WPI RESEARCH

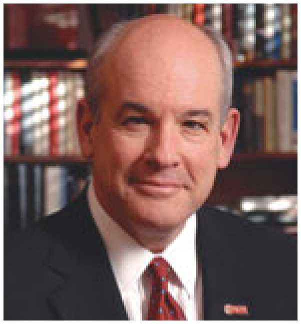
DISCOVERY AND INNOVATION WITH PURPOSE AT WORCESTER POLYTECHNIC INSTITUTE FALL 2012

Alchemists of the Alloys

How the Wizards of Washburn are forging the future of metallurgy

The Strength of Interdisciplinarity

A message from President Dennis D. Berkey



Among WPI's many impressive attributes, one that particularly stands out for me is the ability to create rich, interdisciplinary curricula and imaginative and important research projects of interest to students, partners, and sponsors alike. In my nearly four decades in higher education I have not seen this done any better than here at WPI.

In my opinion, an important contributing factor to this success is WPI's makeup as a true polytechnic, one of only five in the country, and one of the nation's oldest; meaning that we do not claim to be a fully comprehensive research university, but rather one with concentrated research strengths in closely related fields (those of science and engineering) with strong, overlapping interests. Hence, cross-disciplinary and interdisciplinary thinking comes naturally and enthusiastically to our faculty and students. Equally influential, I would submit, has been WPI's pioneering curriculum, known as the WPI Plan, offering our students a unique, project-based experience that emphasizes collaborative learning and work, and places great importance on outcomes rather than simply on mastery. Working across disciplines with other talented teams and individuals is a common requirement in the professional world; so, too, at WPI.

Likewise, the spirit of collaboration empowers faculty to imagine boldly, well beyond conventional expectations, what is possible in their own research; interdisciplinary behavior is simply second nature at WPI. This explains, in part, why WPI was the first university in the country to offer an undergraduate major in robotics engineering. A rapidly expanding field, robotics engineering reflects the growing importance of interdisciplinary thinking, for it demands a broad range of skills and knowledge, requiring faculty and students to integrate and apply knowledge from at least three major disciplines (computer science and both electrical and mechanical engineering).

The world has no better example of the power of interdisciplinary thinking than the engineering marvel we witnessed this past summer when NASA landed a 2,000 lb. mobile science lab called *Curiosity* on the surface of Mars. It does not surprise us here, though it is a source of pride, to discover that one of our graduates, Richard Cournoyer '98, MFE '99, held an important leadership role in this project, overseeing six divisional machine shops at the NASA Jet Propulsion Lab that were charged with building a significant portion of *Curiosity*, as well as its amazing descent vehicle.

You will find innovative thinking and interdisciplinary research quite prominent throughout this edition of *WPI Research*, beginning with our cover story on metallurgy, where innovative approaches are breathing new life into one of mankind's oldest disciplines. Our story on Big Data—featuring humanities professor Brent Faber, head of WPI's new Analytics Lab, as well as social science and policy studies professor Mike Radziki and computer science professor Elke Rundensteiner—shows how faculty from different disciplines collaborate in an effort to develop new analytic tools that can better handle the vast amount of data that now dominates our modern world. And our story "Robots for the Real World" reveals the multidisciplinary approach that computer scientists and engineers take in their efforts to create robots that are more human-like.

I have long maintained, and indeed have expressed such before in this very publication, that the most pressing problems facing our world are interdisciplinary in nature. From energy shortages to healthcare to feeding the world to environmental challenges, the solutions needed will require new approaches, new ideas, new ways of thinking—which is what interdisciplinary research is all about.

"The spirit of collaboration empowers faculty to imagine boldly, well beyond conventional expectations, what is possible in their own research; interdisciplinary behavior is simply second nature at WPI."

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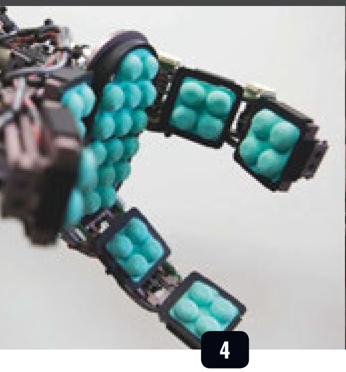

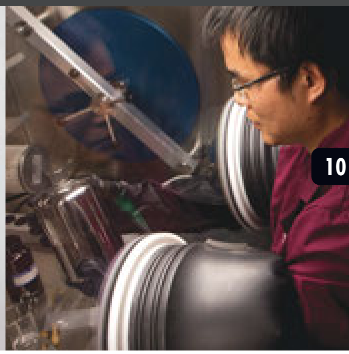

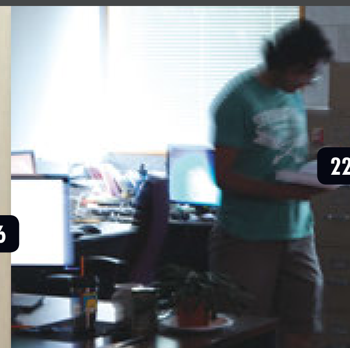

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WATCH VIDEOS RELATED TO THIS ISSUE
In the pages that follow, you'll see QR codes like this one (which links to WPI's Research site). Snap them with a smart phone to watch the videos. You'll need a QR code reader app for your phone. All of the videos are available at YouTube.com/WPI.

