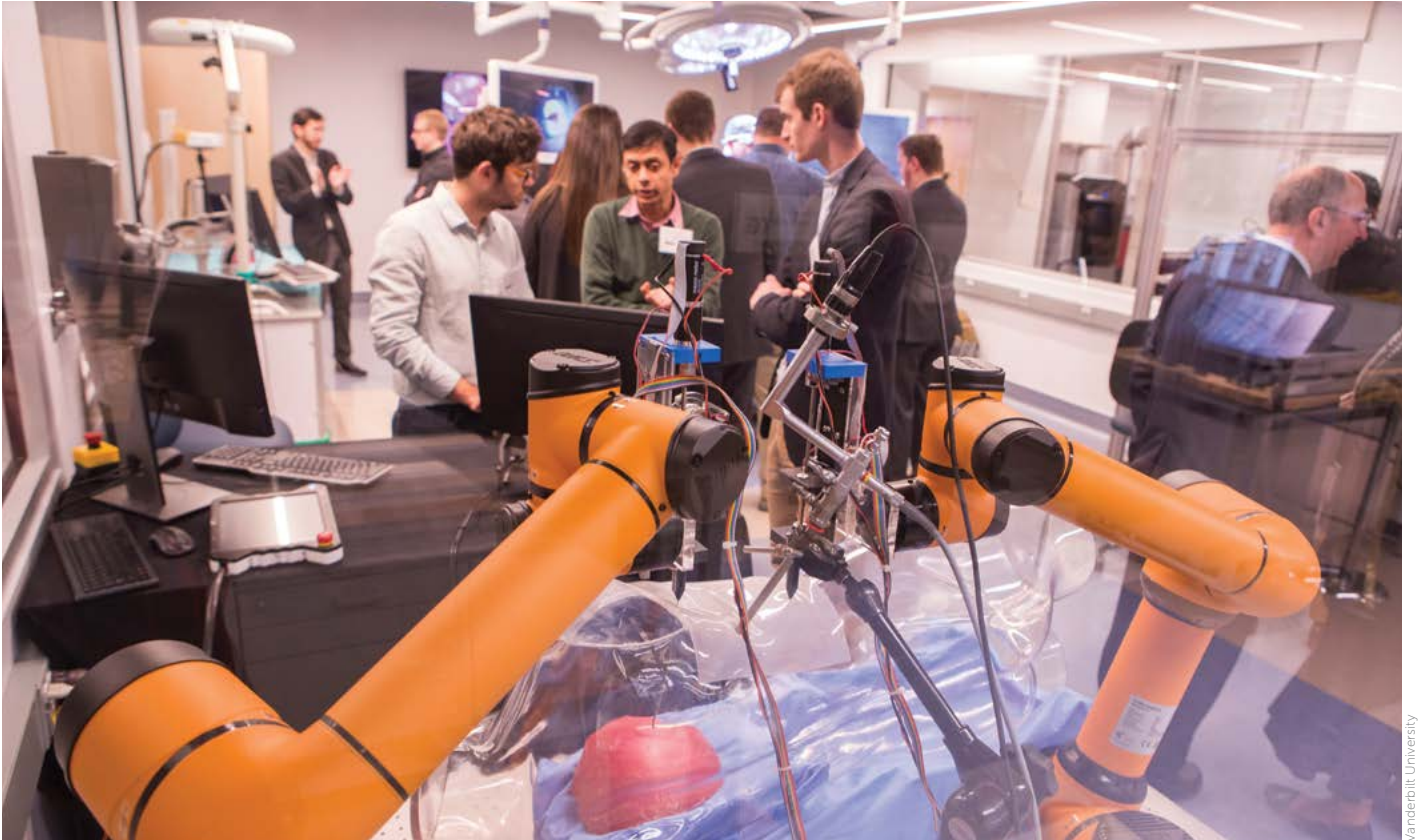
"The results are what I have dreamed to obtain since I worked on thermal transport through nanowires when I was a PhD student over 20 years ago," Li said.

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"The results are what I have dreamed to obtain since I worked on thermal transport through nanowires when I was a PhD student over 20 years ago.

Deyu Li
Professor of Mechanical Engineering

Immersive clinical training elevates engineering PhD programs

VISE alumni positioned to transform medical procedures

At the side of clinicians, Winona Richey gained big-picture knowledge of workflow, patient experience, and existing technology in the operating room. The exposure ignited ideas to improve tumor marking and surgery for breast cancer.

Carli DeJulius shadowed a rheumatologist and multiple orthopedic surgeons, observing six joint replacement surgeries and interacting with patients who have osteoarthritis and other joint diseases. Her research focuses on drug development for osteoarthritis.

She and Richey are biomedical engineering PhD students in an intensive training program supported by nearly $2 million from the National Institute of Biomedical Imaging and Bioengineering. The goal is to go beyond, far beyond, theory and spark ideas with the potential to transform health care.

Preliminary reports from the first five-year grant cycle suggest the program makes a difference—those immersive levels of clinical contact significantly improved trainees' understanding of procedural medicine and their ability to identify important questions that, once solved, could create breakthroughs in clinical care.

IMMERSIVE CLINICAL CONTACT

In the first five-year grant cycle, improvements were assessed in the ability to ask important questions in surgery and intervention, knowledge of surgical technologies, and understanding of procedural medicine. According to a self-reported survey, trainees observed at least 15 procedures and had at least 48 hours of clinical contact.

Significantly, the trainees reported a perceived improvement of 34% in their ability to pose important questions affecting human health.

"The engineering, surgery, and intervention ecosystem we have built at Vanderbilt is something wholly unique and with no parallels," said Michael Miga, Harvie Branscomb Professor and co-founder of the Vanderbilt Institute for Surgery and Engineering. "Many institutions have engineers who collaborate with physicians. Vanderbilt is different. It's much, much more."

At left: Patrick Anderson, PhD '20, right, discusses robot-assisted, flexible endoscopic surgery with colleagues at the grand opening of new VISE space in December 2018. Anderson was in the first cohort of the immersive clinical training program.

Below: Andria Remirez, left, and Margaret Rox, right, work on a concentric tube robot designed to perform endonasal surgery, using a setup that demonstrates how orbital tumors would be removed through the nose. Rox is in the training program's third cohort.

"**Technological advances to patient care in the next century will be better than any science fiction fantasy you find in your favorite books.**"

Michael Miga,
Harvie Branscomb Professor and Professor of Biomedical Engineering

Clinical immersion for traditional graduate engineering education is not common, he said, but is essential to advance procedural medicine.

"With such integration, the technological advances to patient care in the next century will be better than any science fiction fantasy you find in your favorite books," said Miga, also professor of biomedical engineering.

He and Robert F. Labadie, professor of otolaryngology, head, and neck surgery and a VISE affiliate, reported on the program in *Biomedical Engineering Education*, the official educational journal of the Biomedical Engineering Society.

REAL DOMAIN EXPERIENCES

The training program, which VISE administers, is for PhD students in biomedical engineering, electrical engineering, mechanical engineering, and computer science. The NIBIB funded it with a grant of almost $1 million in 2016 and renewed it in May 2021 for another five-year cycle (Grant NIH/NIBIB T32EB021937).

In the first of two core courses, trainees attend lectures by 10 or more physicians who present their procedural specialties, interwoven with lectures on related engineering principles. A second course provides clinically mentored immersion experiences in the operating
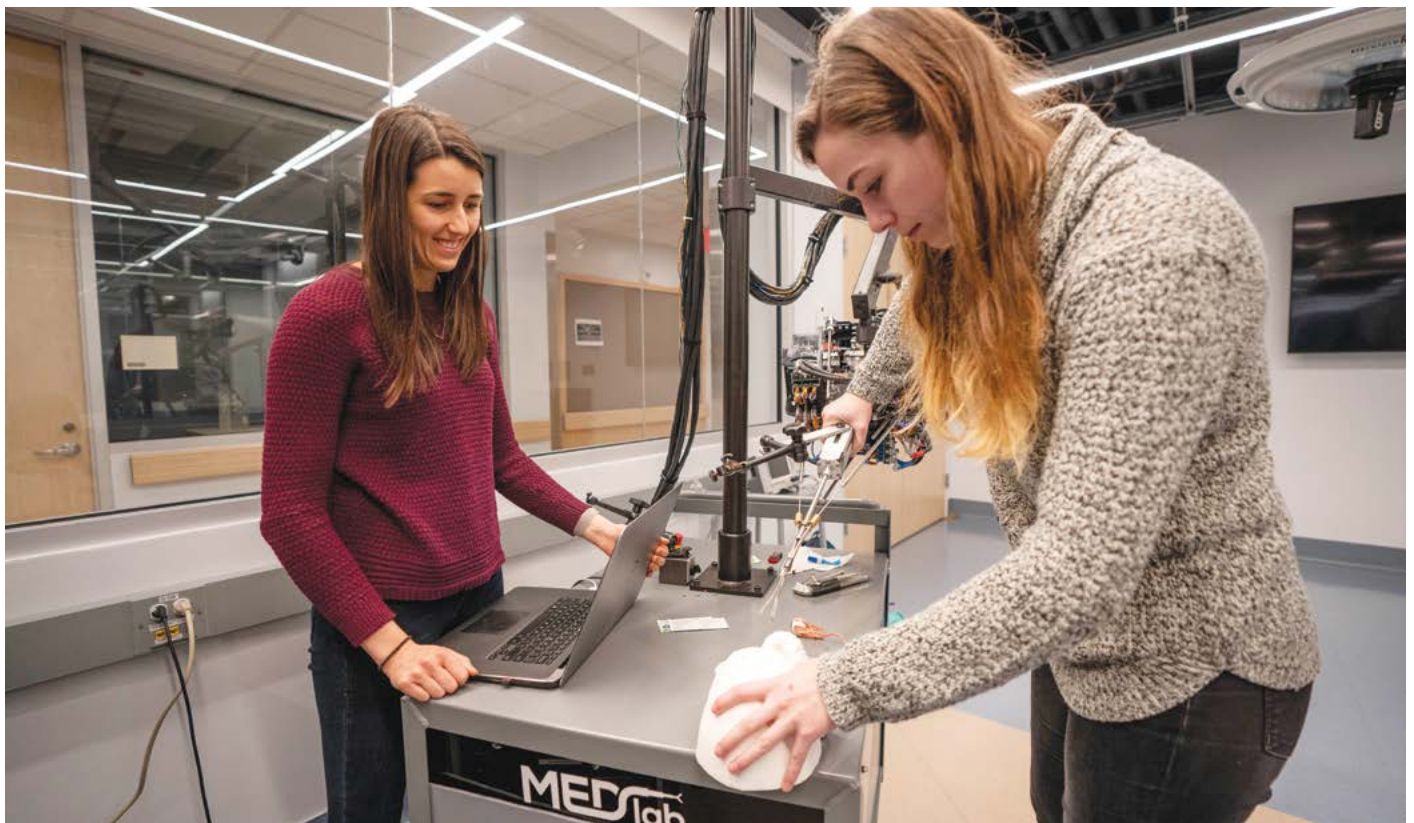
Continued from previous page

room or interventional suite, at clinical conferences, and in patient rounds.

