University of Delaware

MECHANICAL ENGINEERING

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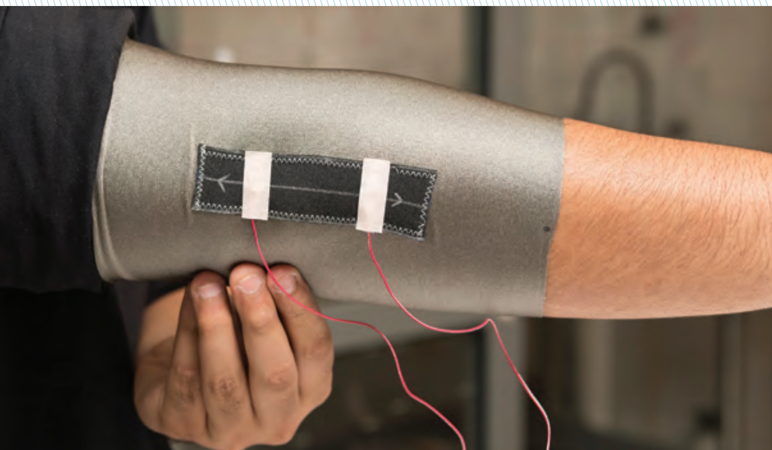
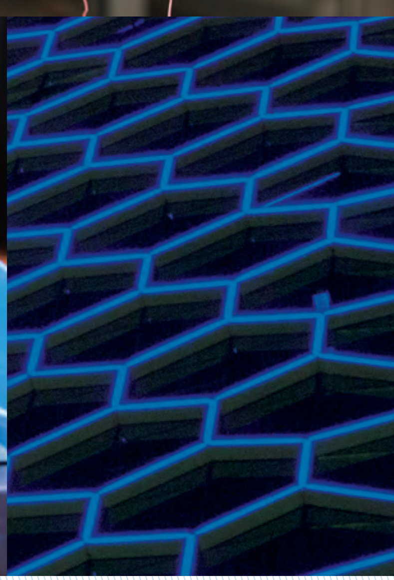
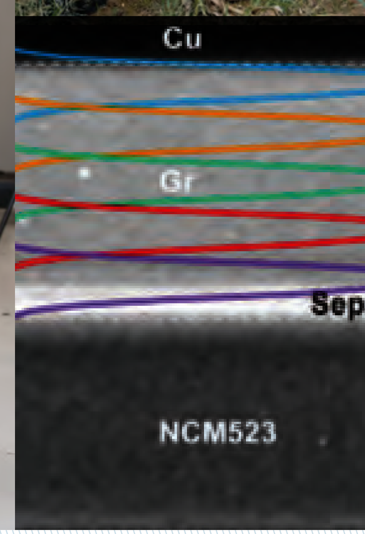
2019 NEWS







INSIDE

SPOTLIGHTS ON OUR HIGH-IMPACT, MULTIDISCIPLINARY RESEARCH

BIOMEDICAL ENGINEERING | COMPOSITES AND ADVANCED MATERIALS | CLEAN ENERGY
NANOTECHNOLOGY | COMPOSITES & ADVANCED MATERIALS | ROBOTICS AND CONTROLS

UNIVERSITY OF DELAWARE
ENGINEERING

Our society is increasingly mobile, connected and reliant on technologies and processes pioneered by engineers. The world needs more problem-solvers, and the value of a mechanical engineering degree has never been more apparent.

At the University of Delaware, we empower students to become innovators and world changers. That means providing them with an education that is modern, relevant, and customizable.

For example, we are now offering a new twelve-credit undergraduate concentration in manufacturing systems—which joins existing concentrations in aerospace engineering and automotive engineering. Manufacturing jobs are on the rise, and we are providing our students with a foundational expertise and a credential that will allow them to succeed in a variety of manufacturing settings, from composite materials to medical devices to semiconductor materials and more.

In 2018, we debuted a fully online 30-credit master of science in mechanical engineering so engineers can deepen their expertise and learn from our expert faculty no matter where they live. We are also pleased to announce that in 2019, we are launching a new master of science in robotics (MSR), which is built upon our broad and deep expertise in robotics and control. (Learn more about our excellence in robotics on pages 16 and 22) A unique and exciting aspect of our new MSR program is that it will expose students to the implementation of robotic systems in air, land, and sea.

Of course, our academic offerings are just one part of what makes our Department of Mechanical Engineering special. On the pages that follow, you will learn more about our impactful research in rehabilitation, smart textiles, batteries, automated vehicles, 2-dimensional materials and more. You will meet several of our faculty members and be inspired by the story of Tsu-Wei Chou, Unidel Pierre S. du Pont Chair, a composite materials expert celebrating his 50th year at UD.

We are also pleased to share good news about several of our outstanding students. They are inventing products, building vehicles, improving equity in the University community, and in one case, even fighting fires in between classes. Catch up with alumni, including a CEO who developed life-saving armor for military and civilian applications, a four-person team of Blue Hens working on improved jet engines, and a few professors who came back to educate the next generation of #Hengineers.

How do you change the world through engineering? To keep up with our news and events and learn how to get involved with our department, visit me.udel.edu and join the conversation on the social media channels listed on this page.

AJAY PRASAD

DEPARTMENT CHAIR
ENGINEERING ALUMNI
DISTINGUISHED PROFESSOR

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@UDengineering

LinkedIn
University of Delaware Department of Mechanical Engineering

IN THIS ISSUE

654

STUDENTS

22% growth over 5 years

UNDERGRADUATE

549 students
in Spring 2019

Degree
Bachelor's in
Mechanical Engineering

Minors
Biomechanical and Integrated Design

Concentrations
Aerospace, Automotive Engineering,
and Manufacturing Systems

GRADUATE

105 students in Spring 2019

Degrees
Ph.D. in Mechanical Engineering

Master of Science in
Mechanical Engineering
(thesis or non-thesis, campus or online)

Master of Science in Robotics

Graduate Certificate in Composites
Manufacturing and Engineering

Graduate Certificate in
Composite Materials

4 + 1 Program BME/MSME

CORE RESEARCH AREAS

Biomechanical Engineering,
Clean Energy and Environment,
Composites and Advanced Materials,
Nanotechnology, Robotics and Controls

FACULTY & RECOGNITION

6

Named Professors

Suresh Advani
George W. Laird Professor of
Mechanical Engineering

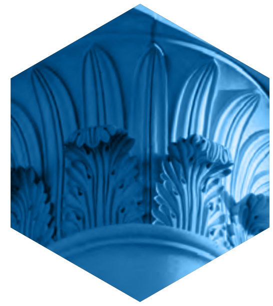
Thomas Buchanan
George W. Laird Professor of
Mechanical Engineering

Tsu-Wei Chou
Unidel Pierre S. du Pont Chair

John W. Gillespie Jr.
Donald C. Phillips Professor of Civil
and Environmental Engineering

Andreas Malikopoulos,
Terri Connor Kelly and John Kelly
Career Development Professor

Ajay Prasad
College of Engineering
Alumni Distinguished Professor

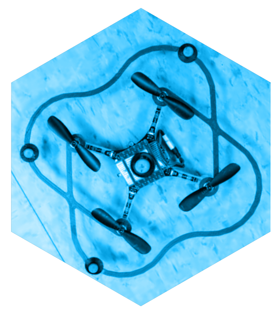


FACILITIES

23,620 square feet
of lab and supporting facilities

2,000 square feet
of teaching facilities

3,570 square feet
of student design and collaboration space



POINTS OF PRIDE

Design Studio
Robotics MS Degree
Composites Certificates

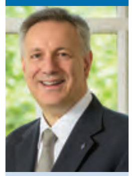
RESEARCH

$6.1M
in sponsored research expenditures

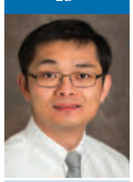
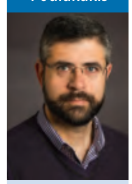
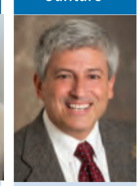
Major Funders
National Institutes of Health (NIH), Defense Advanced Research Projects (DARPA), National Science Foundation (NSF), U.S. Department of Energy (DOE), Federal Transit Administration, Defense Threat Reduction Agency, Federal Highway Administration

Industry/Research Partnerships
ExxonMobil Corporation, UT-Batelle, Xergy Inc., DuPont Company, Venturewell, Praxis Inc., Osteo Science Foundation, Delaware Economic Development Office, Johns Hopkins University, University of Southern California, University of Pennsylvania, Baylor University, University of Texas at Dallas, Rice University, University of Delaware Research Foundation

Mechanical Engineering Faculty Research Matrix

	Suresh Advani	Dennis Assanis	Thomas Buchanan	Jenni Buckley	David Burris	Tsu-Wei Chou	Heather Doty	Joseph Feser
								
Biomechanical Engineering			■	■	■			
Clean Energy and Environment	■	■			■			■
Composites and Advanced Materials	■				■	■	■	■
Nanotechnology					■	■	■	■
Robotics and Controls								

	Kun (Kelvin) Fu	Jack Gillespie	James Glancey	Jill Higginson	Zubaer Hossein	Guoquan Huang	Michael Keefe	Joseph Kuehl
								
Biomechanical Engineering		■		■				■
Clean Energy and Environment	■	■			■			■
Composites and Advanced Materials	■	■	■		■		■	
Nanotechnology	■	■			■			
Robotics and Controls						■		

	X. Lucas Lu	Andreas Malikopoulos	Ioannis Poulakakis	Ajay Prasad	Valery Roy	Michael Santare	Leonard Schwartz	Herbert Tanner
								
Biomechanical Engineering	■			■		■		
Clean Energy and Environment				■	■	■	■	
Composites and Advanced Materials						■		
Nanotechnology				■				
Robotics and Controls		■	■					■

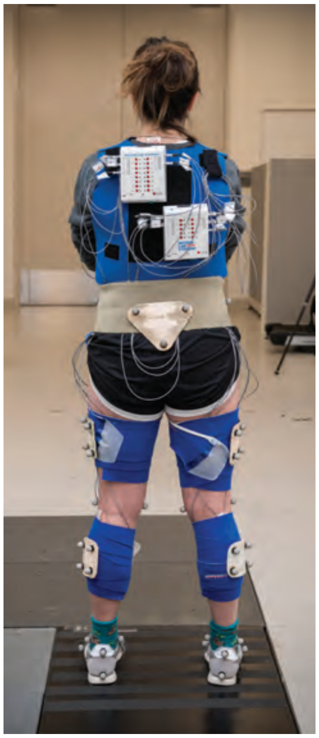
	Erik Thostenson	Lian-Ping Wang	Liyun Wang	Bingqing Wei	Adam Wickenheiser	Pierre Yao
						
Biomechanical Engineering		■	■			
Clean Energy and Environment		■		■	■	■
Composites and Advanced Materials	■			■		
Nanotechnology	■	■		■		
Robotics and Controls					■	

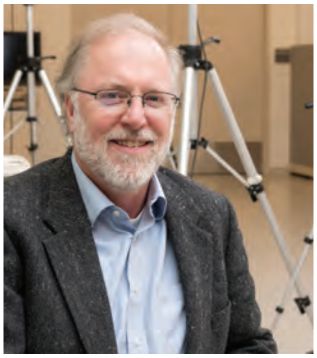
THEORY MEETS PRACTICE

Buchanan Lab uses engineering science to improve rehabilitation

This work was supported by the following grants: Eunice Kennedy Shriver National Institute of Child Health And Human Development—R01-HD087459; National Institute of Arthritis and Musculoskeletal and Skin Diseases—R01-AR046386, R01-AR048212; National Institute of General Medical Sciences—P30-GM103333, R37-HD037985, T32-HD007490, U54-GM104941; National Institute For Child Health And Human Development, F30-HD096830; Foundation for Physical Therapy; and Promotion of Doctoral Studies (PODS) – Level I Scholarship.

ACL tears aren't just painful in the moment—they also increase a patient's risk of developing osteoarthritis later on.





Megan Leibowitz, a doctoral student in physical therapy, demonstrates motion capture technology used to study how people walk.

Tom Buchanan is the George W. Laird Professor of Mechanical Engineering.

At UD, a research team led by Tom Buchanan, the George W. Laird Professor of Mechanical Engineering and Director of the Delaware Rehabilitation Institute, is teasing out what exactly happens to cartilage as a result of ACL injuries. The team hopes that this insight can be utilized in the development of improved osteoarthritis prevention strategies.

The team uses MRI results, finite element models, gait analysis to study ACL injuries and determine which stresses on cartilage may be indicative of osteoarthritis. To complete this research, they utilize facilities at the University of Delaware's Center for Biomedical and Brain Imaging as well as UD's Science, Technology and Advanced Research (STAR) Campus. At STAR, the team collaborates with UD's top-ranked Department of Physical Therapy to collect data from patients and understand the clinical aspects of the injuries they study. "Based on what we identify, maybe physical therapists could treat patients differently," said Buchanan.

The results of one recent paper, published in the *Journal of Orthopaedic Research*, were surprising. The team studied knee gait variables, muscle co-contraction and knee joint loading in young people with a history of ACL trouble. They found that high muscle co-contraction does not always result in high knee joint loading, thought to be associated with arthritis. "This suggests that arthritis isn't just caused by really high forces, but can also be caused by too low forces on the joint," said Buchanan. The ideal range of forces may in fact be a very narrow window.

Laura Sturgill, a biomedical engineering undergraduate in the class of 2019, joined Buchanan's lab as an undergraduate research assistant in 2018 because she wanted more experience studying the mechanical aspects of biomedical engineering. "These applications of statics and dynamics are especially interesting," she said.

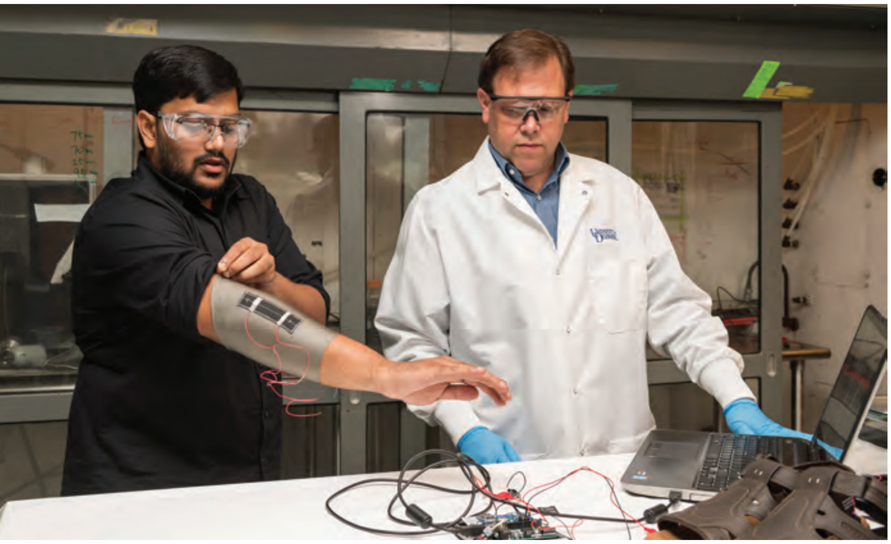
Kelsey Neal and Jack Williams, doctoral students in mechanical engineering, use motion capture and MRI to assess the effects of ACL tears. Neal chose to study in Buchanan's lab because she wanted to work on rehabilitation engineering and was impressed by the unique setup that allows her to work so closely with clinicians. "We can see how we are affecting patients' lives," she said.