Groundbreaking Tests Explore Post-earthquake Fires

In many large earthquakes, much of the damage to buildings and infrastructure is the result of fires that break out in the aftermath of the seismic event as building systems designed to suppress fires and prevent their spread fail.

In the spring of 2012, a team of researchers from WPI's Fire Protection Engineering Department, led by associate professor **Brian Meacham**, took part in an unprecedented, $5 million study of the effects of earthquakes and post-quake fires on high-value buildings like hospitals and data centers. Supported by a coalition of government agencies and industry partners, the study was centered on a five-story building (at right) constructed atop the nation's largest outdoor shake table, located at the Englekirk Structural Engineering Center at the University of California, San Diego.

Among the systems installed in the building were passive fire protection components, including doors, ceiling systems, partition walls, and firestop materials, and active fire suppression systems, including a heat-activated fire door and sprinklers. After each in a series of simulated earthquakes, some registering as high as 7.9 on the Richter scale, Meacham and his team inspected those systems. They also ignited pans of heptane and used temperature and smoke movement sensors to assess how damage from the simulated earthquakes might affect the ability of the active and passive systems to contain fires and prevent the spread of smoke.

While most systems performed well for small and moderate earthquake motions, some experienced failures under larger motions, including the exterior balloon framing system, which separated from interior walls and floor slabs, creating the potential for smoke to spread to floors above. "It will take some time before we assess all the data, but trying to better understand this failure mode and implications for fire spread is important," Meacham says.

The test results will likely point to needed "changes to codes, standards, and design guidelines, and to fire safety management plans, evacuation plans, response and recovery plans, and business continuity plans for hospitals and emergency responders," he says. "By understanding better what could happen, hospitals and emergency responders can be better prepared to address whatever conditions they face should a post-earthquake fire occur."

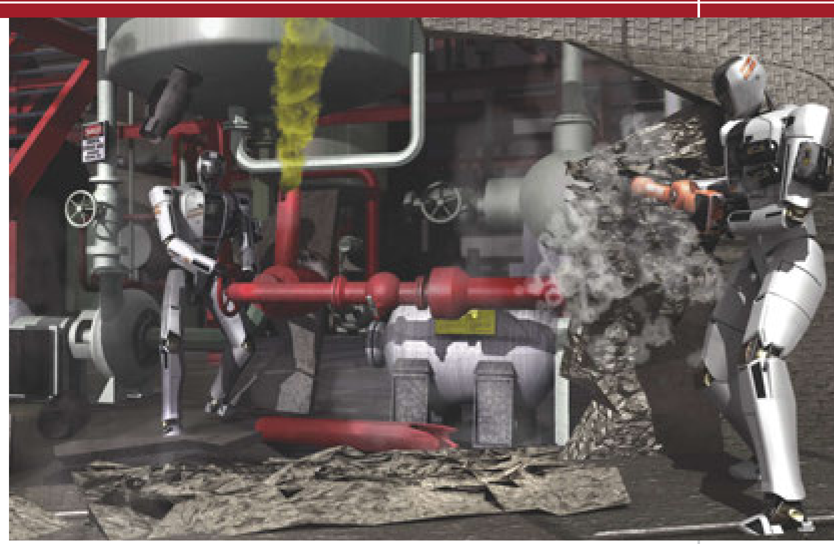
New Insight into Monarch Butterfly Navigation

To successfully navigate 2,500 miles from the northern United States to central Mexico each fall, the monarch butterfly uses a time-compensated sun compass. Critical components of this compass mechanism include light-sensitive circadian clocks located in the insect's antennae, which enable it to maintain a constant flight direction despite the changing position of the sun throughout the day.

A study published this year in the prestigious journal *Nature Communications* shed new light on how the butterfly's brain uses the information from those clocks and what happens when the clocks malfunction. The study, conducted in the lab of Steven Reppert, MD, professor of neurobiology at the University of Massachusetts Medical School, was co-authored by **Robert Gegear**, assistant professor of biology and biotechnology at WPI.

In a series of experiments, the team learned that timing information from the two antennae is integrated within the butterfly's brain, but that the clocks in each antenna work independently. In fact, only one antenna is needed for successful navigation. However, if both antennae are present, but send conflicting circadian information to the brain, the brain tries to knit the divergent data together and ends up pointing the butterfly in the wrong direction.

Robots That Will Go Where Humans Fear to Tread



It sounds like a science fiction scenario: a nuclear reactor is racing toward meltdown, and someone needs to close a valve to stop cooling water from leaking out of the reactor. Unfortunately, radiation levels near the valve would be fatal to a human being. The solution: send in a humanoid robot that can drive to the reactor, clamor over debris, climb a ladder, break through some concrete, locate the valve, and crank it closed. Sometime in the next three years, a robot may successfully achieve a mission very much like that one to win a $2 million prize through the DARPA (Defense Advanced Research Projects Agency) Robotics Challenge.

The challenge is intended to spur the development of advanced technologies that can enable human-like robots to execute complex tasks in human-engineered environments and to work where it is too risky to send people.

"This is the most exciting humanoid robotics project ever undertaken in the United States," notes Dmitry Berenson, assistant professor of computer science and robotics engineering. "Other countries have made advances in this area, but there has been resistance to humanoid robots here, partly for cultural reasons and partly because they are very difficult to work with. But humanoid robots can be useful in many scenarios, everything from helping elderly people live in their own homes to responding to disasters, so it is exciting to see DARPA investing in the research foundation for this field."