Included are sessions with surgeons and interventionalists researching and treating conditions that span procedural medicine: brain tumor surgery and neuromodulation implants to robotic surgeries in the lung, prostate, and kidney, arterial and ablation therapies in the liver, radio-oncological procedures in breast and eye, and more.

The approach, Miga said, provides engineering PhD students with "real domain experiences."

"Too often, rather than beginning with observations of clinical barriers, trainees are either introduced to a research laboratory's perspective or integrated into a standardized design framework," he said. "Without these raw observational experiences, innovation may become inhibited and, frankly, we might lose out on some really exciting engineering ideas."

Richey, for instance, wondered about breast cancer procedures after observing several of them.

"Almost all patients have biopsy clips implanted near the tumor, but most have a separate localization device implanted as well. Shouldn't we be able to leverage those biopsy clips for localization? If we could, that would eliminate a second, painful procedure," she said.

"The opportunity to work closely with clinicians throughout my training has provided me with invaluable knowledge in developing technology that will easily integrate into the operating room." **V**

SPECIALIZED MASTER'S PROGRAM ADVANCES CLINICAL TRANSLATION

A new professional master's degree program aims to blast the bottleneck between breakthroughs in biomedical science and clinical translation that improves diagnosis and care.

The Master of Engineering with a surgery, engineering, and intervention focus is a 30-credit hour program that promotes extensive exposure to clinical domains. Beginning with the fall 2021 semester, three tracks are available:

■ Interventional imaging, therapeutics, and delivery,
■ Modeling, simulation, image analysis, and data science, and
■ Robotics and medical devices.

The degree is offered by the School of Engineering in partnership with the Vanderbilt Institute for Surgery and Engineering.

A look at the first clinical training program graduates

Six engineering PhD recipients haven taken positions in startups, health care research, and medical device development. More than a dozen other trainees in the VISE program will graduate in the next few years.

Patrick Anderson
Mechanical engineering, PhD '20
Lead mechanical engineer at EndoTheia, Inc., in Nashville, a startup focused on flexible endoscopy

Shikha Chaganti
Computer science, PhD '19
Siemens Healthineers, research and technology manager

Hernan Gonzalez
Biomedical engineering, PhD '21,
MD expected '22
Medical Scientist Training Program, VUMC
Applying to neurosurgical residency programs

Jon Heiselman
Biomedical engineering, PhD '20
Memorial Sloan Kettering Cancer Center, postdoctoral research scholar

Katie Ozgun
Biomedical engineering, PhD '21
RIVANNA, ultrasound systems engineer.
RIVANNA is a privately held designer, manufacturer, and distributor of medical technologies and services based in Charlottesville, Virginia.

Megan Poorman
Biomedical engineering, PhD '18
Hyperfine, clinical scientist. Hyperfine develops, manufactures, and distributes point-of-care MRI systems.
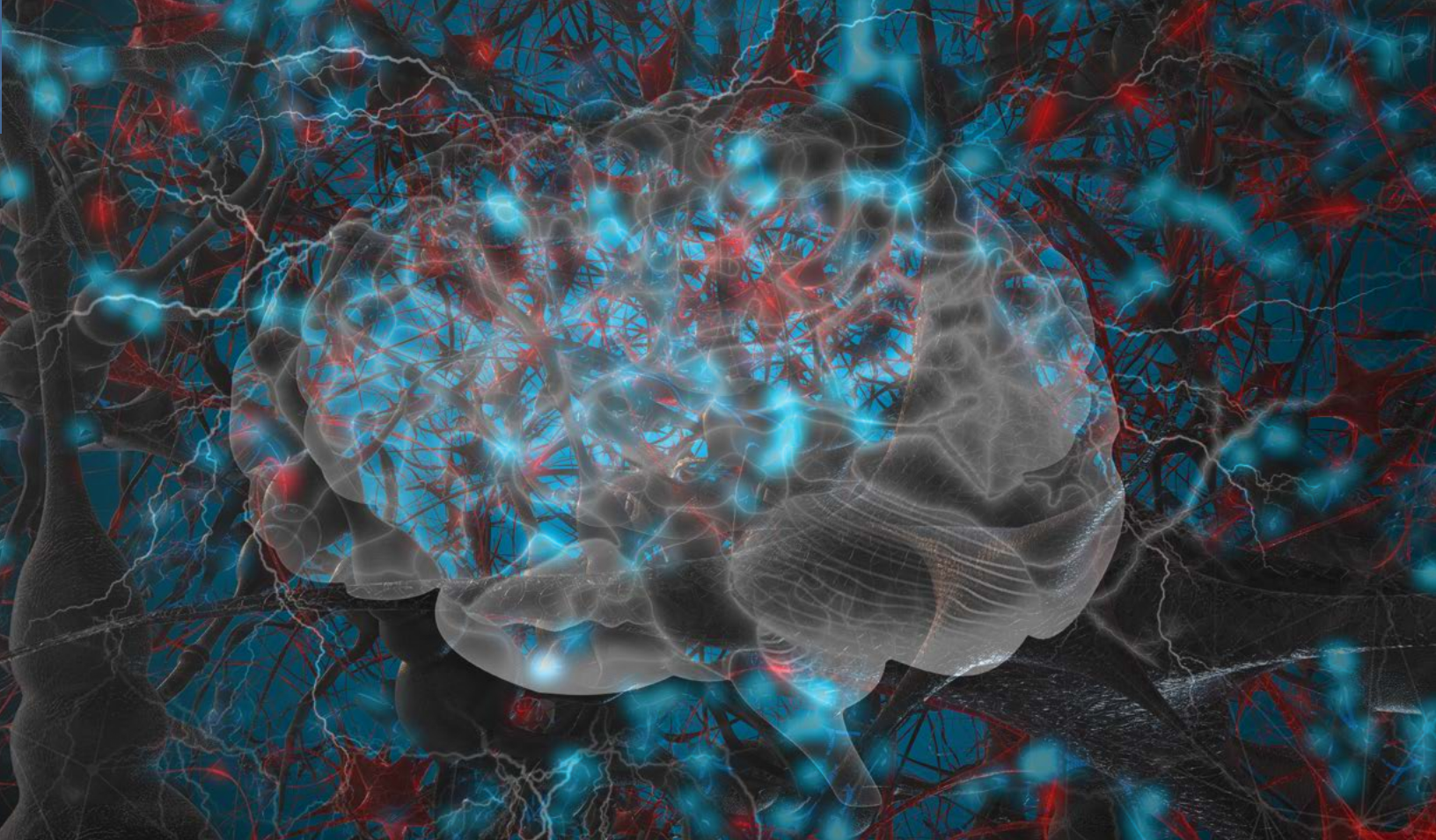
LESS INVASIVE PROCEDURE TO REDUCE EPILEPSY SEIZURES

For individuals with drug-resistant temporal lobe epilepsy, open brain surgery is the current standard of care to reduce seizures, and four of every five patients remain seizure-free after the procedure.

But perceived risks of a craniotomy make many patients and referring physicians hesitant. More than 90 percent of U.S. patients who could benefit don't pursue the option, which involves drilling through the skull into the brain to destroy the small area in the hippocampus where the seizures originate.

A project to develop a less invasive procedure got a big boost this year with a $2 million National Institutes of Health grant to further refine a needle-size robotic surgery system with real-time MRI guidance for drug resistant temporal lobe epilepsy. The eventual goal is to provide a minimally invasive way to achieve the benefits of surgery but use a steerable needle delivered through the patient's cheek, with thermal therapy to the brain.

The grant is from the National Institute of Neurological Disorders and Stroke, one of about 20 specialized institutes within NIH. The project's research components include demonstrating that the system accurately targets a defined amount of tissue, monitors the temperature, and treats the proper volume of tissue.

"This will pave the way for clinical translation of this technology in collaboration with industry partners, bringing a potentially curative treatment for epilepsy to many more patients," said Eric Barth, professor of mechanical engineering.

The project builds upon earlier work in which the team validated the idea of helical ablation needles and safe pneumatic robots and integrates those subsystems with MRI guidance. Seizures originate in the hippocampus, which is located at the bottom of the brain, and the robotic system can direct a special needle through the cheek and enter the brain much closer to the target area and avoid having to drill through the skull.

Barth and Robert Webster III, Richard A. Schroeder Professor of Mechanical Engineering, are the principal investigators. The team also includes William Grissom, associate professor of biomedical engineering, Dario Englot, VUMC assistant professor of neurological surgery and electrical engineering, and two former VUMC neurosurgery faculty. Barth, Webster, Grissom, and Englot also are faculty affiliates with the Vanderbilt Institute for Surgery and Engineering.

"Our goal is to develop a treatment approach that will prove effective at stopping seizures while minimizing discomfort and recovery time," Englot said.

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New $20 million AI Institute targets engaged learning and education

Vanderbilt University engineering and education faculty are part of a new $20 million, NSF-funded research institute to create artificial intelligence tools to radically improve education, re-imagining learning inside and outside of the classroom.

The NSF AI Institute for Engaged Learning is one of 11 new AI institutes announced in July 2021 as part of a major NSF initiative to advance understanding of AI technologies and how they can drive innovation to address real-world challenges.

"By introducing these technologies, we make learning more ubiquitous, whether it is at a school, coffee shop, museum or at home," said Cornelius Vanderbilt Professor of Engineering Gautam Biswas, lead researcher of the Vanderbilt team. "It also recognizes that learning happens more as a social process and that

students learn better when they are immersed in authentic problem-solving scenarios."

North Carolina State University is the lead institution, and other partners include Indiana University, the University of North Carolina at Chapel Hill and Digital Promise, an educational nonprofit organization.

Researchers will develop narrative-centered AI platforms and characters, or agents, to interact with and support a wide variety of learners. The institute will create a sophisticated framework that analyzes data from interactions

to evaluate what works and what needs refinement to make the tools truly interactive and adaptive to the learning needs of individuals and of collaborating groups. A key aim is to use AI to build more equitable, inclusive educational experiences.