Neal was also drawn to UD because of the Perry Initiative, a nonprofit organization co-founded by associate professor Jenni Buckley to inspire young women to be leaders in orthopedic surgery and engineering. As a program specialist for the organization, Neal runs programs across the country to introduce high school girls to surgical techniques that were pioneered by engineers. Buchanan is a member at large of the organization's board of directors.

Buchanan is also the program coordinator for Delaware's Center for Translational Research ACCEL Program to support and expand clinical and translational research in the state. In October 2018, officials announced that UD and four other institutions will receive $25 million over five years from the National Institutes of Health and the state of Delaware to continue these research programs for improved patient care and public health.

"Engineers play an important role in the expansion of health-related research at UD and beyond," said Buchanan.

NOVEL SENSORS COULD ENABLE SMARTER TEXTILES



UD engineers use carbon nanotube composite coatings

A team of engineers is developing next-generation smart textiles by creating flexible carbon nanotube composite coatings on a wide range of fibers, including cotton, nylon and wool. Their discovery is reported in the journal *ACS Sensors* where they demonstrate the ability to measure an exceptionally wide range of pressure – from the light touch of a fingertip to being driven over by a forklift.

Fabric coated with this sensing technology could be used in "smart garments" where the sensors are slipped into the soles of shoes or stitched into clothing to detect human motion.

The carbon nanotube based coating gives this light, flexible and breathable fabric an impressive sensing capability. When the material is squeezed, large electrical changes in the fabric are easily measured. "As a sensor, it's very sensitive to forces ranging from touch to tons," said Erik Thostenson, an associate professor in mechanical engineering and materials science and engineering.

Photos left to right: Doctoral student Sagar Doshi (left) and Erik Thostenson test an elbow sleeve outfitted with one of their novel sensors; Doshi demonstrates how the sensors could be integrated into a shoe to sense pressure on different parts of the foot as a person walks.

This work was supported by the U.S. National Science Foundation (NSF) CAREER Program (1254540) and the Delaware INBRE program with a grant from NIH-NIGMS (P20-GM103446) and the State of Delaware.

Nerve-like electrically conductive nanocomposite coatings are created on the fibers using electrophoretic deposition (EPD) of polyethyleneimine functionalized carbon nanotubes.

"The films act much like a dye that adds electrical sensing functionality," said Thostenson. "The EPD process developed in my lab creates this very uniform nanocomposite coating that is strongly bonded to the surface of the fiber. The process is industrially scalable for future applications."

Researchers can add these sensors to fabric in a way that is superior to current methods for making smart textiles. Existing techniques, such as plating fibers with metal or knitting fiber and metal strands together, can decrease fabrics' comfort and durability, said Thostenson, who directs UD's Multifunctional Composites Laboratory. The nanocomposite coating made by his group is flexible and pleasant to the touch and has been tested on a range of fibers, including aramid, wool, nylon, Spandex and polyester. The coatings are just 250 to 750 nanometers thick and would only add about a gram of weight to a typical shoe or garment. What's more, the processing technique for coating the fabrics is inexpensive and relatively eco-friendly, since it can be done at room temperature using a water based dispersion without any harsh chemicals.

Exploring Future Applications

One potential application of the sensor-coated fabric is to measure forces on people's feet as they walk. This data could help clinicians assess imbalances after injury or help to prevent injury in athletes. Thostenson's group is collaborating with professor Jill Higginson, director of the Neuromuscular Biomechanics Lab, and her group as part of a pilot project funded by Delaware INBRE. Their goal is to see how these sensors, when embedded in footwear, compare to biomechanical lab techniques such as instrumented treadmills and motion capture.

"One of our ideas is that we could utilize these novel textiles outside of a laboratory setting — walking down the street, at home, wherever," said Thostenson.

Doctoral student Sagar Doshi is the lead author on the paper. He worked on making the sensors, optimizing their sensitivity, testing their mechanical properties and integrating them into sandals and shoes. In preliminary tests, the sensors collect data that compares with that collected by a force plate.

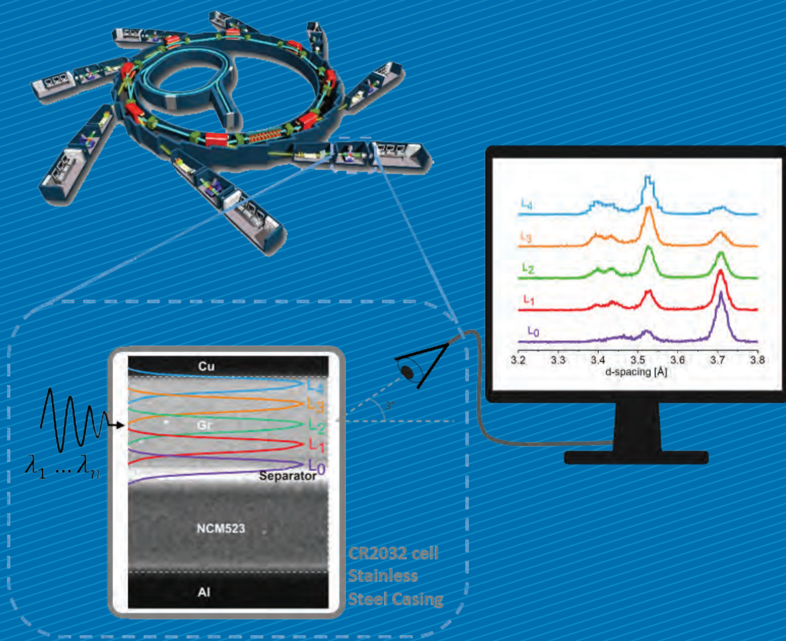
"Because the low-cost sensor is thin and flexible the possibility exists to create custom footwear and other garments with integrated electronics to store data during their day-to-day lives," Doshi said. "This data could be analyzed later by researchers or therapists to assess performance and ultimately bring down the cost of healthcare."

Interdisciplinary collaboration with faculty and students from the College of Health Sciences will help the taem develop applications.

"As engineers, we develop new materials and sensors but we don't always understand the key problems that doctors, physical therapists and patients are facing," said Doshi. "We collaborate with them to work on the problems they are facing and either direct them to an existing solution or create an innovative solution to solve that problem."

Thostenson's research group also uses nanotube-based sensors for other applications, such as structural health monitoring.

"We've been working with carbon nanotubes and nanotube-based composite sensors for a long time," said Thostenson, who is affiliated faculty at UD's Center for Composite Materials (UD-CCM). With researchers in civil engineering his group has pioneered the development of flexible nanotube sensors to help detect cracks in bridges and other types of large-scale structures. "One of the things that has always intrigued me about composites is that we design them at varying lengths of scale, all the way from the macroscopic part geometries, an airplane or an airplane wing or part of a car, to the fabric structure or fiber level. Then, the nanoscale reinforcements like carbon nanotubes and graphene give us another level to tailor the material structural and functional properties. Although our research may be fundamental, there is always an eye towards applications. UD-CCM has a long history of translating fundamental research discoveries in the laboratory to commercial products through UD-CCM's industrial consortium."



THE SECRET LIFE OF BATTERIES

Professor probes the properties of batteries so that he can make them charge faster

You probably use batteries every single day, but do you actually understand how they work? Assistant professor Koffi Pierre Yao is uncovering novel insights about what happens inside the batteries that power our smartphones, laptops, and electric vehicles. He plans to use this knowledge to develop faster-charging batteries that make electric vehicles the go-to automobiles for drivers.

Several of today's electric vehicles, such as the Tesla Model 3 and Nissan Leaf, run on lithium-ion batteries. But it takes inconveniently too long to recharge those vehicles when you can fill up your gas tank in the time it takes to pick up gas-station coffee. In a lithium-ion battery, positively charged lithium ions move through the electrode to deliver energy.

Scientists all over the world do time-consuming research on lithium-ion batteries in an attempt to optimize these power units. "Usually people will make an electrode, test it, make another one, test it, and so on, and it's kind of a serial process," said Yao.

Instead, Yao uses physical probes to look inside batteries while they work and develop a direct physical understanding of how lithium ions flow within batteries. When a battery is charging, the lithium flows unevenly in a way that's difficult to measure. Yao started working on this while he was a postdoctoral associate at Argonne National Laboratory (ANL), a position he held from 2016 until 2018, when he joined UD's faculty.

In a paper published in *Energy & Environmental Science,* a journal published by the Royal Society of Chemistry, Yao describes how he and his colleagues at ANL used X-rays to get a micron-scale movie of how lithium distributes within the electrode while lithium-ion batteries are running.

"We put an industrial-grade battery under an X-ray beam and mapped the distribution of the lithium within the electrodes," he said.

Yao and his colleagues knew that the lithium did not distribute homogeneously. Imagine a group of people running through a small doorway. It takes time for people to spread out into the interior of the room; therefore, there will be crowding at the entry point. That's similar to how lithium moves through the electrode. Still, Yao and his colleagues were surprised at the extent to which lithium scattered inhomogeneously.

The goal is to use this knowledge to reduce testing time and speed up the research and development (R&D) process for these batteries.

In another new paper published in *Advanced Energy Materials*, Yao describes how he and his colleagues used X-rays to quantify the activity in a silicon-graphite electrode. Cell phone batteries typically contain graphite, but silicon offers some potential benefits over graphite. "We're interested in silicon because it can increase the capacity of the electrode by a factor of 10 compared to graphite," he said. However, silicon is less stable than graphite and degrades faster, so a blend of the two may prove to be a viable solution. "Some of the lithium goes into the graphite, and some goes into the silicon," he said.

Yao and his colleagues sought to discover exactly where the lithium ions traveled within this blended electrode. "It's something people haven't previously been able to do in the literature. We provide a clear picture of which of silicon and graphite plays host to lithium at any point in time. Now we can go forward and manipulate this pattern to stabilize the cycling." he said. This knowledge can help Yao in his quest to design novel particles to make faster-charging and higher energy batteries.

At UD, Yao plans to expand upon his research on batteries with his colleagues at the Center for Fuel Cells and Batteries and more. Yao received his master's and doctoral degrees in mechanical engineering from the Massachusetts Institute of Technology (MIT) and his bachelor's degree in mechanical engineering at UD. As an undergraduate at UD, he was mentored by Ajay Prasad, Engineering Alumni Distinguished Professor and Chair of Engineering, who introduced him to electric cars and electrochemistry, the science behind them.

Support for this research comes from the Office of Vehicle Technologies (OVT) at the U.S. Department of Energy. The electrodes used in this work are from Argonne's Cell Analysis, Modeling and Prototyping (CAMP) facility, which is supported within the core funding of the Applied Battery Research (ABR) for Transportation Program. Use of the Advanced Photon Source (APS) at Argonne is supported by the U. S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

EXAMINING 2D MATERIALS, ATOM BY ATOM

Engineers uncover strength, toughness of hexagonal boron nitride

From smartphones that bend to solar panels that wrap around houses, flexible electronics could make consumers very happy. But first, someone has to figure out how to make them. One important question is—which materials are tough enough to maintain their electronic properties under such harsh conditions?

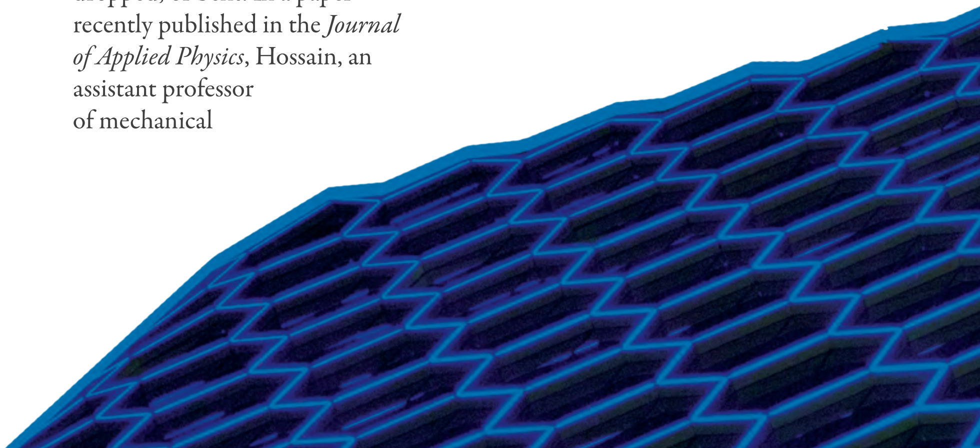
The answer could lie in 2D materials, emerging materials that are single layers of atoms. 2D materials have unique electronic properties, and they are expected to be useful in future electronic devices, nanocomposites, medical devices, photovoltaics, thermoelectrics and more. However, 2D materials are brittle, which has the potential to limit their use.

At the University of Delaware, M. Zubaer Hossain studies ways to control the toughness and strength of 2D materials and understand how they behave under loading conditions, such as being stretched, dropped, or bent. In a paper recently published in the *Journal of Applied Physics*, Hossain, an assistant professor of mechanical engineering, described new insights about the strength and toughness of the 2D material hexagonal boron nitride, which is being investigated for use in part because it is a very good insulator.

"We wanted to understand strength and toughness in this brittle material and try to understand the behavior, strength and toughness along different directions," he said. "And what we find in this work is that they depend a lot on the loading direction."

Imagine that you hold a piece of paper face down in front of you. If you pull the right and left sides straight out, the paper will not bend, said Hossain. However, if you pull those edges downward, the paper will bend. "This same piece of paper has different mechanical properties depending on which direction you load it, and the same idea can be applied to 2D materials," he said. When properties depend on the direction of load, the material is anisotropic.

Hossain sought to determine whether hexagonal boron nitride is anisotropic in regard to strength and toughness, and found that it is. He also wanted to understand how anisotropy in this material affects its electronic properties. If the electronic properties change, the result could pose a problem, or in some cases, an



opportunity—a brand new functionality researchers can utilize. Either way, the scientists need to understand what's happening in order to maximize the use of the material.

Hossain also examined the material up to the maximum stress point to determine whether the loading direction affects failure. "This work shows that the strength or the loading at which a material begins to fail depends strongly on the loading direction," he said. They also determined where the material would start to crack and how to determine the path of the crack. The path is predicted by the loading direction just as other properties are.

Hossain examined the material at the atomic scale—after all, every material is just a collection of atoms bonded through electronic interactions.

"There is an atomistic basis behind this differential response," he said. "The arrangement of atoms is different in different directions." The bonds between atoms change and overlap, and electrons redistribute. This redistribution of electrons depends on the loading direction.