Berenson is leading a WPI group that is part of a multi-university effort to develop a robot to compete in the DARPA challenge. Led by Paul Oh at Drexel University, the team, which has received a $3 million award from DARPA, also includes researchers from Columbia University, the University of Delaware, Georgia Tech, Indiana University, Ohio State, Purdue, Swarthmore, and the Korea Advanced Institute of Science and Technology.

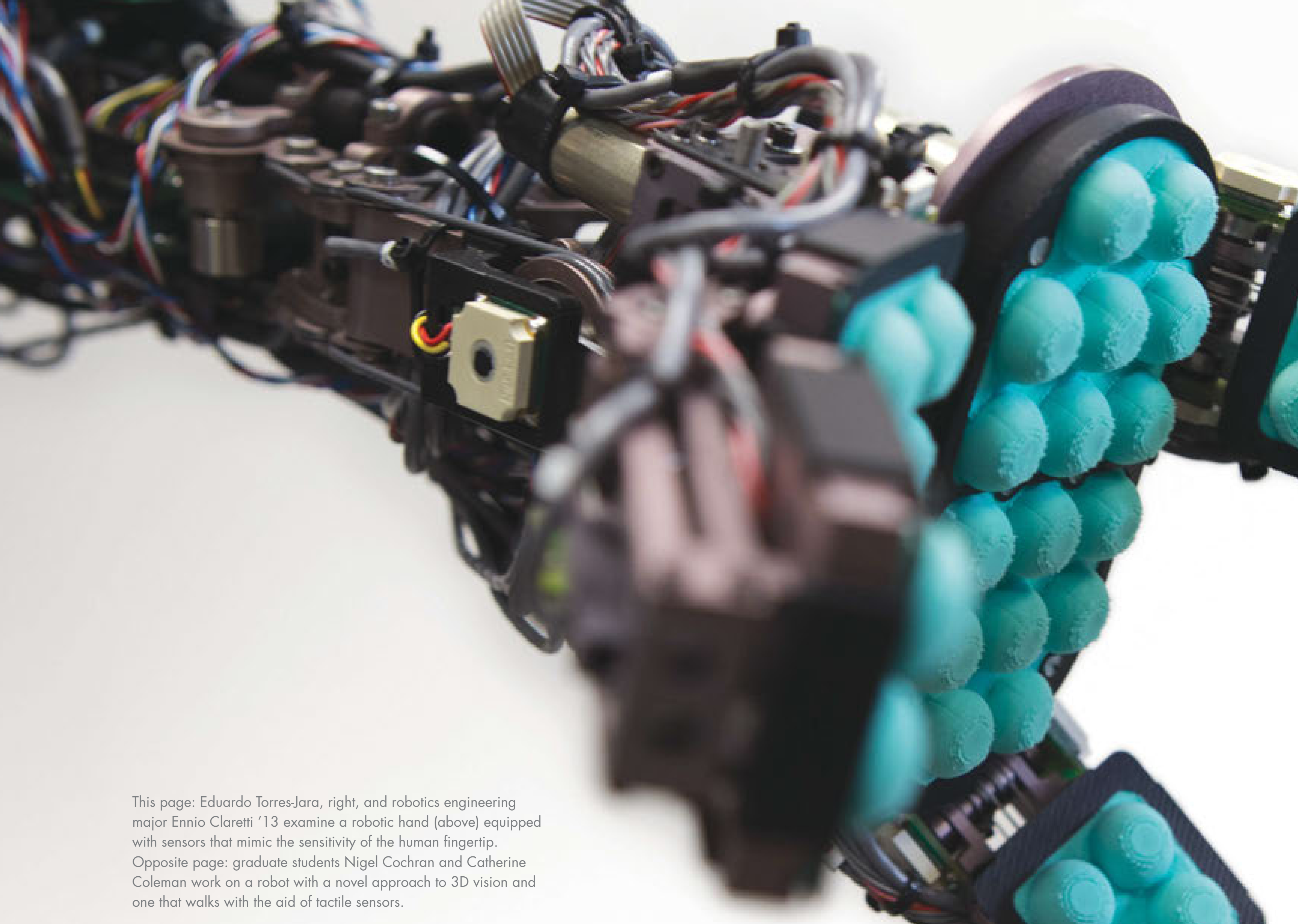
Different university teams are working on the eight tasks outlined in the DARPA proposal. WPI will tackle Task 7: locate and close a valve near a leaking pipe. "This task requires a lot of difficult work," Berenson says. "First, the robot has to locate the right valve. Then it has to determine where to stand, which for humans is intuitive because we can draw on millions of years of evolution and decades of experience. But for a robot this is a very difficult problem because there are all sorts of reachability and balance issues. Finally, it needs to turn the valve, which is also a complex task."

The WPI team will bring several areas of expertise to bear on this task. Berenson's work in motion planning algorithms, which help robots plan out complex actions, will play a critical role throughout the activity. Sonia Chernova, assistant professor of computer science and robotics engineering, will apply her expertise in machine learning and learning from demonstration to the challenge of teaching the robot how to execute the required activities. Rob Lindeman, associate professor of computer science, will draw on his knowledge of virtual reality and novel computer interfaces to develop an interface people can use to give the robot high-level guidance.