The Vanderbilt share of the five-year project is $4.15 million. The team comprises Biswas, professor of computer science and computer engineering, and Maithilee Kunda, assistant professor of computer science and computer engineering; Corey Brady, assistant professor of learning sciences, and Noel Enyedy, professor of science education, both from Peabody College of Education and Human Development; and Ole Molvig, assistant professor of history and communications of science and technology,

Students learn about honey bee behavior and communication by acting like bees, collecting nectar, and taking it to their hive. Researchers are developing an AI platform to analyze how individual students and the group interact with each other, the teacher, and the technology and optimize the progress learners make as the class works through the scenario.
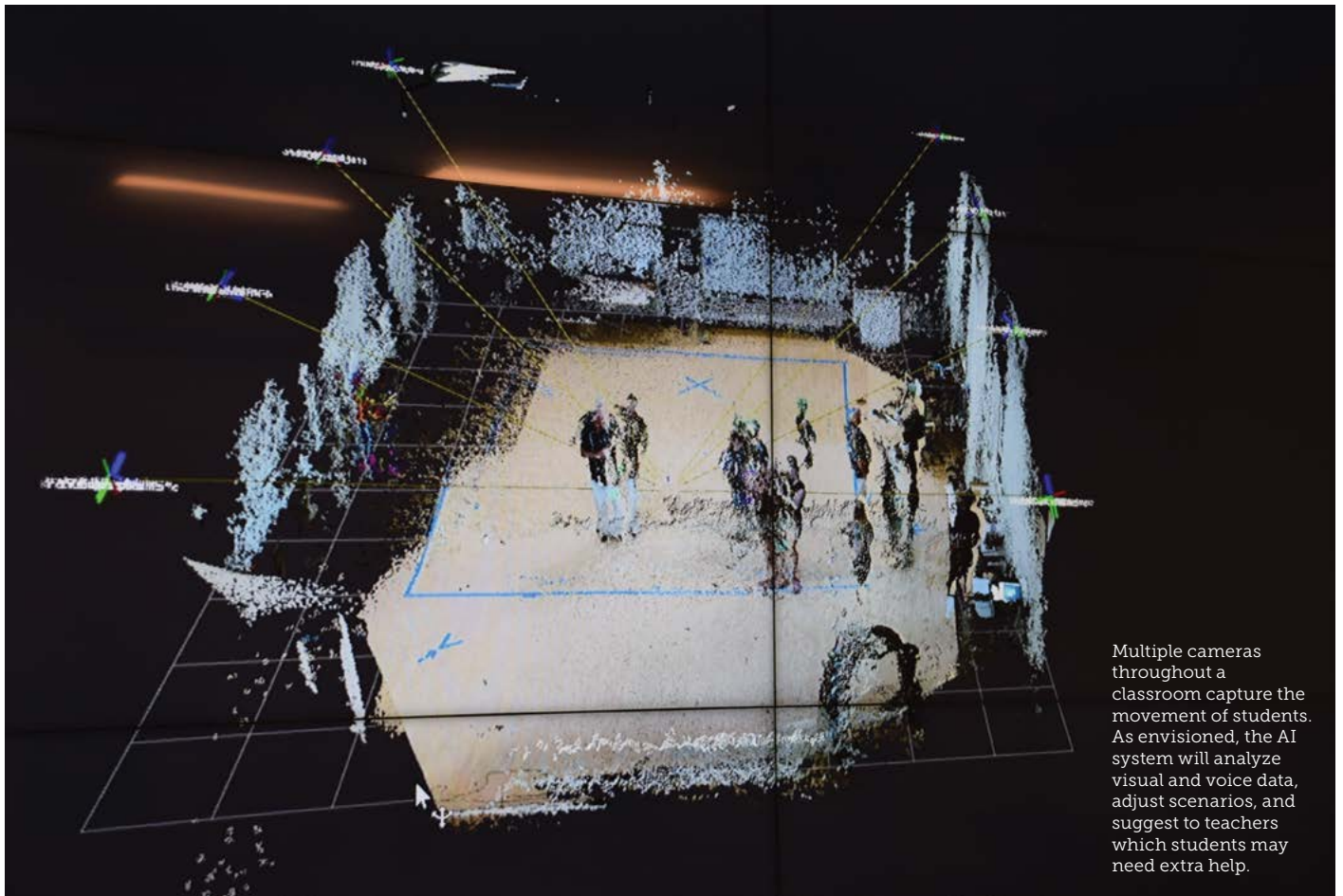
Multiple cameras throughout a classroom capture the movement of students. As envisioned, the AI system will analyze visual and voice data, adjust scenarios, and suggest to teachers which students may need extra help.

founder of the emergent technology lab at The Wond'ry. Molvig is the AI ethics and privacy expert for the $20 million project, which was awarded under the NSF research thrust of Augmented Learning.

The institute will focus on three complementary areas:

- Creating AI platforms that generate interactive, story-based problem scenarios that foster communication, teamwork, and creativity as part of the learning process.

- Developing AI characters capable of communicating with students through their speech, facial expression, gesture, gaze, and posture. These characters, or "agents," will be designed using state-of-the-art advances in AI research to foster interactions that effectively engage students in the learning process.

- Building a sophisticated framework that analyzes data from students to make the tools truly interactive. The system will be able to customize educational scenarios and processes to help students learn, based on information the system collects from the conversations, gaze, facial expressions, gestures, and postures of students as they interact with each other, with teachers, and with the technology itself.

Such a "classroom of the future" might look like this: One group of students is interacting with a Smart Board, while other students work individually or in groups using AI-powered tools, and a teacher presents new material to a subset of the class. Multiple cameras capture the simultaneous interactions with the teacher, among students in groups and between individual students and their technological tools. As the class works through the scenario, the AI-powered analysis identifies adaptations to the individual and collective activities that optimize the progress that learners make in each working unit and as a whole.

By definition, this is a Big Data undertaking. Just five minutes of interactions throughout a classroom produces megabytes of data. Now imagine the data generated in a year-long STEM curriculum for a single grade level.

"It is going to be challenging, but the impacts can be huge," Biswas said. ▼

Biomedical engineers demonstrate potential for first clinically successful osteoarthritis drug

Craig Duvall

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Cornelius Vanderbilt Professor of Engineering Craig Duvall and his team set out to develop a drug for the prevention of post-traumatic osteoarthritis initiation and progression. PTOA, caused by degraded cartilage that cushions the ends of bones in joints, is most seen among young athletes and military personnel. ACL rupture, meniscus tear, patellar dislocation, and ankle instability are among the precursors to PTOA.

The disease leads to earlier onset and faster progression of osteoarthritis following an injury, an accelerated process that benefits research into potential treatments.

The same degenerative mechanisms are in play in PTOA and age-related osteoarthritis, which affects 25 percent of those over 45 in the U.S. MMP13, a protein coding gene, is responsible for degrading cartilage. But researchers have yet to develop a therapy to inhibit the progression that doesn't have adverse side effects.

Traditional drug development approaches have struggled to discover small molecule inhibitors that selectively target MMP13, which is problematic because inhibiting the broader class of similar enzymes can cause side effects and/or toxicities. Additionally, previously tested MMP inhibitors have been delivered systemically, meaning potential activity and side effects in all tissues of the body.

Instead, the research team, which includes former graduate student Sean Bedingfield, PhD '20, and current graduate student Juan Colazo, developed short interfering RNA-based drugs known as siRNAs. A nanoparticle loaded with the MMP13 siRNA is locally injected and binds only to damaged cartilage affected by joint injuries. The targeted, bioadhesive nanoparticle stays in the joint longer to better combat early cartilage damage, and the method also helps to further reduce potential undesirable effects elsewhere in the body, said Duvall, professor of biomedical engineering.

Current treatments like corticosteroid joint injections manage short term pain, but they may worsen cartilage loss when used as an ongoing therapy, he said.

"Direct comparisons to treatment with the current clinical standard—steroids—showed that MMP13

Vanderbilt biomedical engineers have demonstrated the potential for the first osteoarthritis drug that interrupts the disease process rather than solely managing the pain it causes.

The group used packages of engineered nanoparticles to sustainably deliver a type of RNA to the cells in the joint over time. With this technique, a single injection lasted for at least a month and reduced cartilage loss and bone spurs—known to be primary drivers of severe joint pain that ultimately causes patients to seek complete joint replacement.

silencing with the targeted nanoparticles had significant effects on reducing joint degeneration over steroid injections," Duvall said. "This indicates that this approach has the potential to be developed as the first clinically available disease modifying osteoarthritis drug."

The team and its collaborators hope to continue to explore bioadhesive nanoparticles that are easier to scale and last longer. "We'd also like to show safety and efficacy in larger models as a stepping stone toward longer term application of MMP13 siRNA therapies in patients," he said.
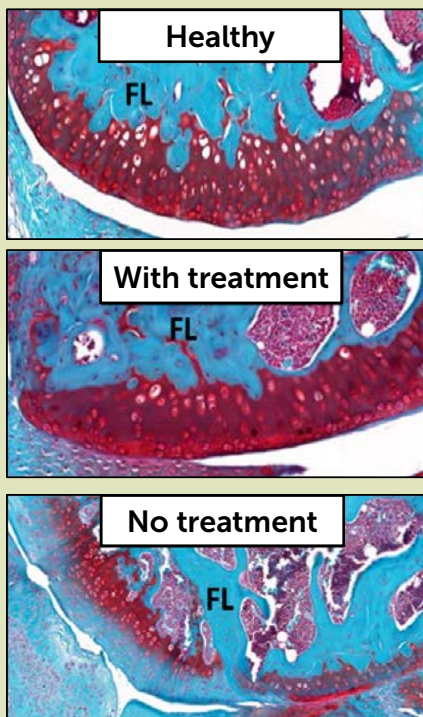
"Amelioration of post-traumatic osteoarthritis via nanoparticle depots delivering small interfering RNA to damaged cartilage" was published in the journal *Nature Biomedical Engineering* in August 2021. The same month, the journal *ACS Nano* published a follow up paper, "Top-Down Fabricated Microplates for Prolonged, Intra-articular Matrix Metalloproteinase 13 siRNA Nanocarrier Delivery to Reduce Post-traumatic Osteoarthritis."

The work was supported by the Department of Defense Peer Reviewed Orthopaedic Research Program, the National Institutes of Health, the Canadian Natural Sciences and Engineering Research Council, the Rheumatology Research Foundation, a VA Merit Award, the National Science Foundation Graduate Research Fellowship Program, the European Research Council, and the European Union's Horizon 2020 Research and Innovation Programme. **V**

> "The targeted, bioadhesive nanoparticle stays in the joint longer to better combat early cartilage damage, and the method also helps to further reduce potential undesirable effects elsewhere in the body."

Craig Duvall
Cornelius Vanderbilt Professor of Engineering

Reducing cartilage degradation

An engineered type of RNA is shown to reduce cartilage degradation from post-traumatic osteoarthritis using non-human models. Left: Stained sections show that blocking MMP13, a protein-coding gene, protects cartilage structure and composition. Below: Micro-computed tomography imaging indicates that MMP13 inhibition reduces unnatural mineralization and bone spurs in the mechanically injured joints. Images acquired by Sean Bedingfield, PhD '20.
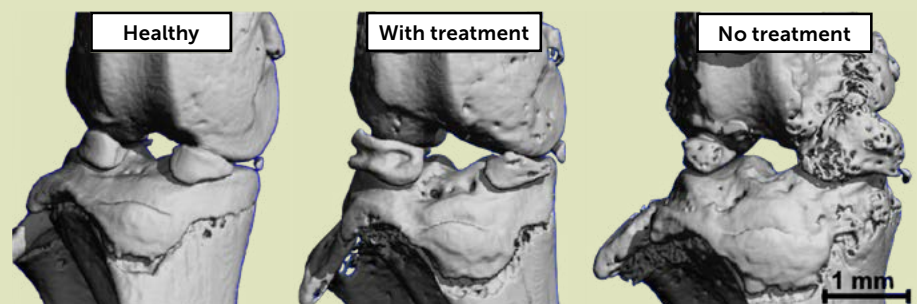
Headband device suitable for use at home with young ADHD patients

A Vanderbilt biomedical engineering professor has developed a prototype headband to measure brain activity that could have widespread application in studying and ultimately treating ADHD and other neurological disorders.