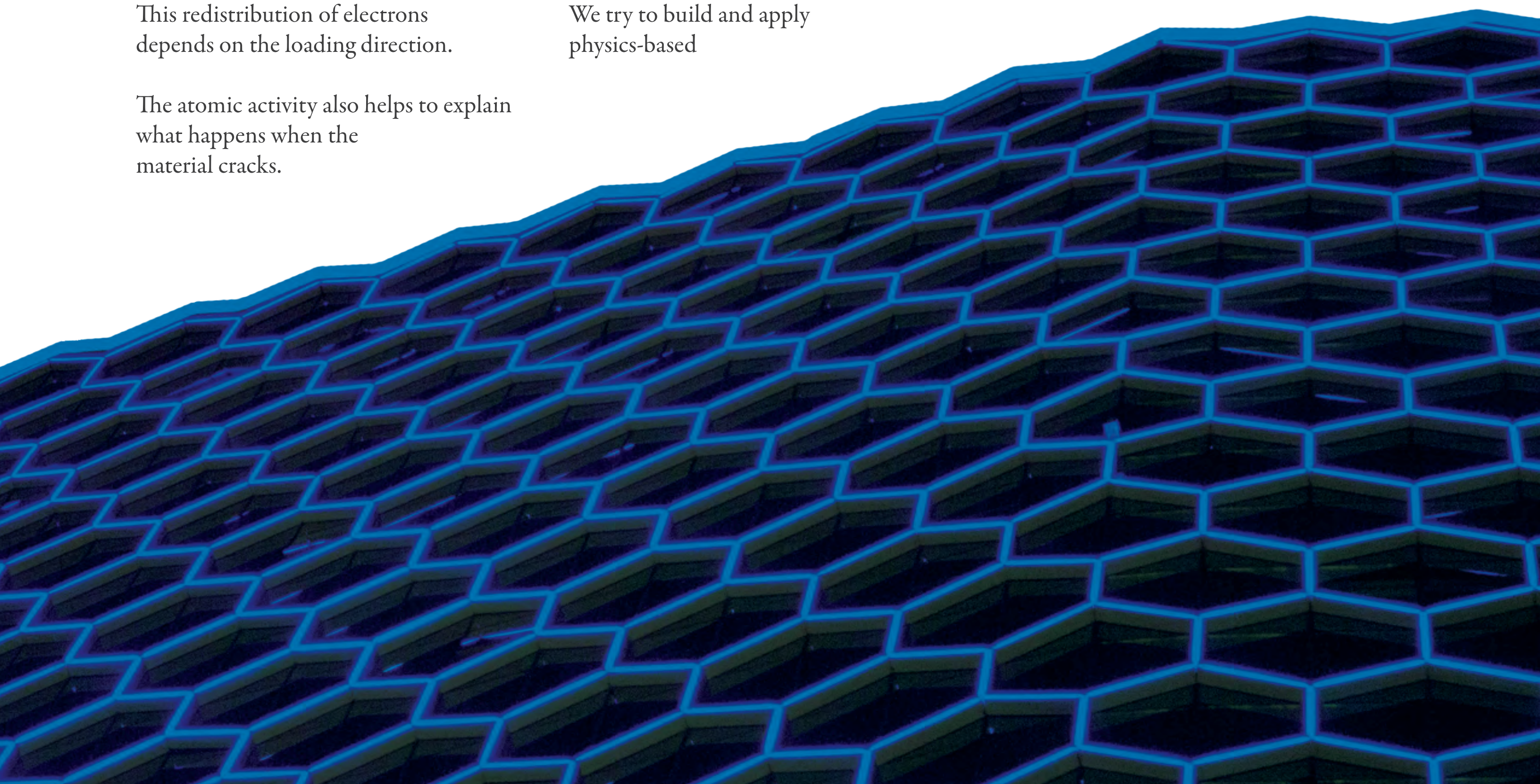
The atomic activity also helps to explain what happens when the material cracks.

When the crack first starts by breaking a bond at the atomic scale, the event may not be detectable from macroscopic measurements, due to time involved in propagation of the stress signal. A broken bond can self-heal so long as the stress leading the bond rupture process stops increasing its intensity. "Defects can self-heal if the loading is just right, but if you go past that critical point, it may not be recoverable anymore," he said.

Hossain's expertise in mechanical engineering allows him to take a unique approach to this research. "Usually material properties and mechanisms at the quantum scale are studied by physicists or materials scientists, mostly under equilibrium or undeformed conditions that are far from the mechanical condition where the fracture processes start nucleating or propagating," he said. "Our research is interdisciplinary. We look at strength and toughness, which are traditional subjects of mechanical engineering, but we try to understand the strength and toughness from a quantum mechanical perspective, which is not usually the case for mechanical engineers. We try to build and apply physics-based analysis and tools to reveal nanoscale mechanisms and to identify their role on the mechanical behavior that we see at longer length scales."

These are increasingly important skills as devices become increasingly fast and sophisticated and consumers demand more versatile products. "Nowadays, we need to be able to engineer behavior at the electronic level," he said.

The co-authors on the paper are doctoral student Tousif Ahmed, master's degree student Zhaocheng Zhang, and undergraduate student Colin McDermitt.



SMARTER, SAFER, MORE EFFICIENT VEHICLES

Malikopoulos' Lab advances control technologies for connected and automated vehicles

Imagine a daily commute that's orderly instead of chaotic. Connected and automated vehicles (CAVs) could provide that relief by adjusting to driving conditions with little to no input from drivers. When the car in front of you speeds up, yours would accelerate, and when the car in front of you screeches to a halt, your car would stop, too.

Andreas Malikopoulos uses control theory to develop algorithms that will enable this technology of the future. Malikopoulos, who was recently named the Terri Connor Kelly and John Kelly Career Development Professor of Mechanical Engineering, pioneers control technologies for CAVs in two laboratories at the University, the UD Scaled Smart City (UDSSC) testbed and a driving simulator facility. UDSSC is a scaled city that can help us prove concepts of CAV coordination at different

traffic scenarios without required significant resources or imposed safety concerns. In UDSSC, we can also conduct experiments repeatedly relying on on-board sensing while intermittent communication and connectivity may be present.

"We are developing solutions that could enable the future of energy efficient mobility systems," said Malikopoulos. "We hope that our technologies will help people reach their destinations more quickly and safely while conserving fuel at the same time."

Making traffic lights obsolete

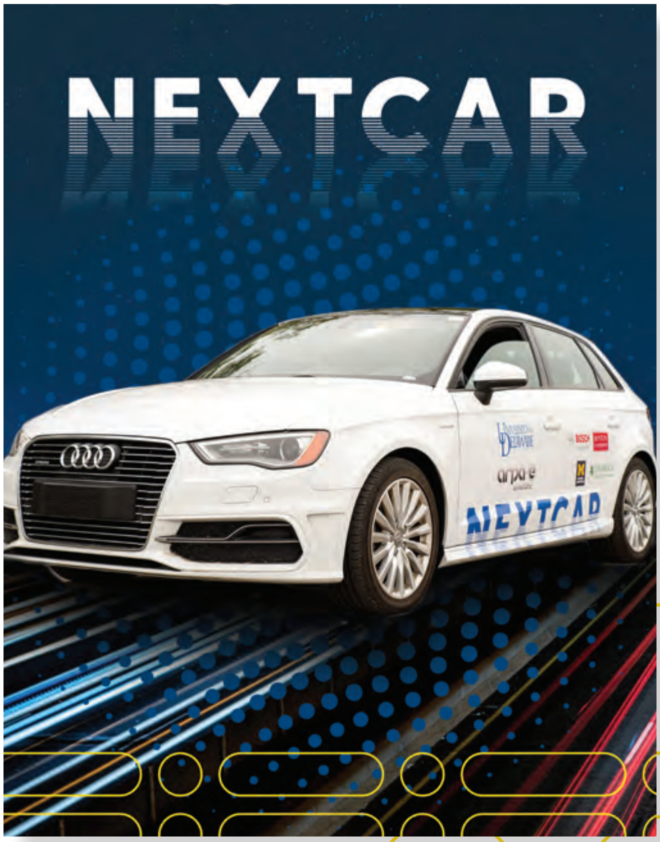
Someday cars might talk to each other to coordinate traffic patterns. Malikopoulos and collaborators from Boston University recently developed a solution to control and minimize energy consumption in connected and automated vehicles crossing an urban intersection that lacked traffic signals. Then they used software to simulate their results and found that their framework allowed connected and automated vehicles to conserve momentum and fuel while also improving travel time. The results were published in the journal *Automatica*.

Saving fuel and avoiding speeding tickets

Imagine that when the speed limit goes from 65 to 45 mph, your car automatically slows down. Malikopoulos and collaborators from the University of Virginia formulated a solution that yields the optimal acceleration and deceleration in a speed reduction zone, avoiding rear-end crashes. What's more, simulations suggest that the connected vehicles use 19 to 22 percent less fuel and get to their destinations 26 to 30 percent faster than human-driven vehicles. The results of this research effort were published in *IEEE Transactions on Intelligent Transportation Systems*.

Malikopoulos has received funding for this work from two U.S. Department of Energy programs – the Smart Mobility Initiative and the Advanced Research Projects Agency – Energy's NEXTCAR program.

Malikopoulos is the principal investigator of a three-year project funded by the Advanced Research Projects Agency for Energy (ARPA-E) through its NEXT-Generation Energy Technologies for Connected and Automated On-Road Vehicles (NEXTCAR) program to improve the efficiency of an Audi A3 e-tron by at least 20 percent. The partners of this project are the University of Michigan, Boston University, Bosch Corporation, and Oak Ridge National Laboratory.



Opposite page: Andreas Malikopoulos tests technologies for connected and automated vehicles on a smaller scale at the University of Delaware's Scaled Smart City (UDSSC) testbed.

This page: Malikopoulos has received funding for this project from the Advanced Research Projects Agency - Energy's NEXTCAR program.

ROBOTS ON THE FARM

Engineers and plant scientists team up to optimize corn growth

Each new technological advancement in agriculture, from tractors to tillage techniques, has allowed farmers to plant and harvest more food in less time. Today's era of agricultural innovation is precision agriculture — optimizing crop performance in farmers' fields based on their individual characteristics. To combat the range of challenges in agriculture, such as improving crop yields and plant resiliency, increasing pest resistance, addressing nutrient insufficiency, and more, scientific insights into the crop are needed. Robots are important tools for precision agriculture because they can quickly collect valuable data to help farmers fine-tune their methods of planting, irrigation, pest control, harvesting and more. Similarly, for scientific discovery that underlies crop improvement, robots make it possible to gather a wide range of information on very large numbers of plants – tens to hundreds

of thousands – in order to break new ground in plant science.

With robotics engineers and scientists who study plant genetics and biology, the University of Delaware is an ideal breeding ground for robotic agricultural technology. Algorithms and circuits can be designed and built in laboratories onsite, and machinery can be tested in "outdoor laboratories" located on the University's Newark campus. With the range of expertise at UD, the on-campus farm with dedicated research fields is a unique asset that facilitates cross pollination of different scientific domains, ranging from biology to engineering to data science, which can open new pathways that address challenges in agriculture.

Revealing the best way to breed

Engineers are an important part of the precision agriculture revolution, according to Adam Stager, a doctoral student in mechanical engineering.

"If you were to measure every single leaf on every single plant in a cornfield throughout the whole season, you'd need to send an army of people through the field to do it in a day," he said. Instead, robots can collect rich data in short time.

"The application of robotics and automation to precision agriculture brings up an array of interesting research problems for us," said Bert Tanner, a mechanical engineering professor, an expert in robotics and control systems and Stager's adviser. By introducing automation into the cornfield, the team has a flexible experimental testbed for several different technologies of interest, from heterogeneous robot cooperation to mobile manipulation.

Tanner and James Adkins, associate scientist at the UD Cooperative Extension, are co-principal investigators on a seed grant from the College of Agriculture and Natural Resources for this project. Randall Wisser, associate professor of plant genetics, is the principal investigator.

The goal was to add high-tech gadgets to a piece of equipment already present in many crop fields: a mobile, overhead irrigation system, which is dotted with sprinkler heads to water crops.

An undergraduate student in Tanner's lab worked with Adkins to develop plans for a platform that piggybacks off the irrigation system, adding a rail and carriage system for the sensors to move along. Then, Adkins fabricated and installed the platform. In an outdoor laboratory dedicated to genetics and breeding research on UD's Newark farm, Adkins mounted the existing irrigation system with a rail and carriage platform. Scott Hopkins, superintendent of UD's Newark Farm, also aided in planning and installation of the platform.

Stager added gear to collect data about plants as they grow in the field. The technologies onboard include LiDAR, which is a surveying system that uses laser light to map the shape and structure of plants, and sensors to measure physiological aspects of the plants you can't see with the naked eye, like how efficiently plants utilize sunlight to make energy. The system also features an RGB camera to capture visible images and a GPS with a very fine level of resolution to record where each data point comes from. This flexible platform provides a framework to tether new technologies and test new ideas.

Opposite Page: Bert Tanner and Randy Wisser are working to introduce automation into a cornfield.

Above: Adam Stager, doctoral student in mechanical engineering, monitors crop data from atop the irrigation system in the outdoor lab at UD's Newark farm during the summer.

Below: UD researchers involved in the robotics work in agriculture include, left to right, Erin Sparks, Pete Moore, Bert Tanner, Adam Stager, Teclemariam Weldekidan and Randy Wisser.

Above: Researchers hope robots will help in observation of corn root development.

Opposite: Adam Stager, a UD doctoral student in mechanical engineering, adjusts the ground robot before sending it into the field.

All this data goes to a computer stored in a waterproof box onboard the system, and the information inside is a treasure trove for Wisser. Prior to the recent emergence of "phenomics" where imaging and remote sensing technologies are used for high-throughput measurement of plants, the primary tool used to collect data were teams of individuals with rulers for some characteristics and subjective scoring techniques for others. The robotic system allows for an unprecedented amount of objective data collection, with the ability to capture repeated measurements on numerous characteristics over the entire life cycle of the plant. In turn, this unlocks the potential to unravel complex biology and develop prediction methods that spur innovations in plant breeding and crop production. "With this system, we can get all kinds of measurements that we could never otherwise get due to limitations of our ability to measure thousands of individual plants," said Wisser.

Each plot in the field contains a population of corn with particular genetic material, allowing researchers to map and dissect the genetic basis of the variation in that particular population.

"This gives us information that helps breeders and biologists advance," said Wisser. "It empowers us to get denser and broader information about the characteristics of the plants." Normally researchers are restricted to low-tech methods such as measuring plant height at the end of the season. Now they can obtain the information repeatedly and study growth curves for individual genetic identities.

"This is a current theme in plant genetics and breeding and biology. People are using remote sensing technologies on different platforms: unmanned aerial vehicles, push carts, tractors. The platform enables you to collect all this of information, but computer scientists, data scientists and biologists then need to process and translate these data into meaningful discoveries. UD is in a great position to bring these experts together and capitalize on the robotic field systems in order to help with breeding the next generation of crop cultivars."

Exposing the roles of brace roots

Erin Sparks, an assistant professor of plant molecular biology, researches corn brace roots, which grow above ground and are believed to stabilize plants by propping them up. Brace roots aren't well understood, even by plant scientists, and Sparks wants to elucidate how they work. "We don't know right now whether they are continually growing, or whether they emerge, pause their growth and are then triggered by something to continue growing," she said.

In order to analyze brace roots, researchers typically have to dig up plants, but Sparks wanted a better way to collect data over time without destroying plants. With seed funding from the Delaware Biosciences CAT program, Sparks and Stager teamed up to develop a solution — a robot that can move through the field and collect pictures of the brace roots through the growing season.

Building on this platform, in collaboration with Joshua Peschel, assistant professor at Iowa State University, Stager and Sparks are also trying to determine if and how robots affect the fields they study. "Basically the question is: As we start to send more robots through the field, what happens to the plants?" said Sparks.

To test this, Peschel built a ground robot with an extended arm called the slapper, which simulates how a robot might run into a plant.

"Our hypothesis is that plants will actually reinforce themselves from being disturbed and that they will become stronger from sending robots through the field," said Sparks. "But the alternate — that it's detrimental to the plants and we're definitely damaging them — is possible as well."