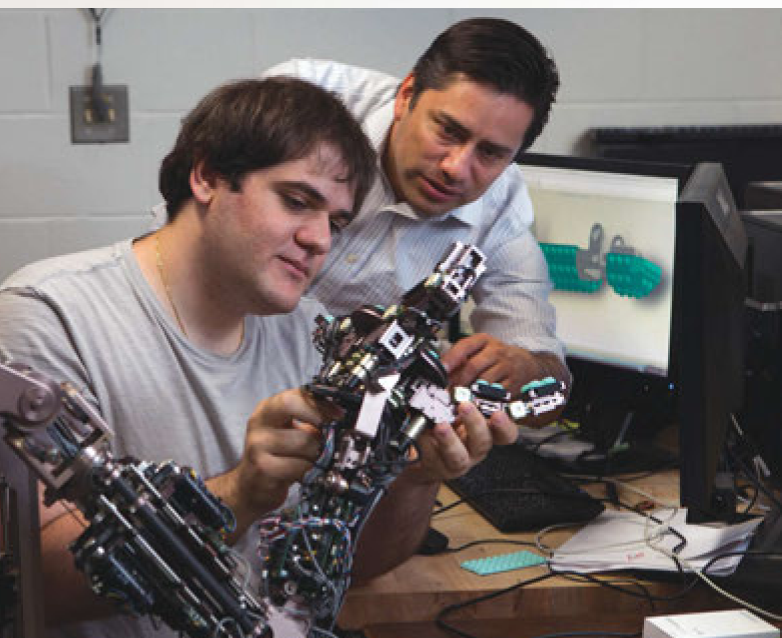
In the months ahead, the multi-university team will be developing its robot systems, first in simulations, then with a Korean humanoid robot called HUBO. This will be a prelude to complicated series of elimination events pitting against one another a host of university and private teams, some funded by DARPA, others self-funded, culminating, perhaps, with one $2 million winner.

Berenson says the challenge ahead is huge, but the opportunity to advance humanoid robotics research makes it worthwhile. "This is an amazing competition," he says. "Whatever happens, I feel very lucky to be a part of it."

In his current work, Gegear is focused on a different pollinating insect, the bumblebee, and its reciprocal relationship with flowering plants. In work that encompasses evolutionary ecology, cognitive psychology, and behavioral neuroscience, he is investigating how the bumblebee's miniature brain is capable of remarkably complex cognitive functions, and how the mental activity of bees and the decisions they make as they gather food and pollinate plants ultimately have profound consequences for the ecosystem and the human food supply.

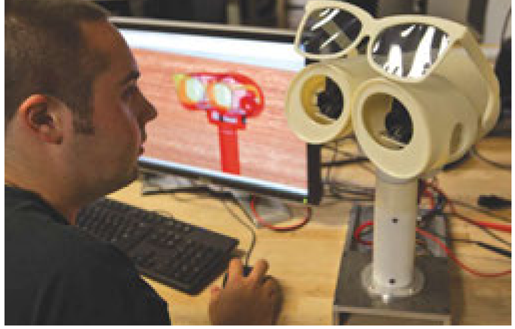


This page: Eduardo Torres-Jara, right, and robotics engineering major Ennio Claretti '13 examine a robotic hand (above) equipped with sensors that mimic the sensitivity of the human fingertip. Opposite page: graduate students Nigel Cochran and Catherine Coleman work on a robot with a novel approach to 3D vision and one that walks with the aid of tactile sensors.



VIDEO EXTRA

Professor Torres-Jara on why robots need to feel.



Robots have proved their worth in well-regulated environments, such as the assembly line, where they can be pre-programmed to perform repetitive, highly constrained tasks. But even in factories, robots need to be re-programmed or even re-engineered when a new product or process alters the parameters of their work. WPI researchers are designing more versatile robots and intelligent agents that can learn quickly and adapt to the challenges they'll face in varied and unpredictable environments—like our own homes.

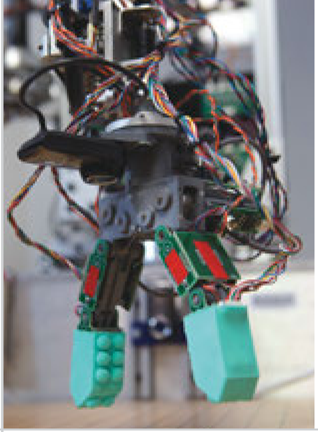
Robots for the Real World

By Joan Killough-Miller

Robots That Reach Out and Touch

Eduardo Torres-Jara, assistant professor of computer science and robotics engineering, is on a mission to broaden the way robots experience the world. In particular, he is working to expand a robot's sensory abilities beyond vision. "I am inspired by the geometry and functionality of the sensory systems that exist in nature," he says. He looks to solutions that have evolved in the animal world, such as how rodents use whiskers—rather than vision—to guide them through narrow passages, or how birds "read" wind conditions with data relayed by multiple sensors on their wing feathers.

He's especially interested in how tactile feedback can be harnessed to improve robot function in locating and manipulating objects. Up to this point, he says, most of



VIDEO EXTRA
Professor Chernova on how robots learn from example.

"Being more interactive with the world gives you more information and better sensory feedback enables you to interact better. Robots that are detached from the world can't perform tasks as well." — Eduardo Torres-Jara

the modeling has been based on vision systems—which has limitations. Rather than adding more cameras, he might begin by investigating how newborns function before their sight is fully developed—or how an adult would search for the TV remote control in the dark.