The device is lightweight, portable, and inexpensive to construct. Prototype components cost less than $250, compared to costs exceeding $10,000 for commercial systems.

Audrey Bowden, associate professor of biomedical engineering, and Hadi Hosseini, a colleague at Stanford University, set out to develop a simple device that children and teens diagnosed with attention deficit disorders could wear at home. Their initial prototype is a single-channel functional near-infrared spectroscopy (fNIRS) headband. Functional neuroimaging is a general term for technologies that spatially map brain activity over time.

The team is now optimizing a newer, 17-channel version, which weighs five ounces with its battery pack, plus an accompanying mobile application for use with a phone or tablet. The next step is testing the device with 30 children diagnosed with ADHD and 30 control subjects. ADHD will serve as the model illness, with eventual application to other neurological conditions such as traumatic brain injury, epilepsy, stroke, ADD, and dementia.

"Successful completion of this first-of-a-kind study will help shift the current paradigm away from in-lab, small-quantity neuroimaging and pave the way for developing effective biomarkers that can be used clinically for diagnosis and early detection of mental disorders, as well as monitoring the response to treatment," Bowden said.

In addition to the mobile app, Bowden and her research group are developing an augmented reality interface to guide positioning of the device when used at home and other natural environments.

"It is one thing to have the device, and it is another thing to use it reliably," said Bowden, who is the Dorothy J. Wingfield Phillips Chancellor's

PhD student Seth Crawford demonstrates a prototype headband for monitoring brain activity in ADHD and other neurological disorders. A mobile app guides users and their caregivers in proper placement of the device, which can be used with children at home.
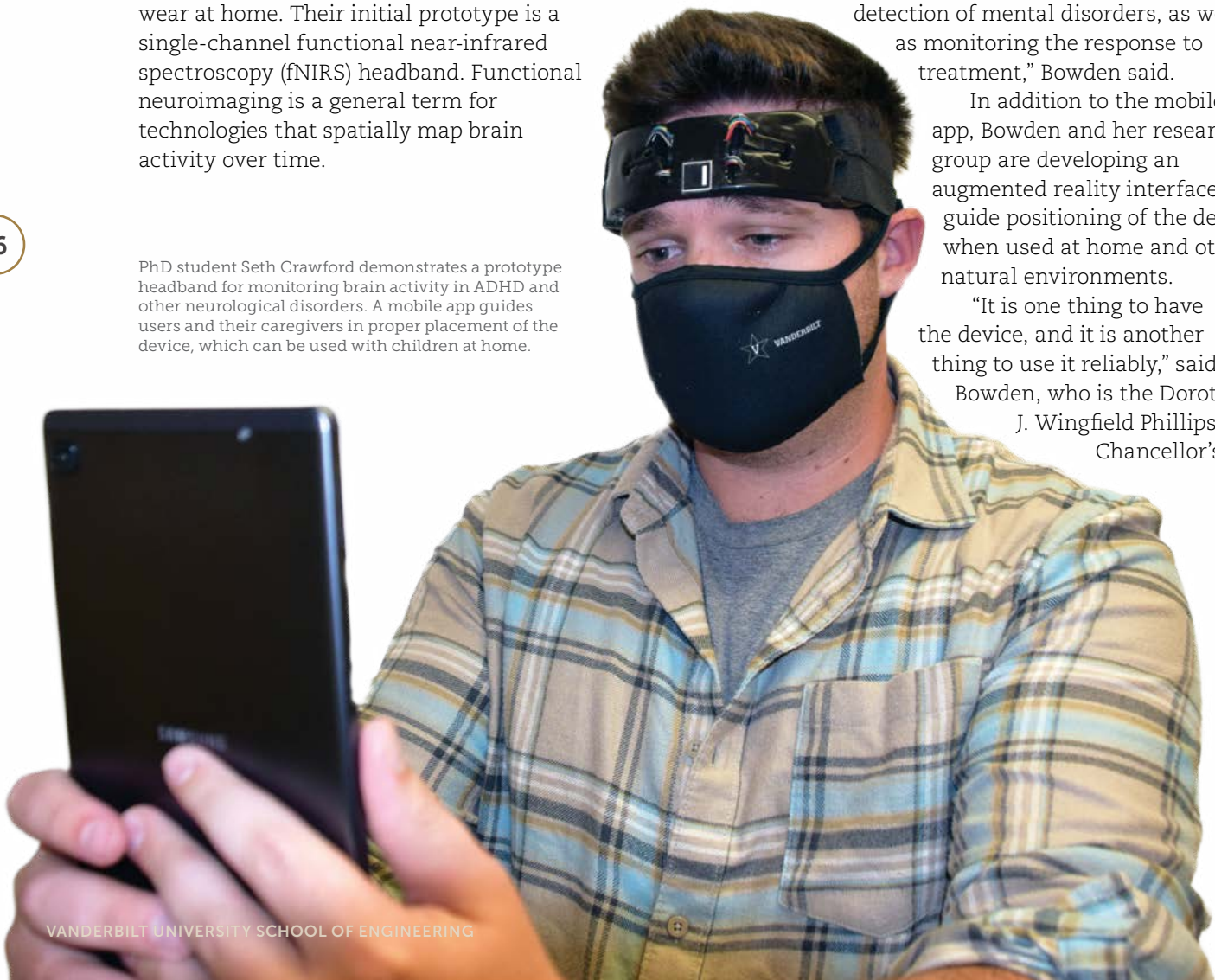
Faculty Fellow. "Traditional fNIRS systems require expert researchers to place the device on prospective participants. Our AR-based technology would enable use of the device in contexts where the researcher isn't there, such as in the home. The flexibility added by the self-positioning option would open the door to more frequent assessment and more reliable information about mental disorders."

Significantly, all the research—device specifications, a parts list, directions to build it, the app, and the AR interface—will be freely available.

"The chief goal of translational research is to move research results and technology out of the lab and into the hands of patients and prospective patients. Providing the technology information in an open-source platform will do just that," Bowden said.

For imaging to diagnose mental illness and neurological disorders, functional MRI has been the "gold standard," but it has received little traction. Issues such as cost and the need to limit patient movement make fMRI studies impractical in many patients. Furthermore, complexity and

The DIY headband device weighs about 5 ounces, including its battery pack. It can be assembled with easily available components for a cost of less than $250, compared to commercial devices that can cost $10,000 or more.

discomfort of existing imaging systems keep most fMRI recordings to less than 10 minutes in length, which adds to the difficulty in reproducing findings at the individual level and studying many patients over weeks or months.

Audrey Bowden

"Research suggests that collecting hours—not minutes—of data per individual patient may be needed to fulfill the clinical promise of functional neuroimaging," Bowden said. "Accumulating evidence suggests that large quantities of highly sampled individual data are critical for determining whether differences in functional brain organization are behavior-related, disease-dependent, or secondary to unrelated events in the brain."

The idea of using portable fNIRS systems in neurology and psychiatry has been investigated for conditions that include traumatic brain injury, epilepsy, stroke, ADD, and dementia, but the systems developed so far are heavy and expensive. The system Bowden and her colleagues have developed is inexpensive, portable, and more tolerant to subject movement, which allows measurement of brain activity in naturalistic situations and is more suitable for children.

The work, "A low-cost, wearable, do-it-yourself functional near-infrared spectroscopy (DIY-fNIRS) headband," was published in the October 2021 issue of *HardwareX*, an open access journal established to promote free and open-source designing, building, and customizing of scientific infrastructure. It is currently being funded by a grant from the National Institutes of Health (NIH R21 MH123873-01). **V**

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New technique corrects for MRI image distortions

Applying deep learning, Vanderbilt and VUMC researchers have created a technique that corrects image distortions and provides more accurate information for researchers, radiologists, and neuroscientists to better interpret brain scans.

"To quantify anything in the brain is highly important," said Bennett Landman, professor of electrical engineering, computer engineering, computer science, and the project's lead researcher. "Incorrect images can distort the image's intensity, understanding of brain size volume or interpretation of connections of brain pathways. If we don't have a true image, we cannot accurately observe or describe brain connections, which will negatively affect neurological research."

Distorted images are common—an image of a three-dimensional object will get squashed or pulled in ways that don't reflect its true appearance. The new algorithm, Synb0-DisCo, developed by the core faculty at the Vanderbilt Institute for Surgery and Engineering and the Vanderbilt University Institute of Imaging Science, synthesizes what the MRI image should look like from anatomically correct images and uses that data to correct the MRI scan that was acquired.

> **"If we don't have a true image, we cannot accurately observe or describe brain connections, which will negatively affect neurological research."**
> **Bennett Landman**

The analyzed datasets—thousands of images to date—include legacy images from the Human Connectome Project, a large-scale NIH-funded project that constructed a complete map of the structural and functional neural connections of the brain, the Autism Brain Imaging Data Exchange, and the Baltimore Longitudinal Study of Aging, the largest effort to understand how the brain develops in aging. Images from projects like these are used by tens of thousands of researchers around the world studying the human brain.

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TAO RECEIVES SUPPORT OF SELECTIVE SPIE GIFT

Assistant Professor of Biomedical Engineering Yuankai "Kenny" Tao is the first School of Engineering faculty member to be supported by an endowment gift from SPIE, the international society for optics and photonics.

This is the eighth major SPIE gift to universities and institutes as part of the Society's ongoing program to support the expansion of optical engineering teaching and research.

"We have one of the few biophotonics centers in the country, and a critical mass of faculty spanning imaging, sensing, laser-tissue interactions, materials, and nanophotonics. This fellowship will be a vital resource as we continue to recruit best and brightest trainees and researchers in optics and photonics to Vanderbilt," Tao said.

His lab develops novel optical imaging systems for clinical diagnostics and therapeutic monitoring in ophthalmology, gastroenterology, and oncology, and most of his research involves multidisciplinary collaborations between investigators in engineering, basic sciences, and medicine.