Stager started the experiment with a commercial robot and then built a custom robot that addressed the engineering challenges associated with this project. How fast should it move? How should it navigate? What if it gets stuck in mud or caught on a root?

Robots under the canopy

Through a new Entrepreneurial Proof of Concept grant from the Delaware Bioscience Center for Advanced Technology, Tanner and Stager are also developing robotic technology that can survey the soil underneath plants.

"The operation of the sub-canopy tracked robot in particular gives us the opportunity to wrestle with one of the central, and sometimes overlooked, challenge in field robotics: uncertain and uneven terrain traversal for robotic vehicles," said Tanner. "It is day and night to operate a robotic vehicle in 'sterilized' lab conditions compared to bringing it out in the real world where it may have to go through mud, rocks, water puddles, undergrowth/weeds, etc."

This is knowledge that transcends the corn field and will inform the development of future robots for land, aerial and underwater use.

Undergraduate student Raymond Zayas is working with Tanner and Stager to develop a system to keep the robots on track as they move throughout the field. Cameras in the robots can use strategically placed tags, like QR codes, in the field to determine their position and navigate to their next location. "This project merges technology and nature," he said.

This work brings together people with differing expertise and skill sets. "I think one of the best things about a project like this is that it brings a lot of people together," said Stager. "I've met so many new people that I've worked with in the field, which is a lot better than being in a lab all day and not really seeing how whatever you're doing in research is used. The practical side of engineering is really brought out when you have a team of people that really build something that's going to go out and collect data."

CELEBRATING 50 YEARS

Tsu-Wei Chou is the longest-serving professor in the College of Engineering

Many of today's technological marvels—from aircraft to automobiles to wind turbine blades—are made of strong, lightweight composite materials, or composites. In the field of composites, Tsu-Wei Chou, Unidel Pierre S. du Pont Chair in Mechanical Engineering, is legendary.

He has published nearly 380 journal articles and book chapters as well as two books. He was named among the top 100 materials scientists of the past decade by Times Higher Education. He has served as editor and then editor-in-chief of the international journal *Composites Science and Technology* since 1985. He has a lengthy list of awards and society Fellowships and most recently was named Honorary Advisor for the Innovation Center for Advanced Nanocomposites, SINANO, Chinese Academy of Sciences. And he is beloved by the dozens of former students he has mentored, who are now engineering leaders all over the world.

As Chou celebrates his 50th year as a faculty member at the University of Delaware, he reflects on how the field of composites has evolved and why his enthusiasm for his job never wanes.

Chou's UD story started in 1969, when he was still a graduate student at Stanford University. The late Professor Jerry Schultz of UD chemical engineering, then on sabbatical at Stanford, approached Chou in the graduate student office and told him about an open faculty position at UD. The new professor would teach in the mechanical engineering department and the materials and metallurgy program—the latter of which pre-dated today's materials science and engineering department.

Chou was intrigued. "Such a totally unexpected opportunity interested me immensely, because unlike most of the students in the department at Stanford, I had a strong interest in applied mechanics," he said.

His first day at UD was September 1, 1969—just 43 days after the moon landing.

As a new professor, Chou taught courses in two programs, which was challenging and rewarding. In 1970, mechanical engineering professor Jack Vinson invited Chou to co-teach a course in composite materials, and in 1974, they established the internationally renowned Center for Composite Materials. In 1985-86, Chou participated in establishing the first composites manufacturing based NSF Engineering Research Center as well as the ARO University Research Initiative Center at UD.

Since Chou's career began, the field of composites has evolved tremendously. For one, the materials are now used in flight and on the road. Chou recalled the first time he boarded a Boeing 787 Dreamliner aircraft, he was excited—it was a moment he describes as marvelous. The plane was a beautiful engineering accomplishment and also the first major commercial application of fiber composites, which comprise 50 percent of the aircraft weight. They are lighter than materials traditionally used in aircraft. "People have recognized the importance of composites on aircraft," said Chou. "A lighter aircraft with the same engine can carry more load, more people."

He thinks automobiles are the next frontier for these composites because while thousands of planes are built every year, millions of cars are manufactured. "Major automobile companies are applying composites to their newest models, and the percentage is increasing every year," he said. "By replacing traditional structural materials such as aluminum and steel with composites, you reduce the weight and increase the fuel efficiency."

Chou aims to continuously identify new research directions and make contributions to understanding the fundamentals of composites. He has studied fiber materials, from glass to aramid to carbon. He has studied matrix materials, from polymer to metal to ceramics. He has worked on theoretical modeling, processing and manufacturing techniques and attacked problems at a variety of scales, from macro to micro to nano. He studies performance from structural to functional.

Composites engineers will continue making contributions from aeronautics and aerospace to infrastructures, from automobiles to soft robotics, and from huge wind turbine blades to nanocarbon based functional composites.

While the field of composites is thriving, and Chou is an important player in its success, he considers his impact on students and co-workers to be his most lasting accomplishment. Chou has mentored dozens of students. He teaches them how to write papers and present at conferences, but he also teaches them how to be successful.

"I think the more lasting impact is that they learn from me is how I approach research," he said. "You have to be hardworking and focused. There's always frustration, failure, disappointment, but you just have to insist that you want to do it and you can accomplish it. That is not easy."

He draws inspiration from an old Chinese saying: Diligence compensates shortcomings.

"I think I can say I've been working diligently all the time," he said. "Looking back, I think that is perhaps the most important fact that has contributed to my 'success.'"

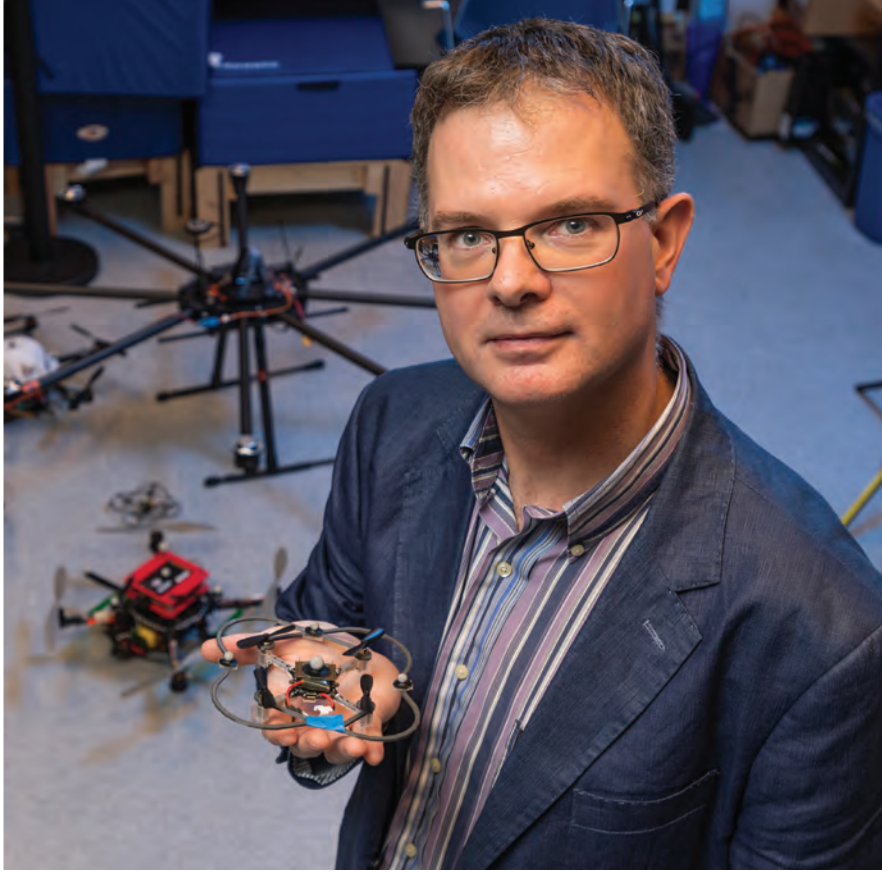
During his first year at UD, Chou was invited to co-author a book with Vinson. That book, *Composite Materials and Their use in Structures*, was published in 1975. Chou dedicated himself—spending nights, weekends, and any smidge of spare time in between all his other research and teaching responsibilities in two programs. These commitments might leave some feeling drained, but Chou felt thankful for the opportunities he received.

He used to take walks on The Green, which was dotted with large elm trees at the time. "I liked to walk around and relax and do some thinking," he said. "Looking back, I felt sorry that my parents never had a life as enjoyable as mine, with peace and quiet. I can devote myself to do what I like to do."

Chou's parents faced World War II and then the civil war in China, conflicts that lasted almost their entire lives. "It was a difficult life, but they worked very hard in order for us to have a good education," he said. "These memories impact me the most."

Today, Chou is as curious and enthusiastic as ever and has no plans to slow down. "When I get up in the morning, I like the feeling that I have something to look forward to for today: things to take care of, students I need to talk to, and problems we didn't resolve yesterday that hopefully we will resolve today or tomorrow," he said. "That kind of motivation is sustaining."

The mechanical engineering department will celebrate Tsu-Wei Chou's 50th anniversary at UD on October 18, 2019. Join us at the STAR Tower Audion for lunch and invited talks by five experts who will discuss current and future trends in composites.



Recognition for Robotics Expert **Herbert Tanner** named Fellow of the American Society of Mechanical Engineers

Today, you can walk into a car dealership and purchase a car that parallel parks itself, thanks to carefully designed algorithms and strategically placed sensors. Engineers like Herbert "Bert" Tanner laid the groundwork for this automotive capability back in the 1990s. He tackled the problem of autonomous parallel parking around obstacles in an undergraduate senior thesis in mechanical engineering.

"I was amazed at how with the right mathematical machinery I could 'design' such control laws that made my systems behave so 'intelligently,' and how the underlying mathematical proofs allowed me to bet my money on them working right," said Tanner, now a professor of mechanical engineering at the University of Delaware. "I marveled how my simulated cars maneuvered and I was hooked."

Since then, Tanner has been on the leading edge of robotics and control technology. Robotic drones have surged in popularity just recently for businesses and hobbyists alike, but Tanner has been working on drones for a decade, and on multi-robot systems in general for more than 20 years. He has published more than 130 journal articles and conference papers and written nine book chapters.

For his contributions to the field of multi-robot systems, Tanner was recently named a Fellow of the American Society of Mechanical Engineers (ASME).

Robotics research

Tanner's research group works on robotics, control and automation. They use theory to design algorithms which are then validated through experimentation. Tanner's current work has a broad range of applications, from promoting rehabilitation for children with special needs, to oceanic sensors networks, nuclear nonproliferation and more.

Sometimes this work involves taking commercially available drone systems and hacking them for new uses. For example, with funding from the Defense Threat Reduction Agency, Tanner is developing networks of autonomous drones to detect carriers of radiation.

And when you work with robots, persistence is key. "Even when the math is correct, your robots will crash about half the time," said Tanner. "It's an iterative process; you eventually learn how to make them work through failure. Nature does not tolerate hasty engineering." He passes this and other lessons on to engineering students. At UD, Tanner has taught classes in subjects such as robotics, vibration and control, dynamics, machine design and nonlinear control. He received the NSF CAREER Award in robotics in 2005, and became senior member of the IEEE in 2008. (IEEE stands for the Institute of Electrical and Electronics Engineers, but the association's membership has expanded with people in related fields, so it goes by IEEE, except in legal documents.) In May 2018, Tanner was awarded the 2018 Outstanding Junior Faculty Member for the College of Engineering and in September he was promoted to the rank of professor.

ASME Fellow status

Tanner joins an elite group as a Fellow of the American Society of Mechanical Engineers (ASME). ASME has more than 130,000 members, and just 3,489 have achieved Fellow status.

Honor for **Jill Higginson**

Professor named Fellow by American Institute for Medical and Biological Engineering

There's a treadmill in the center of Professor Jill Higginson's laboratory, and it's not for impromptu workouts. Higginson studies human motion and gait so that she and other scientists can develop devices to help people recover from injuries and illnesses that limit their mobility.

For her contributions to the field, Higginson, a professor of mechanical engineering and biomedical engineering at the University of Delaware, was recently inducted into the College of Fellows of the American Institute for Medical and Biological Engineering (AIMBE)..

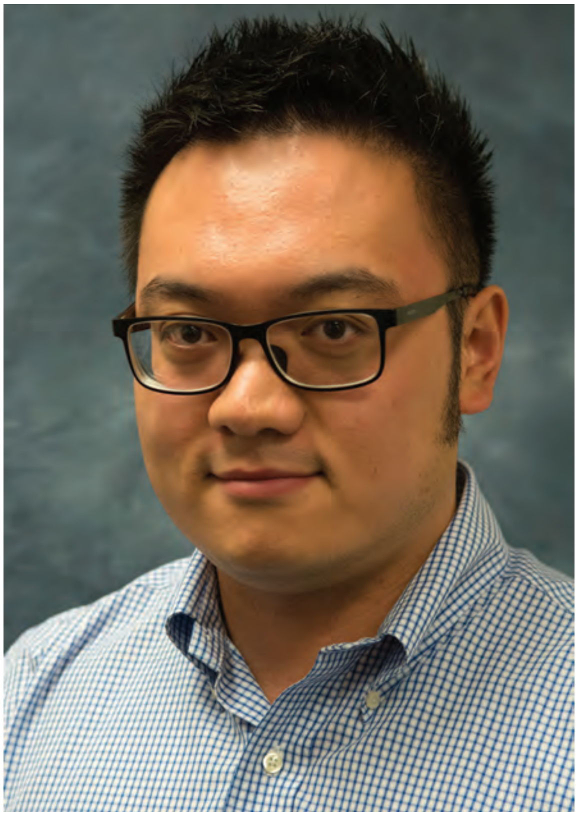
Election to the AIMBE College of Fellows is among the highest professional distinctions accorded to a medical and biological engineer. The College of Fellows is comprised of the top two percent of medical and biological engineers.

Higginson was selected for contributions to the field of neuromuscular biomechanics of pathological movement, musculoskeletal modeling and simulation, and undergraduate research and education. She is one of 156 new Fellows inducted in 2019.

"What an honor to be recognized for doing what I love – interacting across disciplines to address questions relevant to human quality of life and sharing what we learn with others," said Higginson. At UD, Higginson leads a laboratory that focuses on improving the understanding of muscle coordination for normal and pathological movements, which she investigates using experiments and simulation studies. She has published 127 peer-reviewed articles and abstracts, which have garnered 3,049 citations, according to Google Scholar. For example, in an article published last year in the journal Human Kinetics, Higginson and colleagues determined through biomechanical testing that short-term use of walking workstations does not affect young adults' manner of walking.

"Dr. Higginson is an expert in musculoskeletal modeling and simulation of normal and pathological human movement," said Thomas Buchanan, Laird Professor of Mechanical Engineering and Director of the Delaware Rehabilitation Institute. "She uses complex mathematical models to study complex diseases and is one of the leading investigators of the biomechanics of gait in patients that have had strokes. By partnering with investigators with novel treatment approaches (such as rehabilitation robotics and functional electrical stimulation), her team is able to develop patient-specific therapeutic interventions that represent the cutting-edge of rehabilitation in this patient population."