He began his quest by rethinking robot hands. A typical robot has a rigid claw at the end of its arm that opens and snaps closed, regardless of what it is gripping. Our own fingers, by contrast, are soft, flexible, and laden with nerve endings. Torres-Jara has revolutionized the design and control of robot appendages by making them more like human hands, with soft pads that relay feedback from a multitude of sensors.

His novel tactile sensors go hand-in-hand with a more flexible approach to artificial intelligence (AI), one that builds models based on knowledge of the real world, rather that writing algorithms that execute pre-planned tasks. "When we increase sensory data, the software can be written differently, because it's based on the physical environment, with less reliance on pre-planning," he says.

Where conventional grippers can crush or deform objects, Torres-Jara's "smart sensors" are sheathed in a flexible skin of silicone rubber, giving them a gentle grip that yields to an object's contours. With a network of sensors that detects forces in multiple axes, the pads enable a robot to sense and manipulate varied objects without having to know their precise location or configuration. Applied to the feet of the robots in his lab, they offer multiple points of contact, improving the robots' ability to navigate uneven terrain.

His sensors, which can be mass produced inexpensively and easily from existing electronic components, hold great promise for industrial, medical, and military applications. They can be made firmer, to stand up to factory use, or so exquisitely sensitive they can detect a breath of air, or even "read" the raised lettering on a penny. Their commercial uses could range from auto safety devices to bomb disposal apparatus, Torres-Jara says.

When a robot can sense its environment, it doesn't need to be reprogrammed each time the task parameters change. With the "sensitive manipulation" hardware and software that Torres-Jara is developing, every step in an assembly task can be based on tactile feedback, making complex tasks possible—and more reliable. "Now the robot actually knows what is happening," he says, "and if an object moves, the robot can sense that and follow it. Before, with automatic mapping, you had to hope the object was there.

"Being more interactive with the world gives you more information," he says, "and better sensory feedback enables you to interact better. Robots that are detached from the world can't perform tasks as well. By enriching the input from sensory feedback, we will move AI forward."

Robots for the Rest of Us

To succeed in the real world, robots will need more than the ability to sense the environment. They will also need to learn and adapt to changing tasks and user needs, much as living creatures do. Creating this new type of robot is the goal of Sonia Chernova, assistant professor of computer science and robotics engineering, whose research centers on robots that can learn on the job, from their human users—even when the users are not trained experts.

Robots that can learn "on the fly" and function in natural, unconstrained environments would be an asset in the home, where they could assist elderly and disabled people, and in factories, to reduce the need for reprogramming when gearing up for new products. "My fundamental belief

Sonia Chernova, right, and computer science graduate student Russell Toris work in the "apartment" where the robot Toris is adjusting will be controlled by online users 24 hours a day. The users' experiences will help Chernova design algorithms that will permit everyday users to train robots.

is that you have to design the system from the beginning with the end user in mind," says Chernova, who is director of the Robot Autonomy and Interactive Learning (RAIL) lab. "Expecting every single user to become an expert robotics programmer is unrealistic. We want to create an interactive learning system that will work for someone with no prior robotics experience."

To develop a new way of teaching robots, Chernova is pioneering a new way to do robotics research. She notes that roboticists and students are often pressed into service to test software for robots, but their prior knowledge can skew results. Instead, with a five-year, $500,000 CAREER Award from the National Science Foundation, she will bring thousands of users, from all over the world, into the testing process—via a web-based interface. Her RobotsFor.Me system allows researchers to "crowdsource" real-time trials of robotics software, to generate a large volume of data from a wide variety of people. The goal is to produce an open-source framework, for that will enable developers to rapidly and efficiently test algorithms and interfaces on a massive scale.

During the study, users can log on from their home computers at any time of night or day and take a turn at remotely guiding a robot through simple household tasks, such clearing a table, or some light assembly functions that might be used in manufacturing. Users will train first on an onscreen simulation and then advance to the real thing—controlling a physical robot that is monitored by cameras. Each task is structured much like a video game, with rewards for achieving progressive levels of difficulty.

"The robot has its own apartment," Chernova jokes, "but we had to childproof its room. Our test environment—which features simple, modular furniture and basic household utensils—is much more complex and less constrained than those employed in typical user studies. As a result, we are not only developing algorithms for learning in complex places, we are also creating new techniques for keeping the robot and furniture safe."

By compiling and analyzing data from a large number of diverse users, Chernova will gain a better understanding of how robots learn, and how humans typically go about instructing them. Human input tends to be "noisy" and inconsistent, she explains. Chernova is looking for better ways to structure policy algorithms, so that robots can generalize and learn from the smallest number of interactions.

VIDEO EXTRA
Professors Sidner and Rich on "always on" agents.

She has been a leader in demonstrating the success of "active learning"—that is, allowing robots to ask their users for help when input is needed. For example, when straightening up a room, the robot might ask the user to match labels such as "book" or "magazine" to objects it sees in the room, thus expanding its library for object recognition. To select what features to consider, the robot could ask if factors such as color or size are relevant to the task at hand.

A Virtual Home Companion

What changes when an intelligent virtual agent is installed in your home and on, continuously, for months at a time? To start with, you will expect it to interact differently with you on the day it arrives, when it is still a stranger, than on the 10th day, when it has become an acquaintance, and on the 30th day, when it may be transforming into a companion.

With a four-year, $1.8 million award from the National Science Foundation, Candace Sidner, research professor of computer science, is attempting to answer this question in the context of older adults who live alone. Working with Charles Rich, professor of computer science, and Timothy Bickmore, head of the Relational Agents Group at Northeastern University, Sidner is developing a virtual agent that can provide social support and promote healthy behaviors. "We want this technology to broaden people's lives," she says. "Our aim is to increase human contact, not to replace it."