Prior to joining the faculty at Vanderbilt, Tao was an assistant professor in the Department of Ophthalmic Research at Cleveland Clinic and director of the Diagnostic Imaging and Biophotonics Laboratory at Cole Eye Institute.
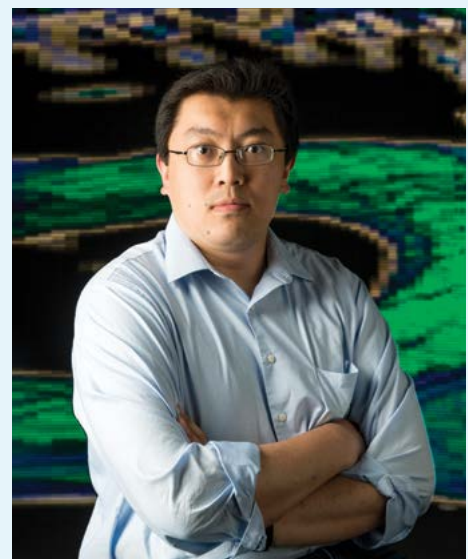
Yuankai "Kenny" Tao

A 35-barge tow travels on the Mississippi River in North Louisiana.

Decarbonization of U.S. waterways poses unique challenges

Landmark study looks at alternative fuels, future propulsion technologies

Compared to rail and truck, the U.S. inland waterway system is the least carbon-intense and most fuel-efficient mode of moving cargo and freight—by several orders of magnitude. Even then, the inland shipping sector contributes an estimated 6.2 million tons of CO_2 each year.

The UN International Maritime Organization in 2018 set a goal to cut the maritime shipping industry's greenhouse gas emissions by at least half by 2050, and much of the push has been focused on the heavy carbon footprint of blue water cargo vessels. But shipping on the inland waterways is getting more attention.

A landmark new report by Vanderbilt transportation and environmental engineers looks toward decarbonization of U.S. waterways and evaluates the potential for possible future propulsion technologies and alternative fuels to reduce carbon emissions.

The comprehensive study, the first to examine the U.S. inland waterway system through the lens of reducing greenhouse gas emissions, was done on behalf of the American Bureau of Shipping (ABS), a leading global provider of classification and technical advisory services to the marine and offshore industries. The research itself was a collaboration between the Vanderbilt Center for Transportation and Operational Resiliency and the Vanderbilt Climate Change Initiative.

"There has been a lot of work focused on decarbonizing the international and coastal shipping sector
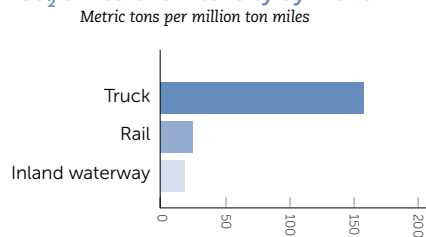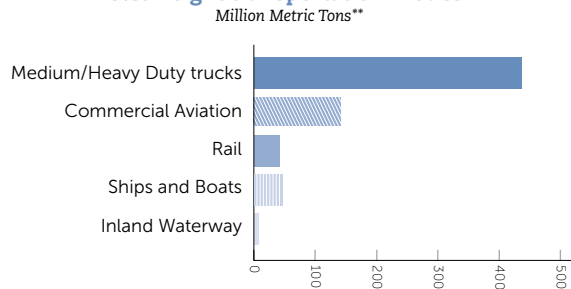
Fuel intensity by transportation mode
Ton-miles per gallon of fuel

Mode	
Truck	
Rail	
Inland waterway	
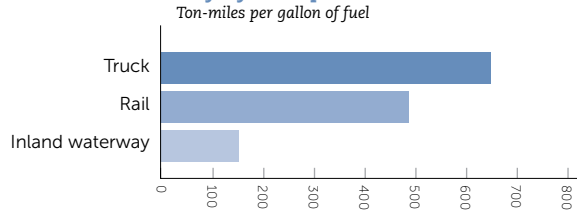
Source: ABS-VECTOR decarbonization report, citing Texas Transportation Institute (2017)

CO₂ emissions intensity by mode
Metric tons per million ton miles

Mode	
Truck	
Rail	
Inland waterway	

Estimated CO2 emissions for U.S. freight transportation modes*
Million Metric Tons**

Mode	
Medium/Heavy Duty trucks	
Commercial Aviation	
Rail	
Ships and Boats	
Inland Waterway	

Decarbonization of the Inland Waterway Sector, ABS, 2021, prepared by the Vanderbilt Center for Transportation and Operational Resiliency

*Non-carbon dioxide greenhouse gas emissions are such a small component of the total emissions from the inland waterway sector and do not have a significant impact on GHG calculations.

**2018 data. Ships and Boats category may include some inland waterway. Data for inland waterways was calculated as part of this project.

Data for other modes was obtained from EPA's annual GHG inventory.

but much less focus on the inland river sector, in part because it is already one of the most sustainable ways to move freight," said VCCI Director Leah Dundon, JD, '97, PhD '17.

"The inland river sector has some unique technical characteristics that present real challenges to successful decarbonization, but we are excited about some of the possibilities and pathways we identified in this report," she said.

LOOKING AT ELECTRIFICATION

One of the big characteristics that gives inland shipping its lower carbon profile—standardization—also makes decarbonization more difficult.

River depth and width, plus the lock system and lock sizes, limit vessel length and overall dimensions, weight, and draft. The maximum underwater depth for a tug and barge, for example, is 10 feet.

The research team found that electrifying larger river boats may not be feasible with current technology because of the large batteries required. However, retrofitting certain smaller boats known as "fleet boats" could be accomplished in the near-term. Converting all fleet boats to electric propulsion is estimated to reduce total annual average industry diesel fuel consumption by approximately 20 percent, or 1,000 kilograms of CO_2 depending on the fuel types used to generate electricity. Each of the 1,000 fleet boats uses about 100,000 gallons of marine diesel each year.

EVALUATING ALTERNATIVE FUELS

Outside of electrification, the potential for using alternative fuels is mixed. Biofuels and methanol present

Team to engineer algae for more productive biofuel potential

Cyanobacteria, or blue-green algae, holds great promise for biofuel production because the free fatty acids they secrete are more easily recovered than those typically produced by green algae.

Such fatty acids, or lipids, are readily converted into fuels.

With a new $1.5 million Department of Energy grant, a three-institution team led by Professor of Chemical and Biomolecular Engineering Jamey Young will work to identify how cyanobacteria can be engineered to do what they do more efficiently and in larger quantities.

"Lipid-based products that can be converted to biodiesel or other value-added biochemicals represent one of the most promising platforms for petrochemicals replacement," Young said.

Cyanobacteria are already capable of producing lipids directly from sunlight and atmospheric carbon dioxide using photosynthesis, but not at the rates and quantities necessary to sustain a commercial biofuel process. The goal of this new project is to understand how lipid metabolism is regulated in cyanobacteria so host cells can be engineered for high-yield production of medium-chain free fatty acids, which are readily converted into fuels.

the most feasible options because they can be used in some existing marine engines and are supported by current infrastructure, according to the report.

Biofuels also have energy density near to that of marine diesel, meaning existing fuel tank-size may be sufficient. Ammonia, hydrogen, and liquefied natural gas—a fossil fuel with lower emissions than diesel—have substantially lower comparative energy density than marine diesel, which would require significantly larger tank volumes. With these fuels, existing tanks could not be used at all.

"Electrification clearly offers smaller inland river vessels swift gains in CO_2 reduction, but the report also explores the wider decarbonization landscape that will need to be navigated to put this sector on a sustainable footing," Georgios Plevrakis, ABS Director of Global Sustainability.

The report includes a case study and naval architect renderings of a retrofitted, weighted, and balanced electrified boat, plus analyses of historic and projected cargo tonnage and current market conditions.

Decarbonization of the inland waterway sector likely will require regulatory or market-based incentives, the authors said. In addition to Dundon, the research team included Craig Philip, research professor of civil and environmental engineering and VECTOR director; David Sehrt, former chief engineering officer, Ingram Barge Company; and civil engineering PhD student Madeline Allen, BA '19.

"These types of grand challenges can't be undertaken alone—they require input and insight from a broad range of skill sets and expertise," Dundon said. **V**
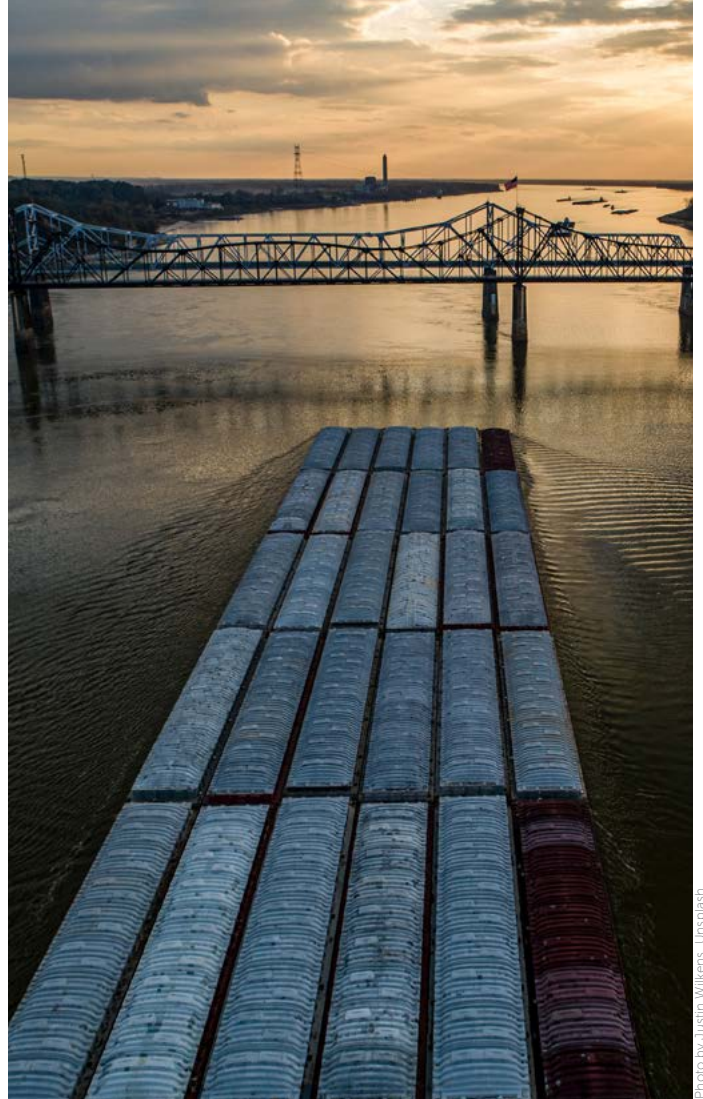
A 56-barge tow travels on the Mississippi River near Vicksburg, Mississippi.

Photo by Justin Wilkens, Unsplash

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Researchers will use the strain Synechococcus sp. PCC 7002, a fast-growing cyanobacteria that is tolerant to heat and brackish water. The organism's flexibility makes it especially attractive to DOE as a biomanufacturing host because its growth does not compete with production of crops or other food sources. The species can be grown using wastewater resources and without organic sources of carbon, such as sugar, on land that is unsuitable for agriculture.