UD has a strong tradition of biological engineering. Other UD faculty members who belong to AIMBE's College of Fellows include: Maciek Antoniewicz, Thomas Buchanan, Prasad Dhurjati, Randall Duncan, Dawn Elliott, Kristi Kiick, Kelvin Lee, Abraham Lenhoff, David Martin, Terry Papoutsakis and Millie Sullivan.



Kun (Kelvin) Fu

In 2018, this assistant professor joined UD from the University of Maryland Energy Research Center, where he was an associate research scientist. Fu holds a doctoral degree in fiber and polymer science from North Carolina State University, a master's degree in textile engineering from Philadelphia University, and a bachelor's degree in textile science and engineering from Donghua University, China.

Fu designs materials and devices using nanostructured and multifunctional fibrous materials including polymers, composites, and textiles and uses advanced manufacturing technologies such as 3D printing to address energy and environmental fundamental challenges and demonstrate concepts for advanced applications. His research activities involve exploration of novel materials and chemistry for the investigation of fundamental material-structure-property correlations in energy related systems, and the game-changing design of advanced materials and devices for energy storage and thermal management in wearable applications.

Adam Wickenheiser

Wickenheiser joined UD as an associate professor in 2018. From 2010 to 2018, he was an assistant professor at the George Washington University. He received his master's and doctoral degrees in aerospace engineering, with a focus on bioinspired flight control and trajectory optimization, from Cornell University, and then conducted postdoctoral research at Cornell on piezoelectric energy harvesting. Wickenheiser also holds a bachelor's degree in mechanical engineering from Cornell.

Wickenheiser studies bio-inspired aircraft and control architectures, adaptive structures, smart materials, and reinforcement learning-based control strategies. He also conducts research on leveraging online resources to promote communities of computational thinkers among undergraduate students. His accolades include the 2011 Intelligence Community Young Investigator Award and the 2015 Outstanding Teacher Award for an Assistant Professor from the George Washington University School of Engineering & Applied Science.

James Glancey

Professor Glancey joined UD's faculty in 1991. He is also an affiliated faculty member at the Center for Composite Materials and an engineer at UD's Cooperative Extension Service. Glancey holds a master's degree and doctoral degree from the University of California, Davis and a bachelor's degree from the University of Delaware. A Registered Professional Engineer, he is principle and owner of Mechanical Design and Forensic Analysis, LLC, and currently serves as a design expert on several patent infringement and product liability lawsuits.

Glancey's research interests are in the application of the solid mechanics, controls, sensors, solid modeling and design to a variety of research problems. His work includes the development of new or improved products and automated processes, the forensics of product failures, as well as a better understanding of the underlying physics of many natural and man-made phenomena. His research utilizes a combination of analysis/simulations, prototyping, and testing. In 2017, Glancey received the George M. Worrilow Award, a distinguished alumni award from UD's College of Agriculture and Natural Resources.

Michael Keefe

Associate professor Michael Keefe joined our faculty in 1985. Since 2000, he has served as associate chair for undergraduate education in the Department of Mechanical Engineering. Keefe holds a master's and doctoral degree in mechanical engineering from the University of Minnesota and a bachelor's degree in mathematics from the University of Notre Dame.

Keefe conducts research that applies computer-aided engineering and solid modeling while primarily teaching undergraduate design courses. He has been President of the University of Delaware Faculty Senate, was elected a Fellow of the American Society of Mechanical Engineers, and was also named 2005 Engineer of the Year by the Delaware Engineering Society. Keefe is currently interested in modeling the response of flexible, fabric-based composite structures to mechanical loading. He continues to be an active member of the design faculty and the Senior Design capstone program.

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The Nowinski Lecture Series honors the late Jerzy L. Nowinski, Professor Emeritus in Mechanical Engineering at the University of Delaware, for his contributions to the field of Applied Mechanics. Each year, one outstanding individual in Applied Mechanics is invited to present a lecture in the series. Dr. Nowinski was the H. Fletcher Brown Professor in the Department of Mechanical Engineering and subsequently the Department of Mechanical and Aerospace Engineering at the University of Delaware from 1961 to 1973.

JACK R. VINSON DISTINGUISHED LECTURE

The Vinson Lecture honors Jack R. Vinson, the H. Fletcher Brown Professor Emeritus of Mechanical and Aerospace Engineering at the University of Delaware. Vinson, who joined the UD faculty in 1964 and taught one of the first composites courses in the US in 1969, was the founding director of the University's Center for Composite Materials in 1974. He served as chairmain of UD's Department of Mechanical and Aerospace Engineering from 1965 to 1979.

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Biomechanics Center to Continue REU

UD's Center for Biomechanical Engineering Research receives REU funding through 2021 For the next three summers, UD will welcome undergraduate students from across the country for an opportunity to apply their engineering skills to biomechanical problems.

NSF has awarded funding to the University of Delaware's Center for Biomechanical Engineering Research (CBER) to be a Research Experience for Undergraduates (REU) site through 2021. NSF first funded this site, called "Dare to BE FIRST" Biomechanical Engineering Foundations in Impactful Research, Science and Technology (BE FIRST), in 2015 for a three-year term. The program hosted 49 students in the last three years. For the next three summers, CBER will host 20 undergraduate students, 10 of which will be supported under the NSF REU program each year.

Students will spend 10 weeks doing hands-on research in a state-of-the-art biomechanical research lab. They will also participate in clinical site visits, scientific and professional development workshops, networking and communication events and a research symposium. In previous years, these summer scholars have also presented their work at national conferences including Biomedical Engineering Society and Orthopaedic Research Society.

Students will be recruited from minority institutions and historically black colleges and universities around the U.S. as well as other institutions with limited research resources. Admission is competitive. Last year, more than 130 applicants competed for 12 positions. This REU site will be led by Jill Higginson, a professor of mechanical engineering, and X. Lucas Lu, an associate professor of mechanical engineering, at the University of Delaware.

UD Hosts Mesoscopic Methods Conference

The 15th International Conference for Mesoscopic Methods in Engineering and Science was held in July 2018.

Local organizers were Lian-Ping Wang, a professor of mechanical engineering, and William Matthaeus, Unidel Professor of Physics and Astronomy. The event featured lectures and talks covering theory, implementations, and applications of mesoscopic simulation methods, numerical methods based on statistical descriptions of molecular motion, thus combining the details of molecular interaction physics and relatively good computational efficiency.

"In the big scheme of things, scientists and engineers are solving a variety of fluid flow problems ranging from flows in microscale devices to atmospheric flows and ocean circulations using a variety of computational methods, a field we call computational fluid dynamics (CFD)," said Wang. "Over the years, the advancement in computer power allows more and more problems to be solved numerically, even turbulent flows and multiphase flows with very little approximations."

Many of the methods discussed involved the mesoscopic approach typically based on the Boltzmann equation, which ties together the more conventional macroscopic CFD approach based on the usual engineering continuum mechanics, and the very expensive microscopic approach based on the molecular dynamics description. The most representative mesoscopic methods now are the lattice Boltzmann method (LBM) and gas kinetic schemes (GKS), said Wang, and the use of these mesoscopic methods for CFD is a relatively new field. LBM has become a viable alternative for CFD in many applications such as turbulent flows, flow through porous media, multiphase flows with complex moving interfaces. "Conventional CFD based on the continuum mechanics has difficulties dealing with these complex flows, and mesoscopic methods are found to be more effective," he said.

Major advances reported at the event include the unified gas kinetics schemes for flows at all Knudsen numbers, cumulant moments based LBM, sharp-interface simulation of dispersed multiphase flow, and phase-field based two-fluid multiphase flow simulation. Some of the building blocks of the LBM method were developed at UD in the 90s.

THESES AND DISSERTATIONS

Brian Graham
Dissertation: Novel approaches to determine the role of diffusive and convective transport environments in articular cartilage function
Advisors: David Burris and Christopher Price

Hao Liu
Dissertation: Carbon nanotube integrated sensors for structural health monitoring of composite materials via electrical property measurement
Advisor: Erik Thostenson

Jinye Liu
Thesis: Computational modeling of quantum confinement in alloy quantum dot-substrate heterostructures
Advisor: M. Zubaer Hossain

Cheng Peng
Dissertation: Study of turbulence modulation by finite-size solid particles with the Lattice Boltzmann Method
Advisor: Lian-Ping Wang

Jun Qian
Thesis: Mechanical characterization of PFSA membrane in fuel cell
Advisor: Michael Santare

Anthony Rossi
Thesis: Switchable parallel elastic actuators in monopod and quadruped applications
Advisor: Ioannis Poulakakis

Sushant Veer
Dissertation: Composing motion primitives under disturbances: a switched systems approach
Advisor: Ioannis Poulakakis

Duanyi Wei
Thesis: A first step to a framework for gait-training with a bilateral approach
Advisor: Ioannis Poulakakis and Jill Higginson

Sai Nitin Yellamilli
Thesis: Polydopamine-coated microcapsules for self-healing in protein exchange membranes
Advisor: Ajay Prasad and Suresh Advani

Minyoung Yun
Dissertation: Study of stochastically varying through the thickness permeability of woven fabric and its effect on void formation in liquid composite molding processes
Advisor: Suresh Advani

Yilu Zhou
Dissertation: Intracellular calcium signaling of chondrocytes and the treatment of osteoarthritis
Advisor: Xin Lu

STUDENT AWARDS

UNDERGRADUATE AWARDS

Outstanding Senior Design Final Presentation Award

Team 119, Siemens Healthcare: Harper Drake, Mary Galanek, John Hughes, Jessica Tentindo

Team 125, WLGore: Connor Karpinski, Tyler Lyness, Christopher Martel, Prescott Weishaar

Outstanding Student (academics plus activity in ASME DE Student Section)
Arnav Prasad

W.Francis Lindell Mechanical Engineering Award Distinguished Seniors
Chris Blackwell, Haley Lloyd

W. Francis Lindell Mechanical Engineering Award Distinguished Juniors
Sophia Marianiello, Tyler Wright

W. Francis Lindell Mechanical Engineering Award Achievement Award
James Ferneyhough, Amanda Lashenick

Mary and George Nowinski Award
Tiange Zhang

Outstanding Seniors
Michael Palmer, Benjamin Silverman, Ethan Wise

Outstanding Juniors
Steven Perez, Arnav Prasad

Outstanding Sophomores
Anne Porter, Austin Weigel

Undergraduate Teaching Assistants
Kelly Caron-Gerstine, Tiange Zhang

Outstanding Student Leaders
Taylor Coleman, Taylor Key, Erin Rezich

Outstanding Student Service to Department
Don Paolo Tiamson, Tiange Zhang

GRADUATE AWARDS

Doctoral Fellowship Award
Fazle Elahi , Yulin Yang

Dissertation Fellowship Award
Nicole Ray

Helwig Fellowships
Kayla Pariser
Kaleb Burch
EJ Carron

Graduate Student Teaching Assistant Award
Kleio Baxevani

This award is in recognition of scholarship and of contribution towards the academic mission of the department through extraordinary work as a Teaching Assistant, as recommended by the faculty of the Mechanical Engineering Department.

Graduate Student Achievement Award
Nicole T. Ray

This award is in recognition of excellent scholarship and creativity in engineering, as recommended by the faculty of the Mechanical Engineering Department.

CCM AWARDS GIVEN TO ME STUDENTS

R. L. MCCULLOUGH SCHOLARS AWARD
Recipient: Sagar M. Doshi, Ph.D.M.E.
Advisor: Prof. Erik T. Thostenson

PROGRESS AWARD
Recipient: Tousif Ahmed, Ph.D.M.E.
Advisor: Prof. Zubaer Hossain

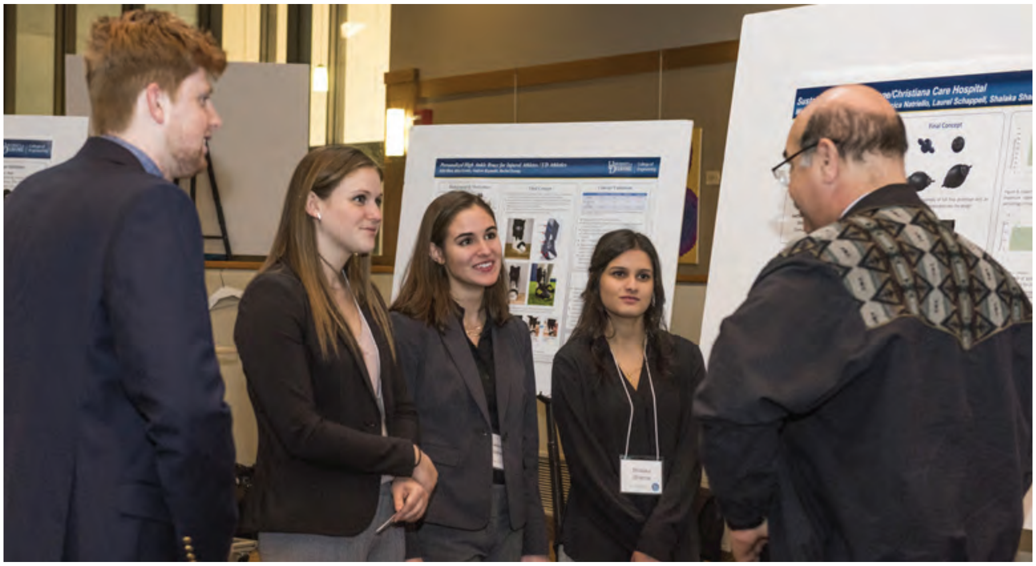
OUTSTANDING SENIOR AWARD
Recipient: Colleen Murray, B.M.E.
Advisor: Prof. Erik T. Thostenson

BIOMECHANICS RESEARCH SYMPOSIUM AWARDS GIVEN TO ME STUDENTS

Top Podium Presentation Awards
Sagar Doshi
Carbon Nanomaterial-Based Novel Functional Garments for Human Motion Analysis

Kaleb Burch
Novel Fabric-Based Force Sensors for Continuous Overground Gait Analysis

People's Choice Poster Presentation Award
Nicole Ray
Combined Effects of User-Driven Treadmill Control and Functional Electrical Stimulation for Poststroke Rehabilitation



Students talk with a mentor at the Senior Design celebration.

I've learned a lot in the last four years, and I can apply it.

This proves that.

–Talia Flamini

PUTTING IT ALL TOGETHER

Senior engineers stretch their skills to solve real-world problems

From theory to application, fourth-year engineering students at the University of Delaware recently tapped into their knowledge to create products and solutions for industry sponsors.

For the Senior Engineering Design program, 228 students from four engineering majors (mechanical engineering, biomedical engineering, electrical engineering and environmental engineering) were split into 44 teams to solve problems for 34 sponsors, companies such as Air Liquide, ILC Dover, Xergy, Christiana Care and more. The teams were guided by 16 faculty members, and their projects were judged by 56 evaluators, including professors and industry experts, at the Senior Engineering Design Celebration on December 12, 2018 in UD's Clayton Hall. Five teams of high school students from Padua Academy in Wilmington also participated, showcasing devices they had designed to help patients with a fear of needles.

Senior Engineering Design asks UD engineering students to synthesize their educational experience to tackle a problem under real business conditions, such as budgetary and time constraints. This experience prepares students for the types of challenges they might encounter in their first jobs and gives them fodder for job interview questions.

"You gain confidence in yourself when you work on a project like this," said Talia Flamini, who with three teammates designed and built an end-of-line inspection system for sponsor Anderson-Negele, a subsidiary of the global instrumentation company Fortive. "I've learned a lot in the last four years, and I can apply it. This proves that."