The virtual agent, named Karen, appears as an animated face on a touchscreen computer. Using computer vision and infrared motion detection, Karen can notice when someone walks into the room or approaches her and then strike up a conversation using a computer-generated voice. Her human host can talk to her by selecting items from a menu on the touchscreen.

These conversations can range from simple chit-chat about the weather, to friendly banter while playing a social game of cards, to more serious discussions about exercise

Dealing Cards...and a Little Friendly Advice

In her role as companion, the virtual agent Karen can emulate the very human skill of using simple chit-chat as a vehicle for transitioning to more serious conversations. In this example, she brings up exercise while playing rummy. Karen's words are spoken; the human responds by making selections on a touchscreen.

I've got terrible cards!

Good move! Here's mine.

- Not too bad
- Give me a minute
- Let's stop after this round

By the way, I have been thinking about a walking buddy for you.

- What's that?
- I don't want to talk about it right now

A walking buddy is someone you go walking with regularly. It's more fun than walking alone.

- Sounds complicated
- How do I get one?
- Let's just play cards

Candace Sidner and Charles Rich are developing technology that will permit a computer agent like Karen to be a long-term virtual companion to an elderly person, keeping their calendar, helping them stay in touch with family, and encouraging then to exercise and eat right.

and diet. Karen can also remind her host about appointments, set up Skype visits with friends and relatives, and carry out other useful tasks. Her behaviors are guided by a computer model that predicts when each activity is most appropriate given the time of day, what has happened so far in the current conversation, and the overall status of the relationship.

"Karen is much more than a simple stimulus-response system," Rich says. "She has long-term goals for the relationship and a memory of past activities, and she can plan for the future."

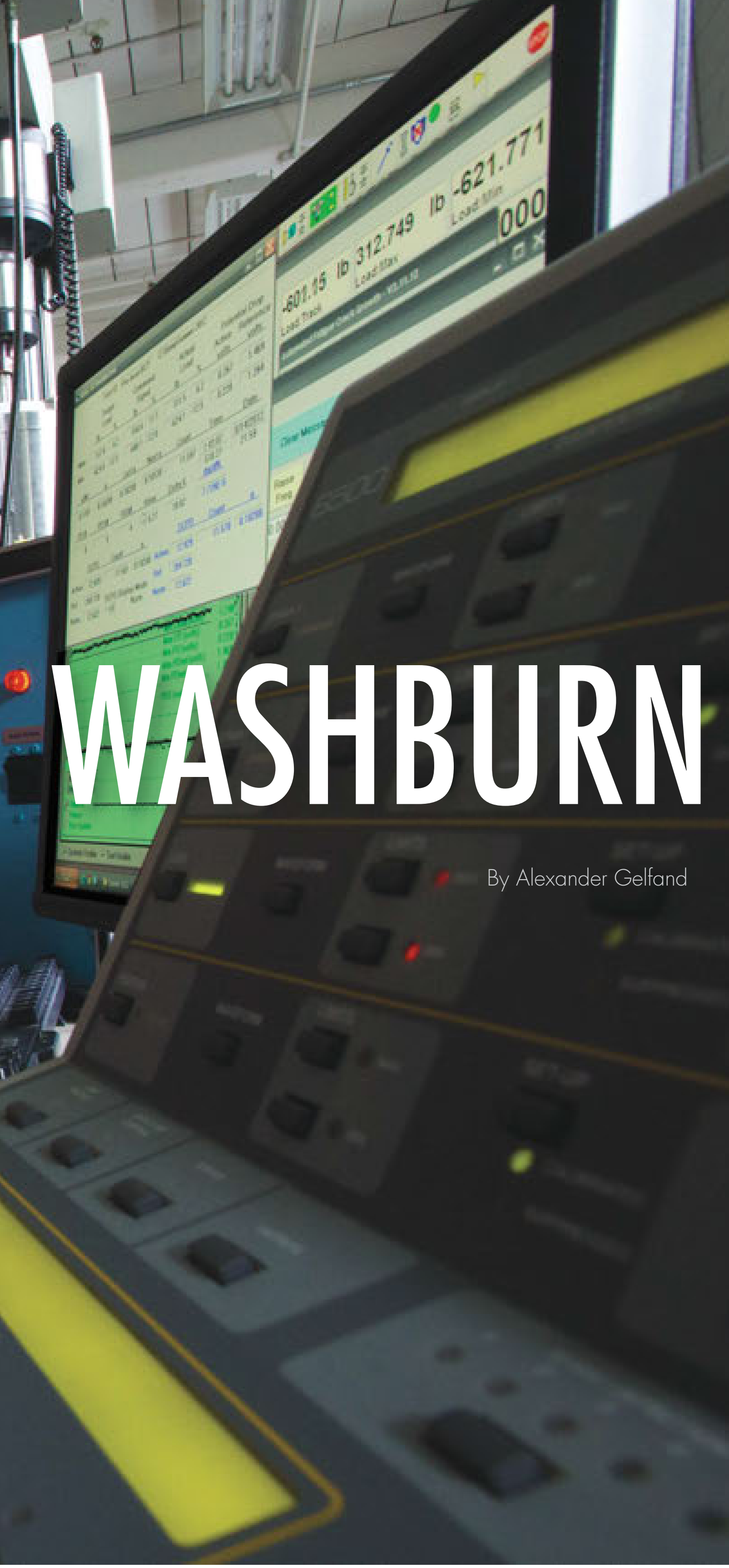
This project builds upon on a long history of research on artificial intelligence and human-computer interaction by Sidner, Rich, and Bickmore. Karen's developers have been gaining real-world experience with the current prototype over the past year through field studies that have put some of her capabilities to the test in the homes of isolated older adults in Boston. In the year ahead, Karen will spend up to six weeks in 20 homes in the project's first long-term study.