Colonial Pipeline shutdown

*Cyberattack shows need for greater supply chain resiliency—
and the role inland waterways can play*

A 12,000-mile superhigh-way snakes through the United States—underused, underappreciated, and underfunded.

Each year, it carries cargo to and from many of the country's oceangoing ports as well as to and from 38 states. The inland waterway system is an unsung hero of the nation's freight transportation system, moving $135 billion annually in raw materials, fuel, construction supplies, and finished goods.

Vanderbilt transportation and logistics engineers believe the time is now for inland waterways to get increased attention. Growing threats from extreme weather events and cybersecurity attacks jeopardize the nation's supply chains, which rely heavily on rail, plus tractor-trailer and medium-duty trucking. The U.S. can build supply chain resiliency with targeted investments in locks, dams, and inland ports, they say.

"The inland waterway system for many is out of sight, out of mind," said Craig Philip, director of the Vanderbilt Center for Transportation and Operational Resiliency. "But the inland waterways are a superhighway with untapped capacity."

Greater use of the system has added benefits: per mile and per ton, shipping by river barge is the least costly, most energy efficient, and safest mode of moving cargo in the domestic U.S. supply chain.

VECTOR is putting the final touches on a case study on resilience strategies for navigable portions and infrastructure of the Cumberland/Tennessee river couplet system. The research will contribute to a national Port Resilience Guide to be published by the U.S. Department of Homeland Security and the Army Corps of Engineers.

COLONIAL PIPELINE SHUTDOWN

A cyberattack that shut down the Colonial Pipeline in May 2021 gave VECTOR researchers a perfect, if disruptive, opportunity to see how much difference the inland waterways could make in gasoline supply.
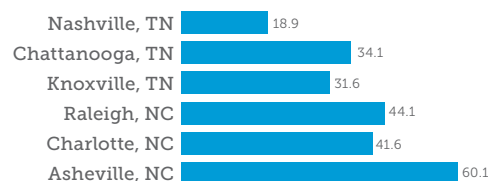
Quite a bit, it turns out.

Using data from the Corps and Gas Buddy, a crowd-sourced app that provides real-time fuel prices and availability, a civil engineering doctoral student looked at what happened in six southeastern cities.

"Our preliminary findings suggest that there is a statistically significant inverse relationship between a city's annual waterborne petroleum volumes (adjusted per capita) and the proportion of gas station outages during this year's disruption of the Colonial Pipeline, especially as the closure stretched on to its second week," said PhD student Miguel Moravec.

A decade ago, two major petroleum companies added river barge service to diversify their delivery modes to the Nashville region, giving it the largest waterborne fuel volume per capita of the cities studied. In Nashville only 19 percent of stations were reported to be out of fuel by the twelfth day of the disruption while in Knoxville and Chattanooga, which receive less waterborne fuel, reported 32 and 34 percent outages, respectively, on the same day.

Between 42 and 60 percent of the gas stations in three North Carolina cities that rely solely on the pipeline for petroleum product delivery had outages two weeks after the pipeline attack.

12th Day Station Outages (%)

| City	Outage (%)
Nashville, TN	18.9
Chattanooga, TN	34.1
Knoxville, TN	31.6
Raleigh, NC	44.1
Charlotte, NC	41.6
Asheville, NC	60.1

Empty Marathon Petroleum Company fuel barges exit Cheatham Lock in Ashland City, Tennessee, and head back to refineries in Texas on May 21, 2021. The U.S. Army Corps of Engineers Nashville District, the fuel industry, and contractors performing maintenance at the lock coordinated to accommodate the movement of fuel barges on the Cumberland River during the Colonial Pipeline shutdown.

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SMOOTH WATERS

One river barge carries as much freight as 16 railcars or 70 tractor-trailers.

National Waterways Foundation

1 barge   =   16 railcars   =   70 large semis/tractor trailers
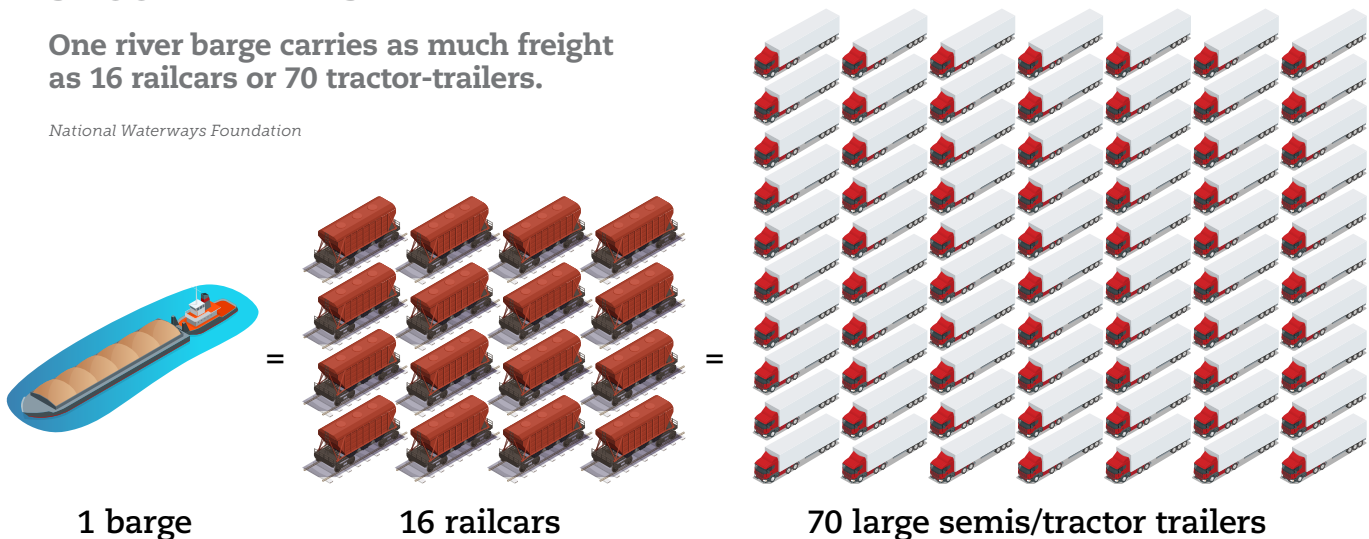
LOCK CLOSURES, FLOOD EFFECTS, EARTHQUAKE UNCERTAINTY

Researchers also are looking at how lock closures, including those from accidents and scheduled maintenance, affect the inland waterway system's ability to move commodities to and from the Middle Tennessee region. The system, standardized around vessels with a maximum draft of 10 feet and locks with width and length limits, is vulnerable to droughts and floods, too. Another piece of the supply chain security puzzle includes how an earthquake along the New Madrid fault would impact rivers and inland ports, not to mention rail lines, major highways, and bridge crossings for both. The New Madrid Seismic Zone is a series of large, ancient faults buried beneath thick, soft sediments that run for 120 miles, crossing five state lines, the Mississippi River in three places and the Ohio River in two places. Experts estimate there is 25-45 percent chance of a 6.0 magnitude or greater earthquake striking in the next 50 years. Destruction would cover 20 times the area of a similar West Coast earthquake because of geological differences in the two regions.

"We cannot underestimate the need for multiple transport delivery options that allow essential goods and products to travel across the country," said Janey Camp, research associate professor of civil and environmental engineering and VECTOR associate director. "This analysis demonstrates that ports, especially inland terminals, continue to be a critical factor in the nation's supply chain. American cities and states will need to keep this in mind as they plan for long-term, resilient infrastructure investments over time."

VECTOR's research on port resiliency will look at the untapped capacity in the system of inland waterways and make recommendations for addressing resiliency of the freight transport system.

"We are not going to build many miles of new freeway and we aren't going to build any new pipelines. But we have this superhighway of inland waterways," Philip said. "Unlike the highways, however, waterways could be utilized today in a greater way."

Using drones to evaluate and direct disaster recovery

A new online gallery of photos taken in the days, weeks, and months following the March 2020 Middle Tennessee tornados is the work of an engineering graduate student who wants to make disaster recovery more equitable.

Daniel Perrucci, a PhD candidate in civil engineering, used bird's eye imagery from drones as well as street-level photography to document pockets of recovery in East Nashville and Mount Juliet, which is about 17 miles east of the city. The storms were of the same strength, caused similar damage, and took the same number of lives in each area.

Perrucci's early comparisons produced one clear trend. The urban area appeared to recover more quickly during the initial relief stages than the rural/suburban one, as gauged by debris piles, blue tarps over roofs and other observations.

March 2-3, 2020 Tornadoes
EF-3 Davidson/Wilson/Smith County Tornado
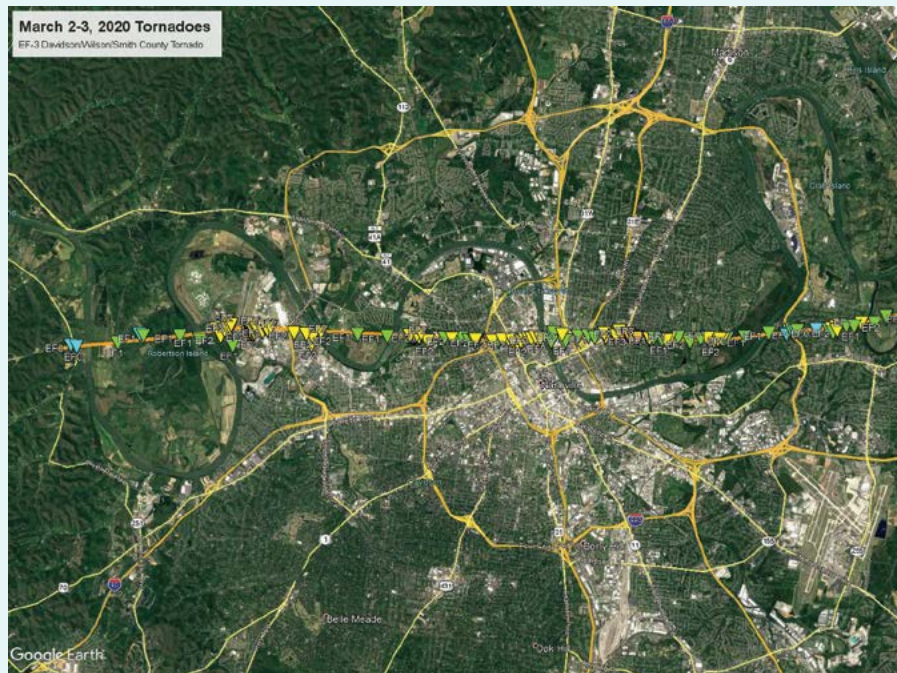
Most disaster relief is allocated using "pen and paper" or computer spreadsheets, and the project shows the potential power of another information source, Perrucci said.