The following projects were recognized at the Senior Engineering Design Celebration with special awards:

PROCESS IMPROVEMENT AWARD

Title: Hologic Streamlined Assembly of HV Wire in X-Ray Detectors
Students: Abdulrahman Aldobiyan, Kevin Hill, Connor Sloan

NEW PRODUCT DEVELOPMENT AWARD

Title: Christiana Care Endoscopic Rib Shears
Students: Victoria Jones, Venkatesh Ramkumar, Anna Schoonen, Jordyn Schrader, Sejal Shah

THERMAL/FLUIDS AWARD

Title: Christiana Care Constant Pressure Suction Drainage
Students: Michael Barboun, Riley Larson, Jessica Natriello, Laurel Schappell, Shalaka Sharma

SYSTEMS/DYNAMICS AWARD

Erin Rezich, NASA

BIOMEDICAL AWARD
Title: Detecting Limb Offloading Events in Horses
Students: Dimitri Duplan, Morgan Gizzi, Kaitlyn Krewson, Robert Snyder, Alison Wright

ENVIRONMENTAL AWARD
Title: UDSSC
Students: Dean D'Souza, Kunzheng Li, Haley Lloyd, Sophia Loewenguth, Michael Lashner, Thomas Patterson, Andrew Reilly, Rachel Silverman, Yiming Wan

ELECTROCHEMICAL AWARD
Title: UD Kinesiology Orthosis Stiffness Testing Device, v2.0
Students: Zachary Goldstein, Caitlin Grasso, Yuxin Ni, Christian Poindexter, Osman Siddiqui

REHABILITATION DEVICE AWARD
Title: UD PT Instrumented Shoe Insole
Students: Abigail Dela Paz, Jackie Haffey, Sama Tima, Sean Vernon

MEDICAL DEVICES AWARD
Title: Globus Periprosthetic Cable Tensioning Devices
Students: Mary Athanasopoulos, Brian Colotti, Ellen Dudzinski, Dylan Ensslin, Kelley Kempski

EXPERIMENTAL OR EDUCATIONAL TOOL AWARD
Title: Avkin Wearable Arterial Line Simulator
Students: Samantha Farley, Rebecca Gerard, Rachel O'Sullivan, Madeline Smith

BEST OVERALL MACHINING AWARD
Title: Siemens Tube Flanging Device
Students: Harper Drake, Mary Galanek, John Hughes, Jessica Tentindo

MOST COMPLEX MACHINING AWARD
Christopher Deely
Team: 400 FSAE Titanium Suspension Blade

MOST CHIPS
Title: Advanced Materials Technology
Students: Andrew Dorazio, Elizabeth Messina, Haley Strongin, Weng Tianyi

DESIGN STUDIO AWARD
Title: UDSSC
Students: Dean D'Souza, Kunzheng Li, Haley Lloyd, Sophia Loewenguth, Michael Lashner, Thomas Patterson, Andrew Reilly, Rachel Silverman, Yiming Wan

DESIGN STUDIO DUCT TAPE & GLUE AWARD
Title: UD Aero SAE
Students: Lauren Icarangal, Justice Calderon, Dylan Cass, Emily Delaney, Jason DePersia, Samhit Dontamsetti, Scott Fagan, Andrew Kacmarcik, Shehroz Khawaja, Sampras Ko, Nicole Moylett, Nick Pannone, Kristen Reilly, Matthew Romeo, Emily Thompson, Nicholas Vecellio

HIGH SCHOOL ENGINEERING DESIGN AWARD
Maria Smith, Rachel Delate, and Alanna Socha

THE KEEFE AWARD
Title: Sawbones Silicone Flash Trimming
Students: Jonathan Dietz, Deepa Nathan, Brian Shultis, Ryan Skinner

MOST VALUABLE PROJECT (MVP) AWARD
Title: Fortive Value Analysis of CX200 Cycle Flex Timer/Counter
Students: Taylor Coleman, Anthony Dorazio, Cade Gertsen, Francis Schauber

GRIT AWARD
Title: Johnson and Johnson Fluid Bed Pneumatic Purge
Students: Kelechi Chukwunenye, Janie Freedman, Luchen Shen, Zachary Swain

PEOPLE'S CHOICE AWARD
Title: Wearable Birthing Simulator for Nursing Education II: The Cervix
Students: Latifa Ali, Bryce Cushing, Victor DeGeorge, Madison Poff, Caitlin Purcell

BIOMEDICAL ENGINEERING CHAIRPERSON'S AWARD
Title: Terumo Hemostasis Valve
Students: Eric Bartholomew, Alex Eisenberg, Stephen Ioele, Carly Pettipaw, Andrew Taylor

MECHANICAL ENGINEERING CHAIRPERSON'S AWARD
Title: UD Aero SAE
Students: Lauren Icarangal, Justice Calderon, Dylan Cass, Emily Delaney, Jason DePersia, Samhit Dontamsetti, Scott Fagan, Andrew Kacmarcik, Shehroz Khawaja, Sampras Ko, Nicole Moylett, Nick Pannone, Kristen Reilly, Matthew Romeo, Emily Thompson, Nicholas Vecellio

Left to right: UD Vice Provost for Diversity Carol Henderson; Erin Rezich; UD President Dennis Assanis

REHAB-2-GO

Kristen Reilly takes device to healthcare design competitions

In between classes, some engineering students use their skills to help others. Kristen Reilly, a senior, spent two years as president of the Orthotics and Prosthetics Club, a registered student organization at UD.

She and her teammates developed a device, Rehab-2-Go, which provides vibrotactile feedback to those learning to walk with a prosthesis. Sensors capture whether the wearer is walking with a heel-toe step. If the subject walks toe-heel or stomps, a vibrating motor gently buzzes their residual limb, yielding a sensation like a cell phone vibration. The device is patent pending and undergoing clinical testing.

Reilly was heavily involved in building the device and wrote her senior thesis about the project. In 2019, she presented her work at Rice University's Global Health Design Competition and John Hopkins Healthcare Design Competition. There, Reilly met with industry professionals, received helpful feedback and met ambitious, likeminded peers.

"I've learned so much from this project," she said. For example, she built skills in electrical engineering and developed an understanding of regulatory issues around medical devices. These lessons will serve her well in her next stage. This fall, she starts a job as a consultant for Deloitte.

ADVANCING THE STATUS OF WOMEN ON CAMPUS

Engineering student recognized for her efforts

Undergraduate student Erin Rezich received the Mae Carter Scholarship Award at the University of Delaware's annual Women of Promise dinner. The March 19 event, held in the Trabant University Center, celebrated the achievements of UD women and the power of mentorship.

The Mae Carter Scholarship is named after former assistant provost of women affairs, Mae Carter. The Mae Carter Scholarship is awarded to a female undergraduate student at the University who carries the values that Mae Carter has represented to the University community of women. The award highlights someone who continuously works to advance the status of women on campus.

Rezich will graduate this spring with a bachelor's degree in mechanical engineering. She has been a teaching assistant in the Spencer Lab Design Studio for nearly three years and has also spent time as a research assistant and resident assistant at UD. An Honors Program student, Rezich has also been involved with the American Society of Mechanical Engineers as both the President and Treasurer, and is an active volunteer with the Perry Initiative, a nonprofit to advance the status of women in orthopedic surgery and engineering

For the past 10 months, she has been a Pathways Intern for the NASA Glenn Research Center in Ohio.

Matthew Heebner (left), Olivia Alexander (middle) and Connor Sproat are UD students who volunteer with the Aetna Hose Hook and Ladder Company Station 9 in Newark.

STUDENT RECOGNIZED FOR VALOR

Matthew Heebner is a firefighter with the Aetna Hose Hook and Ladder Company

Matthew Heebner was looking forward to breakfast—a bagel he'd purchased on Main Street right after machine design class.

Before he could take a bite, he saw a text message that sent him sprinting down Main Street. A house had caught fire in Newark, Delaware, and a woman was trapped inside. Heebner, a firefighter, headed to the Aetna Hose Hook and Ladder Company Station 9, which sits on the corner of Academy Street and East Delaware Avenue in Newark.

Heebner led a crew that was first to arrive at the scene. Some team members worked on hooking up hoses and setting up a ladder to the second floor, where a woman was hanging from the window desperate to escape. Heebner approached the front door. The windows blew out, and the ceiling started to drop. He went through anyway.

"I felt this immense wall of heat," he said. "Had no one been inside our tactics might have changed, but given the circumstances we used an approach that we felt would get our victim out as fast as possible."

The fire burnt through his coat, and he sustained burns to his left shoulder and face. But thanks to the team's coordinated efforts, they rescued the woman from the house, and she recovered.

For their actions in this fire, which took place on November 12, 2018, Heebner and fellow firefighters Greg Pahlavi and Connor Sproat received a Bronze Medal for Valor from the New Castle County Firefighter's Association and New Castle County Fire Chiefs Association.

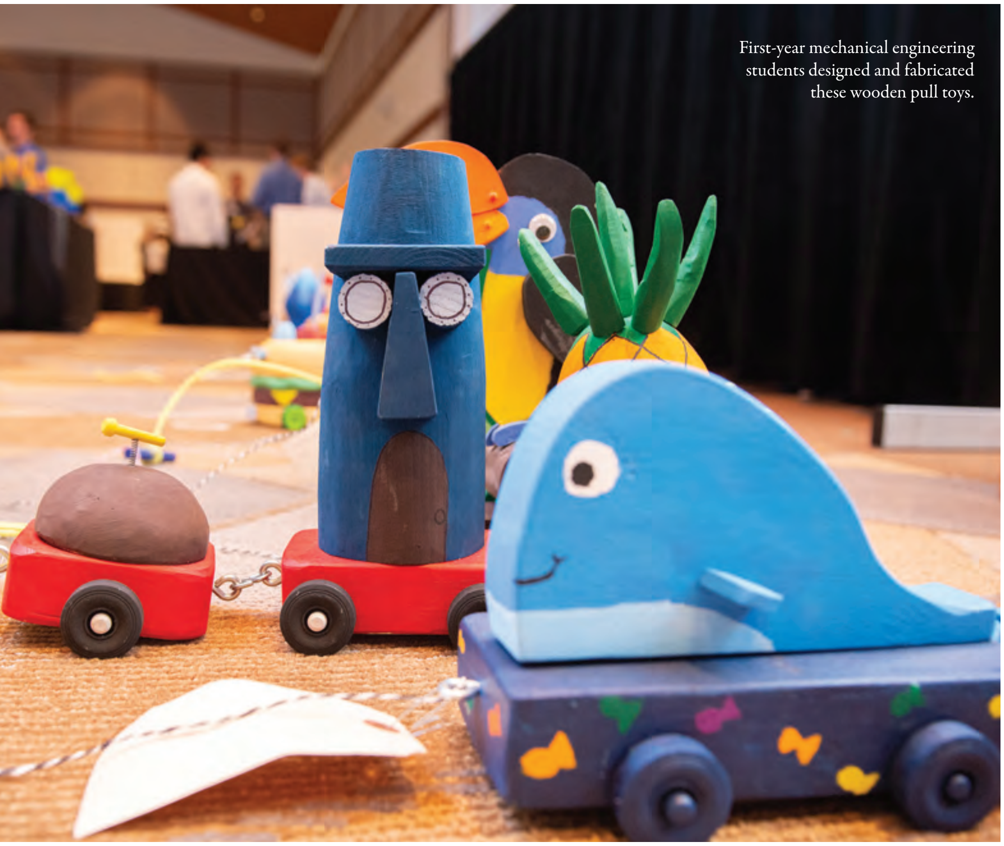
Heebner, a junior in the Honors Program studying mechanical engineering, said he was called to serve because he wants to give back to the community. After college, his dream is to continue protecting others by working as an engineer for the U.S. Department of Defense. "After college I would like to continue serving others as a firefighter regardless of where my career path takes me," he said.

Originally from Montgomery, New Jersey, he started his journey as a firefighter while in high school. Once he got to UD, it wasn't long before the urge to serve kicked in.

"I couldn't stand not riding the trucks," he said. "I'd see them going down Academy Street and think, that should be me. So I put in my application."

His firefighting helps him to stay balanced. "You can't replace the perspective you get by helping people," he said. Firefighting also helps him learn to think with a clear head even when a lot of things are going on at once. These lessons help him push through challenging moments in class.

And, it turns out that his engineering coursework and firefighting career are complementary. "Engineering is all about problem-solving, and we do problem-solving and creative thinking at the fire station all the time," he said. Heebner helps to maintain some of the equipment at the station, so lessons in machine design, fluids, flow, and more are helpful.



First-year mechanical engineering students designed and fabricated these wooden pull toys.

ENGINEERING FOR FUN

Students design and build toys, pitch to Melissa and Doug representatives

A trio of professionals from toymaker Melissa and Doug, a toymaker visited UD in 2018 to evaluate toy prototypes made by mechanical engineering students with help from early childhood education students.

Student-designed toys

The students made toys that were functional, fun and educational, like the Carpet Circuit, which was designed to teach the basics of circuitry.

"The challenge was: How do we take a concept that is usually taught to 8-to-12-year-olds and teach it to 4-year-olds?" said team member Chase Neuberth.

The team created a mat that can be laid on a floor or hung from a chalkboard. The mat is covered with detachable pieces — held on with Velcro — that illustrate the basics of electronics. For example, you can connect a battery-shaped piece to a lightbulb-shaped piece using a rope that represents a wire. The Farmyard Friends Puzzle, a 12-piece 3D pig-shaped puzzle, was designed to increase literacy by helping children recognize letters while developing fine motor skills. Each piece of the wooden puzzle features uppercase and lowercase letters. The Melissa and Doug representatives asked the Farmyard Friends Puzzle questions — and asked for more information after the showcase. "Before today, I didn't know our toy was at a level that Melissa and Doug would express interest," said team member Allison Procak. "This is more than a class project — it can be used in the real world."

Learning the basics

Before they could build their prototypes, students in UD's Computer-Aided Engineering Design course learned the foundations of modeling, drafting and more.

For example, associate professor Jenni Buckley asked students to brainstorm attributes, such as safety and durability, that engineers might consider when imagining new toys.

"Kids are rough with stuff," Buckley said. "Stuff needs to hold up."

Under federal law, all toys sold in the United States must meet American Society for Testing and Materials (ASTM) F9963 safety standards. Among other requirements, toys must be sized so that kids can't choke on them. Corners and edges must be rounded so that no one sustains a cut.

Buckley demonstrated tests that can help engineers meet these standards. For example, during a "choke test," engineers place each toy part inside a cylinder that simulates a child's esophagus to ensure that parts can't become lodged entirely inside the child's throat.

Once all the safety concerns are figured out, there is another important matter to attend to — fun.

"We could make things that are awesome, safe and durable for that age range, but that doesn't mean they will use them," Buckley said. "What attributes might we want to include so that kids actually use it?"

Students show off their creations.

She encouraged students to think about the number of parts, size of parts, and the appearance of their toys. Then there are production considerations. "What manufacturing process am I going to use? What process am I using? Can I make these things in bulk?" Buckley said.

To solve these problems, students relied on engineering theory, physics, computer-aided design, quick experiments and benchmarking. Then they selected materials and thought about how their toys would be mass produced. Would they require computer-automated cutting, which is more expensive than the traditional press? Students, split into teams of four to five, used computer-aided modeling software to sketch out their toys. Then they built and tested their prototypes in the Design Studio, a nearly 6,000-square-foot space in UD's Spencer Laboratory.