The virtual agent technology behind Karen could also be deployed in robots designed to serve as home companions. In fact, the final phase of this research will involve giving Karen a three-dimensional human-like head in a field test that will investigate whether people respond differently to a physically embodied agent than to a virtual one.

"All the software developed through this work," Sidner says, "will be freely available to help other researchers realize the goal of making virtual agents and robots part of the family."

THE WIZARDS OF

Diana Lados, right, and postdoctoral student Anastasios Gavras prepare to run a sample through the rigors of mechanical testing in the Washburn Shops, home to WPI's materials science and engineering programs. Lados studies the properties of metals that make them prone to fatigue, which is the cause of most metal failure.



WASHBURN

By Alexander Gelfand

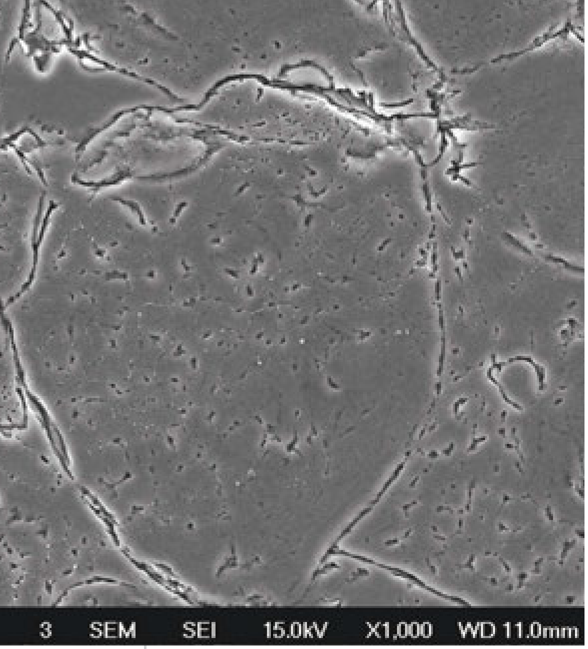
Richard Sisson Jr., George F. Fuller Professor of Mechanical Engineering, has a gift for boiling things down to their essence, and a sense of humor that comes through even when he's talking shop. His colleague Yan Wang, assistant professor of mechanical engineering and an expert on rechargeable energy cells, is "the battery guy." Diana Lados, associate professor of mechanical engineering and a specialist in metal fatigue and fracture mechanics, "breaks things."

VIDEO EXTRA
Professor Lados explains why metal parts fail.

But when Sisson claims that he and his fellow metallurgists have magical powers—"We're the wizards and warlocks," he says from his office in the Washburn Shops—one gets the distinct impression that he's only half joking.

Metallurgy, the science of creating, processing, and using metal alloys, has been a focus of education and research at WPI since the Institute opened its doors in 1868. Where students once gained hands-on experience working in a foundry and crafting products for sale in the Washburn Shops, faculty and student researchers today advance all aspects of the science and engineering of metals in an impressive array of laboratories in Washburn that fall under the umbrella of the Metal Processing Institute (see sidebar, page 14) and the Manufacturing and Materials Engineering programs, which Sisson directs.

Through this research, and through the application of advanced computational tools, they are taking the theory and practice of materials science and engineering to new places, and to new levels of sophistication. They are, as Sisson says, performing feats of metallurgical magic. Fortunately, they only use their powers for good.



VIDEO EXTRA

Professor Sisson on the need for designer metals.

Right, Richard Sisson and graduate student Danielle Belsito examine a metal sample under a light microscope. When viewed under the scanning electron microscope in Washburn, more of the sample's microstructure is revealed, as seen in this image of a cold-sprayed aluminum powder.

Super-Materials by Design

"Metallurgists heat things up and cool things down," Sisson says. "The key is how hot, how long, and how long you cool it in the end," adding that all of those factors affect the nanoscale microstructures inside the alloys, and thus their physical properties. Armed with a $4 million contract from the U.S. Army, Sisson and his colleagues are using computer models to predict the response of metal alloys to heat treatments, with the goal of developing computational tools that can be used to refine existing aluminum alloys and develop new ones that the service can use to build and repair its airplanes and ground vehicles.

The alloys the Army now uses are strong, but not particularly tough or ductile. Typically, they are first turned into powder and then sprayed at high temperatures. Everything from the initial composition of the powders, to the way they are heated, influences their performance. One of Sisson's goals, therefore, is to develop processing techniques that can enhance toughness and ductility without sacrificing strength.

Another is to invent new alloys strong enough to be used structurally, tough enough to function as armor, and light enough to improve the mobility and gas mileage of army vehicles such as Humvees. "They want super-materials," Sisson says. "They want them to have three or four functions at once."