"If one area is slowing, state or even federal funding can be tapped to bring that social equality and recovery up to the standard we would want it to be," he said.
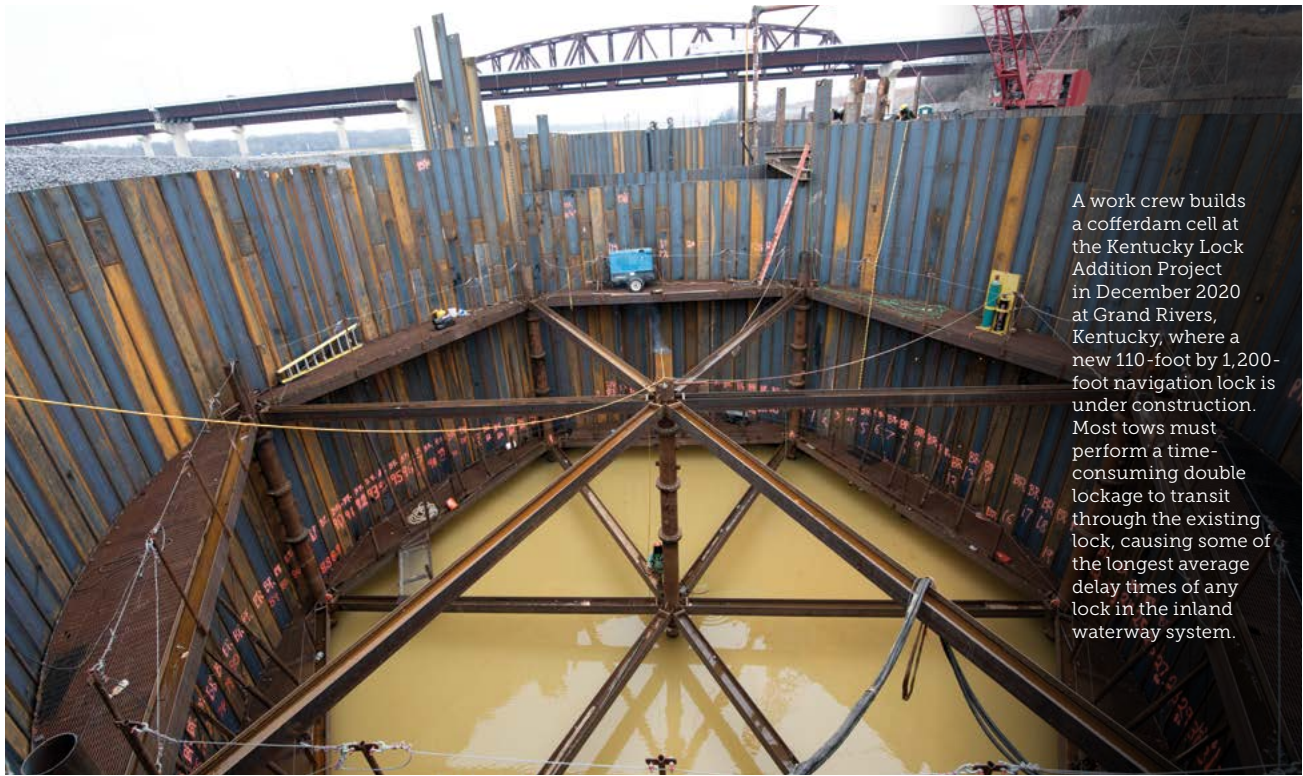
A work crew builds a cofferdam cell at the Kentucky Lock Addition Project in December 2020 at Grand Rivers, Kentucky, where a new 110-foot by 1,200-foot navigation lock is under construction. Most tows must perform a time-consuming double lockage to transit through the existing lock, causing some of the longest average delay times of any lock in the inland waterway system.

(USACE Photo by Lee Roberts)
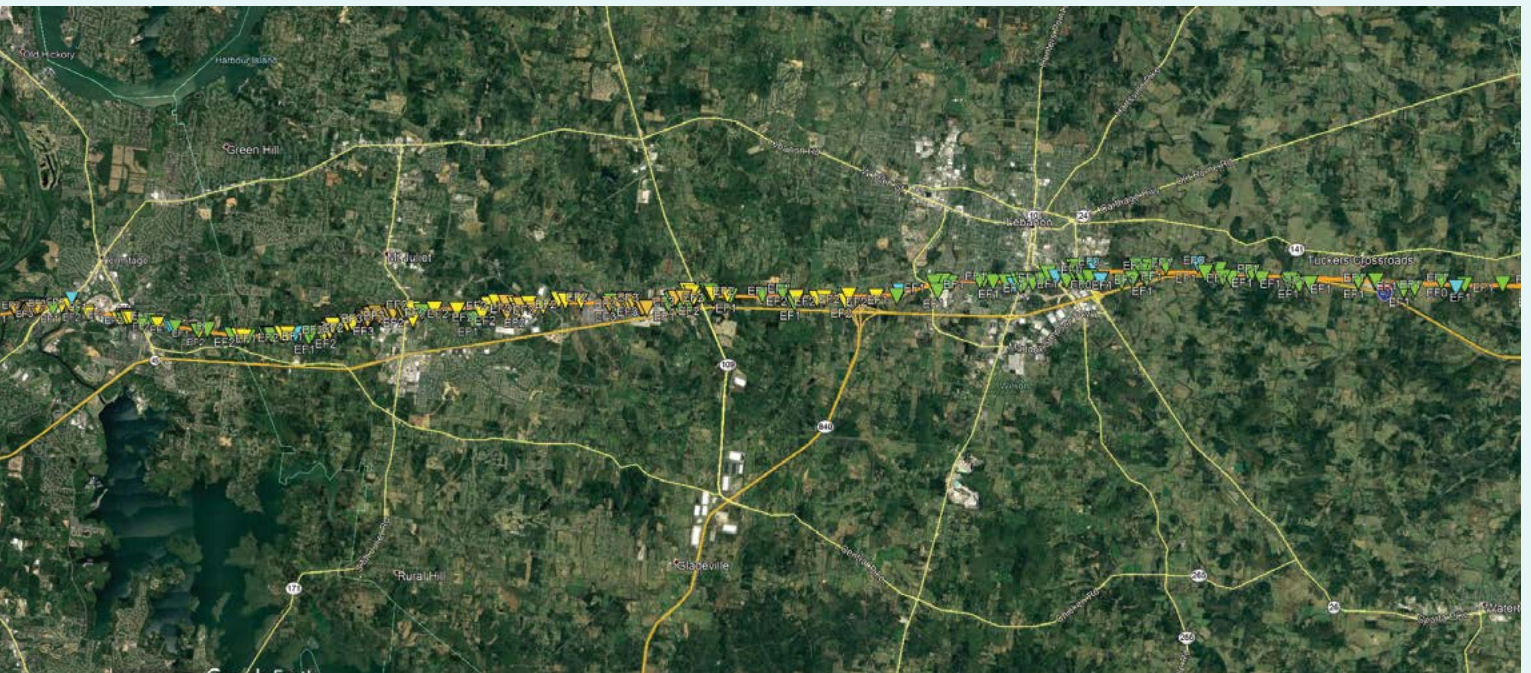
The gallery is available to the public. A related effort involves asking government, NGO, and insurance stakeholders to view the images and make their own observations.

The interdisciplinary nature of Perrucci's work is vital, said Hiba Baroud, Littlejohn Faculty Fellow, assistant professor of civil and environmental engineering, and Perrucci's doctoral adviser.

"We are solving real-world problems that cannot be solved by a single discipline," she said.

Perrucci's work has been part of a 2019-2021 Curb Public Scholars award. The Curb Center for Art, Enterprise & Public Policy provides grants to graduate students who find creative ways to illustrate real-world problems and generate innovative solutions to tackle them.

$5 million NSF Convergence Accelerator agreement boosts disease prediction project

A massive collaboration to show how sensors and data streams can detect biological threats and predict future disease outbreaks has advanced with $5 million in federal funding over the next two years.

The NSF Convergence Accelerator approved Computing the Biome for Phase 2 funding in September 2021. Vanderbilt School of Engineering has a lead role in the project, which involves industry and local government, in addition to academia and the federal government. The collaboration received a $1 million Phase 1 proof-of-concept award in September 2020.

"The Computing the Biome project, which utilizes Microsoft's Premonition platform, is an extremely ambitious pioneering effort aimed at the creation of a global,

real-time system for detecting and predicting biological threats as they evolve in the environment," said E. Bronson Ingram Professor of Engineering Janos Sztipanovits, who is co-principal investigator.

"We are excited to contribute our model-integrated computing technology to this project with the goal of making global impact," said Sztipanovits, who also is director of the Institute

> " I am incredibly excited about the integration of academia, public health organizations, startups and established technology providers to tackle important societal challenges."
>
> **Ethan Jackson**
> *PhD '07*
> *Senior Director, Microsoft*

for Software Integrated Systems and professor of computer science.

Using Harris County, Texas—home to the city of Houston and 4.7 million people—as its test case, Computing the Biome aims to demonstrate an artificial intelligence platform that continuously monitors and predicts biothreats. The first target will be mosquito-borne diseases, identifying areas at high risk of West Nile Virus infections.

Microsoft is the big industry partner, providing sensor nodes, species recognizers, models, and industry leadership. Vanderbilt will contribute to the development of open-source data platforms, application design studios, and AI and machine learning algorithms, plus project management.

Computing the Biome has its roots in a project funded by IARPA, the Intelligence Advanced Research Projects Activity, on which Vanderbilt engineers collaborated Microsoft. The tech giant expanded the project, known as Premonition, led by Ethan Jackson, PhD '07, a former student of Sztipanovits.

"I am incredibly excited about the integration of academia, public health organizations, startups and established technology providers to tackle important societal challenges," said Jackson, a senior director at Microsoft. "Delivering solutions


Ethan Jackson positions a drone during an earlier field test of a pilot program that became Microsoft Premonition. Vanderbilt engineers lead "Computing the Biome," a related project that received a $5 million cooperative agreement from NSF Convergence Accelerator.

requires much more than the fusion of data sets. It requires the fusion of people, ideas and organizations—and this team is going to deliver."

Scientists need rich and timely data about the distribution and evolution of species in the environment to predict human disease outbreaks. Computing the Biome will build new data streams that combine information such as hyperlocal weather, autonomously identified disease transmitting insects, and genetically identified viruses and microbes. Next, the team will develop the AI systems that use those new data streams to detect and predict existing and emerging biothreats.

Tomorrow.io, the second industry partner, provides hyperlocal climate models. The team includes experts from three other universities: Johns Hopkins, the University of Pittsburgh, and the University of Washington.