To make sure their designs were developmentally appropriate with an educational twist, teams were paired with consultants — students taking Early Childhood Inclusive Science Curriculum and Assessment, a course in the College of Education and Human Development. Toys were also tested by real kids in UD's Lab Preschool and College School.

Impressing the experts

Rich Rivellese, national accounts sales analyst at Melissa and Doug, works with retailers, tracking sales and inventory to assess how toys should be stocked. He said the students' efforts to do consumer research and understand their customers stood out.

"They spoke to moms, they spoke to kids, they tested in preschools, so they were really thinking about the end user," he said.

Carrie Aitkenhead, education outreach coordinator at Melissa and Doug, connects with teachers and schools to encourage play in the classroom. She praised the interdisciplinary nature of this project, which paired UD engineering students with education students so that they could all learn from each other and optimize their end product.

"It really comes back to what we do, where there's not just one set of people making something," she said. "It's really a different set of people consulting each other and collaborating, and I think those collaborations were really evident in how great the products were."

Drew Humphrey, talent acquisition manager at Melissa and Doug, is involved in hiring new employees. He said he was impressed with the level of detail of the students' creations.

"These guys have a really bright future in front of them," he said. "The ability to present and do what they did today is something that will serve them throughout their careers and wherever they go."

A bounty of prototypes

First-year mechanical engineering students created simpler wooden pull toys. Aitkenhead praised the simple but beautiful design of one blue toy that evoked images of water exploration.

"Whatever a child does when they pick up this toy, they pick up this toy and they bring their experience," she said. "They might say, 'this is a mom, this is a baby.' They might say: 'this is an uncle and me when we go fishing.' They bring their experience to the toy."

UNDERGRADUATE RESEARCH SPOTLIGHT

Transport in UD's Scaled Smart City Student helps tackle traffic challenges for autonomous vehicles

Yiming Wan is a senior majoring in mechanical engineering from Yangzhou, China.

Q: What is your research focus at UD?
Wan: I study the use of connected and automated vehicles, known in the industry as CAVs, at University of Delaware with Andreas Malikopoulos, an associate professor in the Department of Mechanical Engineering.

Q: What is it about this topic that interests you?
Wan: UD's Scaled Smart City serves as a test-bed to explore the advantages of vehicle-to-vehicle and vehicle-to-infrastructure communication. It is an effective way to test concepts developed for real world traffic scenarios using CAVs. As we know, CAVs are the transportation of the future, so research on a topic like this that will influence the future really interests me.

Q: What is a typical day like?
Wan: We have several groups in Information and Decision Science (IDS) lab and each group is responsible for different tasks on the project. Right now, I'm in charge of drone team. Our team is working on having several drones fly in our mini-city, and then making the drones hover at a road intersection or follow our CAVs. Just like our CAVs can share information with each other to analyze the traffic conditions, our drones also can share information with CAVs. In brief, drones are monitoring the traffic in the city. Because our system is decentralized, after getting information from the drones and the other CAVs, each individual vehicle finds the optimal travelling speed for themselves. So, right now, I'm focusing on coding software for the drones to make sure they can fly in the city and follow the vehicles steadily. So far, we have made six drones fly and hover over certain points in our mini-city.

Q: What is the coolest thing you've gotten to do on the project?
Wan: I have built about 35 second-generation robotic vehicles. I have spent massive time using a computer-aided design software and computer-aided engineering computer program, called SolidWorks, to design the frame of our second-generation vehicles. We then print out the vehicle frame by using the 3D printer in our lab and solder them together. I felt very fulfilled when I finished this work.

Q: What has surprised you the most about your experience?
Wan: The technology has definitely surprised me. When I started working with the drone project, it was the first time that I had used a robotics operating system, known as ROS, and a motion capture system, called VICON, to control the drones. ROS operates on the principle of a series of nodes that publish data (write) to a topic and nodes that subscribe (read) data from a topic. This dynamic framework gives us many opportunities in the field of autonomous drones. The VICON system is a motion capture system that uses an optical camera, which we use to manage and control the motion of the robotic vehicles or drones. I knew this technology had been used in the film industry before I joined lab, but after using this system for our research, its powerful functions really surprised me.

Q: Dreaming big, where do you hope this work could lead?
Wan: Our lab at UD is currently leading research efforts on CAVs. Dreaming big, I hope that some of these technologies will hit the road in the coming years in the U.S. and in the rest of the world.

Q: If you had to summarize your experience in only one word, what would it be?
Wan: Progressive. I think I have made a lot of progress from a person who knew nothing about connected and autonomous vehicles, to someone who is doing cutting-edge research today. I have learned a lot in our lab at UD, so "progressive" would be the best word to describe my experience.

Q: What do you enjoy when you are not doing research?
Wan: In my free time I enjoy playing basketball, fishing, traveling and searching for delicious food.

A BANNER YEAR FOR BLUE HEN RACING

University of Delaware Formula SAE team captures highest finish yet

If you dream of building or driving a race car, you can do it at UD—all while earning an engineering degree.

Just ask Sean Nelan. The recent electrical engineering graduate led UD's Formula SAE team, which builds a prototype race car, to its best-ever finish in competition at the annual Formula SAE competition in Lincoln, Nebraska, held from June 20 to 23, 2018. UD finished 23rd, up from 43rd in 2017.

In this competition, cars are judged on cost, presentation, design, acceleration, braking, skidpad (a tight figure-8), autocross (one run down a track) and endurance (a two-driver, 30-lap event). Some teams opt to skip some of the events, but the UD team completed them all.

"Our big goal this year was to finish all the events," said Nelan. "We designed our car primarily for reliability, and we met that goal well. In the future, the team will focus even more on the cost, design and business presentations."

Nelan was one of five drivers for the team and drove during the acceleration test. The team had a problem with the car's spark coil at one point, but they fixed it within about 15 minutes and kept going. "It was a bit unnerving at first, but it felt good to push through the engine issues," he said.

The students crafted their car in UD's Spencer Lab, using 3D printers, a computer numerical controlled (CNC) mill and more. They partnered with the Center for Composite Materials to utilize carbon fiber material in the vehicle's body.

Steve Timmins, a mechanical engineering faculty member, advised the team. He said that this year's team was successful in part because they built upon a solid design utilized in competition previously. The vehicle's chassis must be built from scratch each year, but other parts and systems can be re-used, he said.

"In 2018 the students focused on optimizing existing designs, rather than starting over from scratch, for most subsystems," he said. "The focus was more on making it work and designing for durability than for trying completely new (and risky) approaches.

The bulk of the car was designed and built in the FSAE Senior Design capstone course, advised by Timmins. Many parts were manufactured before the 2017 Thanksgiving break, leaving time for assembly at the end of the semester, and, more importantly, time to redesign parts that did not work out as planned, he said. Then, in January, a group of five students completed the vehicle.

The team will compete at the 2019 FSAE Lincoln competition from June 19 to 22. The team began development in September 2018, and the car being tested for 2019 competition is 100 pounds lighter than the 2018 car and the first new car ever to be complete and driving during spring break.

ENGINEERING A SAFER WORLD

Alumnus makes armor for the U.S. military, police cars, schools, restaurants and more

George Tunis, III, '85, sails and surfs after work to exercise and clear his mind. As the CEO of Maryland-based Hardwire, LLC, Tunis and his team of 60+ employees do serious business: designing, manufacturing, and testing body armor and ballistic shields to protect people from gunfire and explosives.

They make the lightest soft body armor in the world, hard body armor plates, and other protective gear out of composite materials, including ultra-high-molecular-weight polyethylene (Dyneema®). "These materials are so strong, Dyneema is the only manmade fiber stronger than spider silk," said Tunis.

Hardwire, LLC makes lightweight armor to protect people from gunfire and explosives.

Journey to Hardwire

As a teenager, Tunis built skateboards out of fiberglass, an early lesson in flexible materials that can bend and twist. Later, at UD, Tunis studied composites under Jack Vinson, one of the founders of the Center for Composite Materials and the H. Fletcher Brown Professor Emeritus in Mechanical Engineering.

While subjects like fluid mechanics and structures interested Tunis, his Senior Design project really got him jazzed. An avid surfer and sailor, he built a catamaran and wrote programs in Fortran to predict the performance of a sailboat under load. He won an award for his ingenuity. "When I was a senior, that's when I really fell in love with engineering," said Tunis.

After graduating with a bachelor's degree, Tunis worked for DuPont Composites for six years as the program manager for the U.S. Navy, designing and producing composites for naval ships and submarines. He kept building boats in his garage in his spare time, and with investment from the Carpenter family, his longtime friends and benefactors to UD's Athletics program, Tunis formed Hardcore-DuPont Composites and led the development of numerous patented large-scale composite structures for the marine, infrastructure, rail, and shipping industries. In 1990, Tunis won Sailing World Sailboat of the Year. He then founded SCRIMP Systems LLC in 1993.

With further investment from a member of the Walton family (of Wal-Mart fame), Tunis's company went on to build wind blades, railroad cars, and the first composite bridges in America. For his integrated composite railcar, Tunis was awarded the Owings Corning Grand Design Award in 1996. In 1998, he sold Hardcore-DuPont Composites and moved to Ocean City, Maryland.

Tunis has always loved the beach, but surfing and sailing didn't keep him occupied for long. He got bored and started thinking about ways to combine steel with composites. Tunis had an idea to put steel fibers into composite materials to reinforce buildings against strong winds and earthquakes—hence, the birth of Hardwire® the product and Hardwire, LLC.

Making the world a safer place

Hardwire® has been used widely in Europe to reinforce buildings that were constructed before the introduction of concrete with rebar. "These structures are very old and were built by incredibly skilled masons," said Tunis. "They work for centuries until an earthquake hits." Buildings that were constructed quickly after World War II needed reinforcement, too.

The business flourished. "We've made enough Hardwire® to circle the globe five or six times," said Tunis. But a few years after he started the business, the world changed. "Out of love of country, we started working on armor after 9/11," he said. Tunis realized he could make lightweight, strong, anti-ballistic products to help the United States military protect people from emerging threats. Soldiers in the wars in Iraq and Afghanistan were being injured or killed by improvised explosive devices, and they needed to be equipped with protective material, fast.

With funding from DARPA, Hardwire, LLC started producing some of the world's lightest armor within just three months. Tunis and his team tore down an old soup-can factory and

Left: Emergency response shields can protect people in a crisis. Top right: Police cars were outfitted with shields by Hardwire, LLC. Bottom right: Trucks outfitted with Hardwire, LLC armor have been utilized in Iraq.

built a plant that outfitted 125 large trucks with armor per week in huge vacuum presses. They sent 2,500 armored trucks to Iraq in the first surge, then 2,500 to Afghanistan in another.
"It was the most insane thing I've ever done," said Tunis. "There was a huge amount of engineering going on." As Hardwire, LLC ventured into the realm of ballistic material, Tunis hired a number of Blue Hens. Scott Kendall, '87, the vice president of engineering at Hardwire, LLC, is a former Air Force F-16 pilot and Wing "Top Gun" instructor. with a bachelor's degree in mechanical engineering from UD. Jeremy Balliet, '03M, the director of manufacturing, has a master's degree in electrical engineering from UD and was awarded the Bill Baron Fellowship for excellence in the field of photovoltaic research. Matthew Kraeuter, '01, Hardwire's General Counsel, received his BS in Business Administration while also studying physics before receiving his law degree from University of Baltimore. The number of Blue Hens working at Hardwire now stands at seven.

The trucks manufactured by Hardwire, LLC brought thousands of people home in one piece. "War is a cruel but brilliant teacher," said Tunis.

Today, Hardwire LLC makes armor for police cars. After outfitting fleets of vehicles, Tunis saw a survey of feedback from officers. "What I saw handwritten hundreds of times: I feel safer. I am safer," said Tunis. He feels motivated and honored to help protect officers from gunfire. Hardwire, LLC has also armored more than a dozen bridges. And since mass shootings have become an unfortunate reality of American life, schools, restaurants, bars, offices, and other establishments are buying the company's products to protect students and customers. Some restaurants and bars have armored plates disguised as ads or graphics that people can grab in the event of a shooting. "That's the beauty of armor," said Tunis. "If you can make it blend in, it doesn't look militarized."

Fire code demands a fire extinguisher every 75 feet, and "we look at ballistic shields as the next thing that should be hanging next to fire extinguishers," said Tunis.

A Blue Hen for life

Tunis says his success can be traced back to a moment at UD. "Senior Design launched my career," said Tunis. "It allowed me to explore my passions."

In 2018, he visited Spencer Lab, where students were using computer numerical control machines, 3D printers and more. "We love to see these kids getting hands-on experience," he said. Tunis even hired one of the students he met for an internship. Almost a third of the engineers who work at Hardwire, LLC graduated from UD. "Our company is full of Delaware engineers," said Tunis. "I love them. They're great leaders, great engineers, socially adept, and a joy."

RETURN OF THE BLUE HENS

Our department includes some faculty members who once attended UD as students themselves. We asked three of them why they returned to their alma mater to teach and build their research enterprises.


BUCKLEY

Associate professor Jenni Buckley graduated from UD with a mechanical engineering degree in 2001. She went to the University of California, Berkeley for her master's and doctoral degrees in mechanical engineering with a focus on computational and experimental methods in spinal biomechanics. She joined our faculty in 2011 and in 2018, she was named to the American Society for Engineering Education's "20 Under 40" list.

What is your favorite memory from your time as a UD student?

Buckley: I have a lot of favorites, honestly. But one that sticks out for me is the bonding with my classmates that happens in the wee-hours of the morning. I was part of a little pack of students who'd work out of the Spencer Lab basement computer lab. We'd be there until all hours working on homework sets and group projects. It was hard work, but we also had a lot of fun, ragging on each other, imitating the professors, and generally behaving like 18-22 year old nerdy hooligans. I'm still friends with these people, and, honestly, not much has changed when we get together.

Why did you return to UD as a faculty member?

Buckley: I wanted to give back to the community that raised me. I feel like my undergraduate experience in the Mechanical Engineering Department made me into an engineer. When I got to grad school, I realized how valuable the training was here at UD, especially the hands-on and design elements that I honestly didn't appreciate as much as an undergraduate. I also had excellent mentoring from faculty who are now my colleagues, specifically Profs. Mike Santare and Tom Buchanan, and I wanted to teach and advise students as well as they did for me.

How has UD changed since you were a student here?

Buckley: Our program is a lot bigger than it was 20 years ago. I graduated with a class of 40 students, and now we're at least triple that class size. We also have a lot more hands-on training and project-based learning than we did when I was a student. I'm proud that we have built up the design courses even as our classes have grown. Even though we're much bigger than we were back then, I still feel like we have a tight-knit undergraduate community. The Design Studio helps with that, as does our practice of hiring undergraduate teaching assistants and supporting service organizations like the Mechanical Engineering Student Squad (MESS).


FESER

Assistant professor Joe Feser received bachelor's and master's degrees in mechanical engineering from UD in 2003 and 2005, respectively. He earned his doctoral degree from the University of California, Berkeley and returned to UD as a faculty member in 2013. In 2017, he received and NSF CAREER award to explore the physics of thermal energy transport in materials with embedded nanoparticles.

What is your favorite memory from your time as a UD student?