E. Bronson Ingram Professor of Engineering Janos Sztipanovits, who also is director of the Institute for Software Integrated Systems, is co-principal investigator for a massive project that will use Harris County, Texas to demonstrate an AI platform that continuously monitors biothreats. The first target will be mosquito-borne diseases, identifying areas at high risk of West Nile Virus infections.
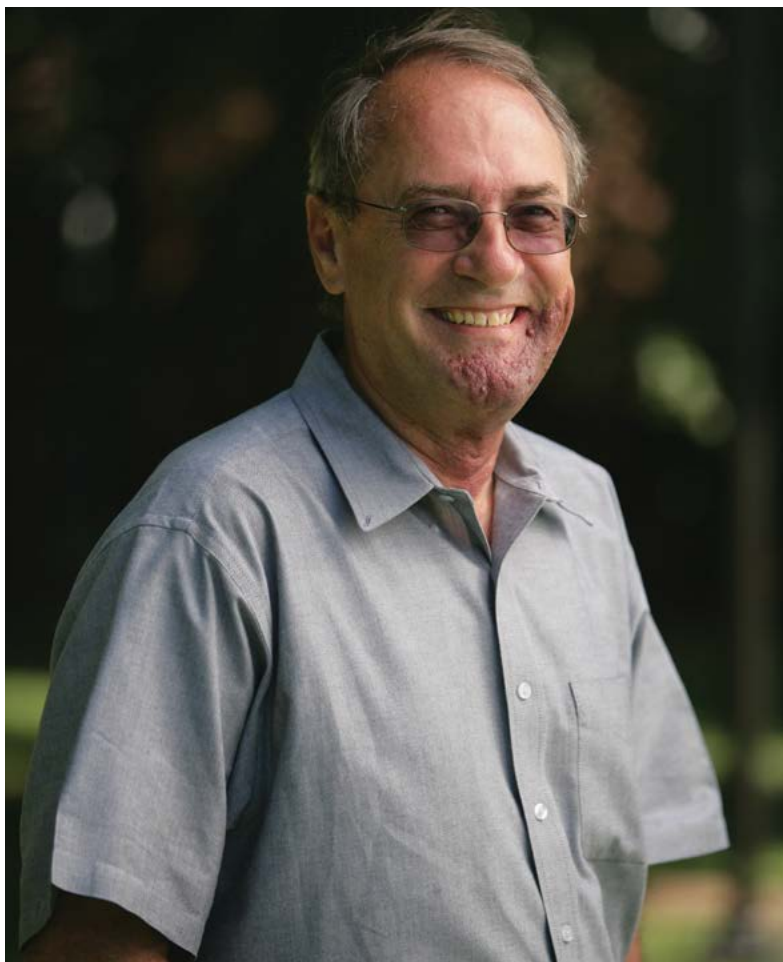
In developing the foundations for the air taxi safety system, researchers will use the Airbus Vahana UAM, among other vehicles.

Reinforcement Learning and data drive NASA air taxi project

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Before urban commuters take to the skies, a multi-institution team with Vanderbilt engineers and funded by NASA will develop and test the foundations of safety management for commercial, self-piloted air taxis.

Such aircraft must communicate with each other. They must respond to hazards, from weather to equipment malfunction to "uncooperative" other aircraft to prevent collisions and crashes. And all this must unfold in real time, in defined corridors separate from existing air traffic routes but without continuous air control support on the ground.

Reinforcement learning, a form of machine learning, is central to the $2.5 million project.

"This is a very exciting task," said Cornelius Vanderbilt Professor of Engineering Gautam Biswas, who heads the Vanderbilt effort. "A machine learning algorithm is not like a person—it can do only what it has been trained for. It can analyze a situation better than a human, but it doesn't have the intuition to deal with unusual situations."

These vehicles, called eVOTLs, for electric vertical takeoff and landing, resemble a cross between a helicopter and a small airplane. They don't need the long runways of passenger jets or even smaller planes, but their lighter, pilotless profile makes them more susceptible to certain types of risk.

The project tackles three types of hazards: adverse convective weather, winds, and fog; corridor incursion by non-cooperative aircraft; and vehicle and component level degradation and faults. Vanderbilt engineers, as experts in tracking performance of components and monitoring degradation, are focusing on the latter.

A key innovation they bring to this work is the idea of using reinforcement learning algorithms for online fault tolerant control. "What happens when a fault occurs? How can aircraft keep flying by adjusting its controller? Should it continue or alter its route, or is the situation so bad the vehicle must find a place to land immediately?" Biswas said.

"All of this decision making has to happen on board," he said.

The approach also incorporates condition-based maintenance to support safe flights and will require a cloud infrastructure for prognostics, risk evaluation, and hazard response functions.

Automated aircraft control is not new. Autonomous systems handle more and more functions in commercial and military flights each year with software trained by system models. The difference with the eVTOL safety management project is that it will be data-driven.

NASA has been testing such aircraft at its research center in Hampton, Virginia. The agency is exploring how different aircraft technologies and configuration will perform in an urban environment, and researchers will use this data. With the information trove, the team will tackle not only what and how a "machine" learns, but also how to make the leap into "learning as you go."

> "That is the interesting thing and the challenge—how rich is your data? If you don't consider the limitations of your data, you will fail.
>
> **Gautam Biswas**
> *Cornelius Vanderbilt Professor of Engineering*

"All of this will be done in a data-driven manner," Biswas said. "That is the interesting thing and the challenge—how rich is your data? If you don't consider the limitations of your data, you will fail."

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The research team will fly the Tarot T-18 octocopter at NASA Langley for safety demonstration experiments. The application will be package deliveries with the vehicles flying at low altitudes.

Administration

Dean
Philippe Fauchet, Bruce and Bridgitt Evans Dean
philippe.fauchet@vanderbilt.edu
(615) 322-0720

Senior Associate Dean for Graduate Education and Faculty Affairs
E. Duco Jansen
duco.jansen@vanderbilt.edu
(615) 343-3773

Senior Associate Dean for Undergraduate Education
Cynthia Paschal
cynthia.paschal@vanderbilt.edu
(615) 343-3773

Associate Dean for Research
Peter T. Cummings
John R. Hall Professor of Chemical Engineering
peter.cummings@vanderbilt.edu
(615) 343-3773

Associate Dean for Development and Alumni Relations
Teresa Rogers
teresa.rogers@vanderbilt.edu
(615) 322-4934

Associate Dean for External Relations and Director of Communications
Christopher Rowe
chris.rowe@vanderbilt.edu
(615) 343-3773

Associate Dean for Academic Programs
Julianne Vernon
julie.vernon@vanderbilt.edu
(615) 322-2441

Associate Dean for Strategic Learning Programs
Jules White
jules.white@vanderbilt.edu
(615) 343-7472

Assistant Dean for Academic Services
Adam McKeever-Burgett
adam.w.mckeever-burgett@ vanderbilt.edu
615-343-8061

Assistant Dean for Professional and External Education Programs
Joanne Wang
joanne.wang@vanderbilt.edu
(615) 875-8386

Assistant Dean for Design
Thomas Withrow
thomas.j.withrow@vanderbilt.edu
615-322-3594

Chief Business Officer
Hector O. Silva
hector.silva@vanderbilt.edu
(615) 875-8079

Departments

Department of Biomedical Engineering
Michael King, Chair, J. Lawrence Wilson Professor of Engineering
mike.king@vanderbilt.edu
(615) 322-3521

Department of Chemical and Biomolecular Engineering
Kane Jennings, Chair
kane.g.jennings@vanderbilt.edu
(615) 322-2441

Department of Civil and Environmental Engineering
Douglas Adams, Chair, Daniel F. Flowers Professor and Distinguished Professor
douglas.adams@vanderbilt.edu
(615) 322-2697

Department of Computer Science
Xenofon Koutsoukos, Chair
xenofon.koutsoukos@vanderbilt.edu
(615) 322-2771

Department of Electrical and Computer Engineering
Bennett Landman, Chair
bennett.landman@vanderbilt.edu
(615) 322-2771

Department of Mechanical Engineering
Nilanjan Sarkar, Chair, David K. Wilson Professor of Engineering
nilanjan.sarkar@vanderbilt.edu
(615) 322-2413

Division of General Engineering
Yiorgos Kostoulas, Director
yiorgos.kostoulas@vanderbilt.edu
(615) 343-4965

Research Groups

Vanderbilt University School of Engineering fosters strong partnerships inside the university and with its research peers. The combination of innovative research, commitment to education, and collaboration with a distinguished medical center creates an invigorating atmosphere for faculty members, research staff, graduate students and undergraduates.

Biophotonics Center at Vanderbilt
Anita Mahadevan-Jansen, Orrin H. Ingram Professor of Engineering, Professor of Biomedical Engineering
vanderbilt.edu/vbc

Vanderbilt Center for Mechanobiology
Cynthia Reinhart-King, Cornelius Vanderbilt Professor of Engineering, Professor of Biomedical Engineering

Center for Rehabilitation Engineering and Assistive Technology
Michael Goldfarb, H. Fort Flowers Professor of Mechanical Engineering

Karl Zelik, Associate Professor of Mechanical Engineering
engineering.vanderbilt.edu/create

Consortium for Risk Evaluation with Stakeholder Participation
David Kosson, Cornelius Vanderbilt Professor of Engineering, Professor of Civil and Environmental Engineering
cresp.org

Frist Center for Autism and Innovation
Keivan Stassun, Stevenson Professor of Physics & Astronomy, Professor of Computer Science
my.vanderbilt.edu/autismandinnovation/

Institute for Software Integrated Systems
Janos Sztipanovits, E. Bronson Ingram Professor of Engineering, Professor of Computer Science, Professor of Electrical and Computer Engineering
isis.vanderbilt.edu

Institute for Space and Defense Electronics
Ron Schrimpf, Orrin H. Ingram Professor of Engineering, Professor of Electrical Engineering
isde.vanderbilt.edu

Laboratory for Systems Integrity and Reliability
Douglas Adams, Daniel F. Flowers Professor, Distinguished Professor of Civil and Environmental Engineering
vu.edu/lasir

Multiscale Modeling and Simulation Group
Peter Cummings, John R. Hall Professor of Chemical Engineering
my.vanderbilt.edu/mums

Vanderbilt Center for Environmental Management Studies
Mark Abkowitz, Professor of Civil and Environmental Engineering Professor of Engineering Management
vanderbilt.edu/VCEMS/

Vanderbilt Center for Transportation and Operational Resiliency
Craig Philip, Research Professor of Civil and Environmental Engineering
vanderbilt.edu/vector

Vanderbilt Institute for Data Science
Douglas Schmidt, Cornelius Vanderbilt Professor of Engineering, Professor of Computer Engineering and Computer Science
vanderbilt.edu/datascience/

Vanderbilt Institute for Integrative Biosystems Research and Education
John Wikswo, Cain University Professor, Professor of Biomedical Engineering
vanderbilt.edu/viibre

Vanderbilt Institute of Nanoscale Science and Engineering
Sharon Weiss, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering
vanderbilt.edu/vinse

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Benoit Dawant, Cornelius Vanderbilt Professor of Engineering, Professor of Electrical Engineering
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Vanderbilt University Institute of Imaging Science
John Gore, Hertha Ramsey Cress Professor of Medicine, University Professor of Radiology and Radiological Sciences, Professor of Biomedical Engineering
vuiis.vanderbilt.edu

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