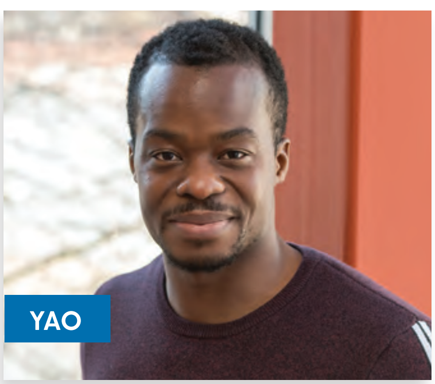
Feser: I can't point to one specific memory, but I would say that the one year I spent living in the Russell C dorm on campus was one of the most fun in my life. Twenty years later I still hang out with the friends I made my freshman year.

Why did you return to UD as a faculty member?

Feser: I returned to UD for a number of reasons. First, nearly all of my family all lives within an hour drive of Newark. After living in Berkeley, CA for Urbana, IL for 8 years, I was ready to be close to home, and I can say that it's just great to be able to practice my craft without sacrificing my family life. On a professional level though, I also knew from experience that UD was both an excellent research university and a university that deeply cares about its teaching quality - which I can sadly attest is not true of all research universities. In the department of mechanical engineering, I also saw an unmet need for a researcher with heat transfer research expertise, where I knew I could bring something fresh to the table, and I'm happy to say that it's working out well.

How has UD changed since you were a student here?

Feser: While I can't comment on the whole university, the quality of the undergraduate mechanical engineering program has vastly improved since I left in 2003. The classes are more fun - with hands-on design emphasized in seemingly every class - and our Design Studio is one part Maker Space, one part study-space, and one part hang-out space. Students now also play in a more active role in teaching, serving as both teaching assistants, running the day-to-day tasks in our Design Studio, and directly participating in recruiting at the department level. In general, undergraduates are much more engaged than they were 20 years ago, it's really resulted in a significant increase in student morale.



Assistant professor Koffi Pierre Yao graduated from UD with a bachelor's degree in 2010 and then went on to earn a master's and doctoral degree from the Massachusetts Institute of Technology in 2013 and 2015, respectively. Yao studies batteries in hopes of making electric vehicles more viable for everyone.

What is your favorite memory from your time as a UD student?

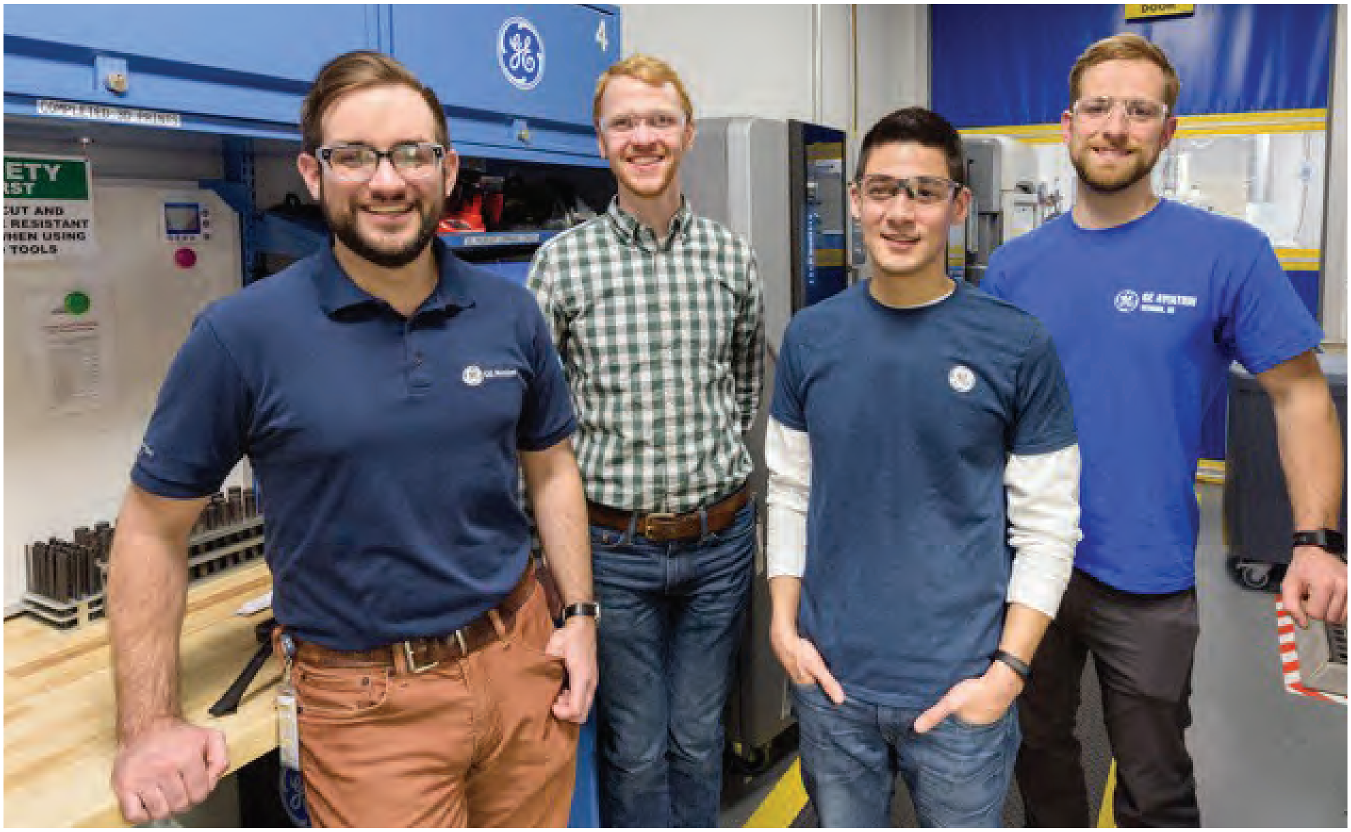
Yao: My favorite memory as a UD student was in my freshman year. As a fitting entry into Mechanical Engineering, we were instructed to build a Rube Golberg machine to turn one paper of our MEEG 101 textbook at the end of the semester. There was a lot of patching and last minute taping and gluing, but my team did turn that page! The exercise solidified my passion for mechanical engineering. It was a unique way to bookend a freshman semester as an engineer.

Why did you return to UD as a faculty member?

Yao: I returned to UD to be part of the faculty that confirmed to me that engineering was indeed worth being passionate about. My journey in higher education took me from the University of Delaware to the Massachusetts Institute of Technology. In graduate school at MIT, I had the opportunity to visit several universities, interacting with the faculty and administration. UD remained the more inviting campus, the place where I thrived as a student; logically, therefore, the place where I would thrive as faculty. Particularly, the mechanical engineering faculty at UD fosters a culture of professionalism with a heavy touch of relaxed openness and collegiality. It is quite simply easier to fit in at UD.

How has UD changed since you were a student here?

Yao: UD has evolved drastically since I was last a student here. The campus has undergone very positive updates. The STAR campus is one such obvious example. It went from being a plant producing Chrysler vehicles to a beautiful array of research buildings. My home-court of Spencer Laboratory now boasts a state-of-the-art student "hobby shop"; it is a prize I am quite resentful not to have had available to my 2010 cohort. Lecture rooms throughout the campus are now technological powerhouses that make it far easier to wear the shoes of instructor. Yet the iconic fixtures remain to my delight. It would have been disappointing not to see the Trabant center still vibrant with raucous students and the RISE program in DuPont still mentoring minority but aspiring engineers. Those pillars should retain their status forever.



Above: UD engineering graduates working for GE Aviation in Newark include (left to right) Sam Kurkoski, Reid Bremble, Vince Uathavikul and Tyler Walker.

Below: The GE9X engine (left) is much larger than engines that it is designed to replace. The GE9X is designed to be more powerful and more fuel efficient than previous engines. It scheduled to be used on the newest version of Boeing's 777X, which has two engines and will be used for long-haul flights.

UD GRADS HELP GE FLY

Team of young Blue Hens ride leading edge of jet technology

Consider the humble coffee cup. Its simple duties conceal a deceptively formidable character: The ceramic it is made of is harder than steel, and the scalding liquids it holds never seem to do it much harm.

Now imagine a roaring, flaming jet engine — possibly the pinnacle of 20th century power plant engineering — and try to envision what a touch of ceramics might do to make it even better.

A young and blade-sharp group of University of Delaware engineering graduates are doing just that at the Newark-based outpost of GE Aviation, which has been working for years to incorporate ceramic parts into the next generation of massive jetliner power plants. Through countless calculations, ceaseless tests and constant refinement, the four Blue Hens are pushing the final phase of GE's quest to completion — not too many years after they won their UD mechanical engineering degrees.

There's Reid Bremble, Class of 2015, the plant's guru of transforming raw materials into ceramic-based composite materials, and Vince Uathavikul, Class of 2007, a former furniture designer who came to GE seeking bold challenges. Tyler Walker, Class of 2013, left a good job with Chrysler to be here, and Sam Kurkoski, Class of 2014, already finds himself flying around the country fine-tuning production processes.

Meeting these men, it's tempting for an older outsider to wonder at how they could be pushing technological boundaries at such an age. One is a mere 24, the others are not too far past that. Yet they speak with a maturity and commitment beyond their years; possess a steady-handed confidence forged in these high-temperature, high-pressure labs.

They know what they are working on is revolutionary. And it amazes them every day that they are the ones working on it.

"We're doing something that is done nowhere else in the world," said Walker, lead manufacturing engineer.

At its simplest level, their work seems simultaneously improbable and brilliant: Take sand and carbon (silicon carbide), bake it in an oven, stretch it out into fibers, then cover the fibers with more melted silicon carbide. The hardened result is a ceramic material, very distantly related to your morning coffee mug.

This ceramic — known as Ceramic Matrix Composite, or CMC — is the pit bull of materials technology. It's light, strong, and can resist ferocious conditions. Use it on space ships, and not even the blazing heat of re-entry can penetrate it. Put parts made from it in a jet engine, and that engine will weigh less, and be able to run hotter and more efficiently.

First, though, someone has to figure out how to make the parts out of endless paper-thin sheets of CMC material, which has to be layered into molds like a super-high-tech lasagna. Then, they need to fine-tune the process so that it's cost effective for GE to make the parts in large numbers and market them.

That's where the UD crew comes in.

Already, the Newark team has invented production processes and made the earliest prototype parts for GE's first-generation CMC-fortified engine, and now they're busy fine-tuning the parts for its next big release — the GE9X engine being designed for the planned Boeing 777X jetliner.

GE has made a $1.5 billion bet that they will get it right — more than 700 of the giant 11-foot-diameter GE9X engines are already on order, and GE expects the market to grow tenfold over the next decade.

At the Newark plant, the main focus now is on three crucial GE9X parts: the liner of the combustion chamber where fuel is ignited; the nozzles that direct the flow of hot gasses; and the shroud that lines the hottest part of the engine.

Bremble oversees a very early part of that parts production: Fine-tuning the best ways to add a secret coating to the fibers and turn them into sheets.

"Without Reid, there's no fiber, and without fiber, there are no parts," said Austin Capone, CMC manufacturing engineering manager at the plant.

Walker then works to figure out ways to "lay up" the sheets into handmade, part-shaped molds so they can be baked.

"It's an art," said Walker, who must design the multi-piece metal molds from scratch. "A lot of times, it's inventing the process. For a lot of the technology, there's no recipe — the recipes are developed here."

Meanwhile, Kurkoski leads the development of the nozzles.

"Having everyone under one roof as you're developing is crucial," Kurkoski said. "And I get to see these things from cradle to shipment."

As a lead manufacturing engineer, Uathavikul is busy exploring ways to move beyond those stationary parts and put CMCs into rapidly moving components such as the turbine blades. But before that can happen, the priority is on constantly improving the manufacturing process for the GE9X, which flew for the first time in March and needs to be ready for certification next year. The 777X is expected to enter service in 2020.

When it does fly, the Blue Hens will be with it in spirit.

"I really did fall in love with UD," said Kurkoski. "It really clicked for me, and I had a lot of hands-on experiences while I was here. I was well-prepared."

SUPER CERAMIC FACTS

Ceramic Matrix Composites are 1/3 the weight of currently used super-alloys.

CMCs can operate at temperatures up to 500°F higher than super-alloys.

Higher operating temperatures mean engines run at higher thrust and/or more efficiently.

Hotter-burning engines also mean reduced fuel consumption and fewer pollutants.

CMCs in power turbines could reduce emissions and the cost of electricity.

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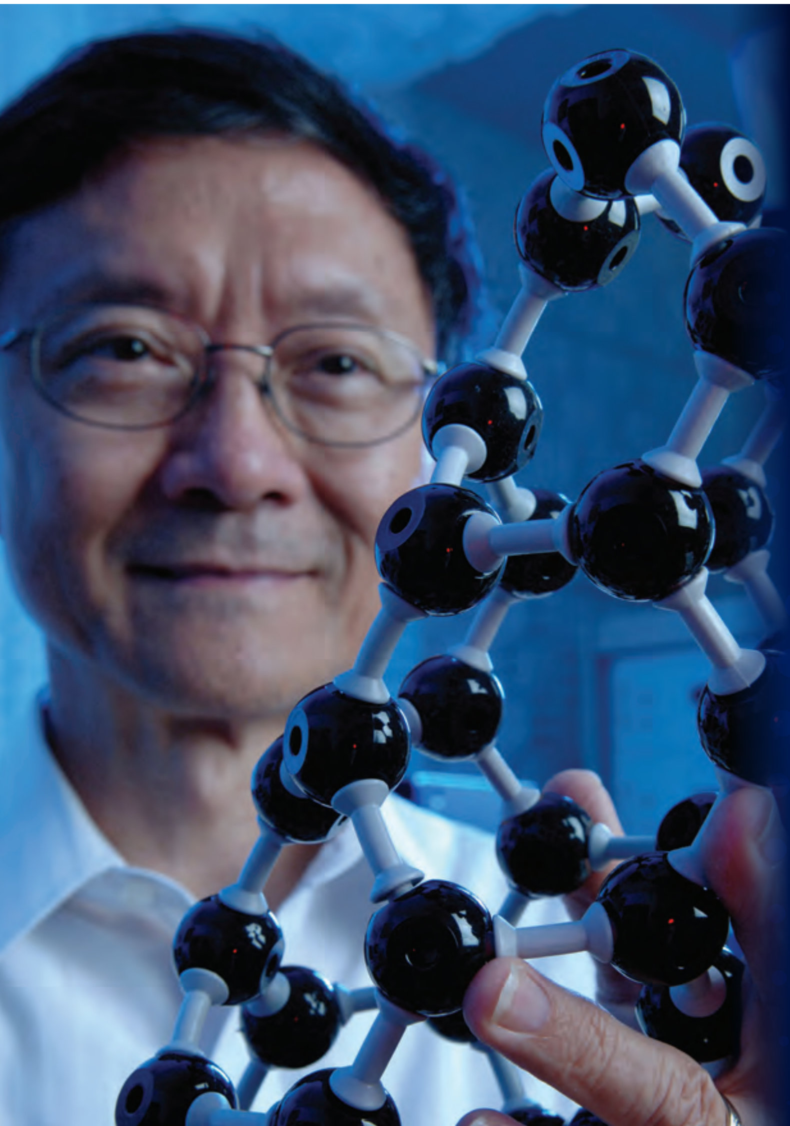

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Read about Tsu-Wei's tenure at UD on page 20.