That's a tall order. But Sisson has more than a few tricks up his sleeve. For example, the databases that he uses to power his computer models often lack crucial data on the physical properties of specific alloys. So Sisson is conducting physical experiments to fill in those lacunae, improving his ability to accurately simulate each step in the creation, treatment, and application of a given metal. Ultimately, that will help him design new and better materials—a task that depends on understanding exactly what properties are required, and which processes will produce the microstructures needed to generate them.

Sisson is also investigating a low-temperature method of applying the alloys, known as cold spraying, that accelerates the powders to supersonic speeds without actually melting them. Though well-suited to preparing vehicle parts at relatively low cost, the process is still in the experimental stages.

Sisson acknowledges that developing next-generation alloys using next-generation technologies is no small undertaking. But the wizard of Washburn is undeterred. "If it was easy," he says, "everyone would be doing it."

VIDEO EXTRA

Professor Wang on how to make a better flow battery.

Recharging Energy Storage

Yan Wang, director of the Electrochemical Energy Laboratory, is attempting to perform some magic of his own: by offering a novel spin on a type of rechargeable fuel cell called a flow battery, Wang hopes to help take wind and solar power mainstream.

In a conventional flow battery, electrolytes are stored in external tanks and pumped across a membrane in a central chamber to generate the chemical reactions that store or release electrical energy. Flow batteries don't need electrodes, which simplifies their design. Because they require less physical packaging material, they are more compact and cheaper to manufacture than ordinary batteries. And they are easy to scale since, as Wang explains, "the total energy is not limited by your battery size." Need more capacity? Just build bigger tanks.

That makes flow batteries the leading candidate for storing the energy generated by wind turbines and solar cells for use across an electrical grid when the sun isn't shining and the wind isn't blowing. But current flow battery designs have their limitations. For one thing, the metals used to make the electrolytes are not very soluble, resulting in low energy density. And while existing flow batteries store energy more cheaply than ordinary rechargeables (Wang says flow battery storage costs $300–$500 per kilowatt hour, compared with $1,000 per kilowatt hour for standard lithium-ion batteries), they aren't cheap enough to be commercially viable. The U.S. Department of Energy, for example, has set a goal of $100 per kilowatt hour for grid storage. Wang aims to meet that goal by doing away with conventional electrolyte solutions entirely. Instead, he wants to fill his flow batteries with thick suspensions of undissolved nickel and zinc particles. Because they are mostly metal, those dark, gooey suspensions (Wang has dubbed them "Worcester crude") possess 10 times the energy density of other electrolytes, and are much cheaper to produce. And because the suspensions

Yan Wang, center, and graduate student Qina Sa watch graduate student Zhangfeng Zheng prepare samples in the glove box in Wang's battery research lab. The team has developed a novel design for flow batteries, which are used for energy storage in power grids. The design uses thick suspensions of metal particles.

are based on water, they're safer than electrolyte solutions that rely on flammable organic solvents, like the ones that occasionally cause lithium-ion batteries to explode.

Wang and his students are building a prototype and working to improve the electrochemical performance of the suspensions. And while he has his eye on grid storage, Wang also envisions a day when cheap, clean, compact flow batteries might trickle down to other applications—like electric cars.

Imagine, for example, a vehicle whose fuel tank holds Worcester crude instead of gasoline. Never mind plugging into an outlet and waiting to recharge the battery once it runs down; thanks to Wang, a driver could simply pump out the depleted suspension and pump in a fresh load, "just like pumping gas."

Bridging a Knowledge Gap

Like Wang, Diana Lados is interested in saving energy. But she comes at it from a very different angle. She recently received a five-year, $525,000 CAREER Award from the National Science Foundation to boost vehicle energy efficiency (and decrease greenhouse gas emissions) by replacing heavy structural materials like steel and cast iron with lighter metals such as aluminum, magnesium, and titanium. "Each 10 percent reduction in vehicle weight results in a 5 to 8 percent increase in fuel economy, and corresponding reductions in CO2 emissions," says Lados, who founded and directs WPI's Integrative Materials Design Center (iMdc).

Before those lighter materials can be widely adopted, however, engineers first need a better understanding of what causes them to fatigue, or break under repeated stress—a process that begins with microscopic cracks and ends with large fractures.

Replace, Reduce, Recover...Sustain

"Sustainable development is, perhaps, the most pressing issue of the 21st century," says Diran Apelian, Alcoa-Howmet Professor of Mechanical Engineering and director of the Metal Processing Institute. "At the same time, it is a remarkable opportunity for practitioners of materials science and engineering, as many of the approaches that can address the challenges we face are materials-centric."

Two years ago, WPI took a bold step toward elevating the role of materials research and education in sustainably. With a major award from the National Science Foundation, the university, in partnership with the Colorado School of Mines and Katholieke Universiteit Leuven in Belgium, established the Center for Resource Recovery and Recycling (CR^3).

Under the direction of Apelian, the center has set itself the goal of becoming "the premiere industry-university collaborative dedicated to the sustainable stewardship of our Earth's resources." Its focus is new technologies for maximizing the recovery and recycling of metals used in manufactured products and structures.

"This is a global issue," Apelian says. "It is significant that this is the first NSF-funded research center that includes a European university. In many ways, European nations are ahead of the United States when it comes to the recovery and reuse of materials. We have a lot to learn from their experience."

With its 38 members, including major materials producers, manufacturers, and leaders in recycling technology, CR^3's researchers are engaged in a wide range of projects, from developing ways to recover indium, rare earths, and ruthenium from plasma displays to pioneering real-time sensors for analyzing melts to boost the recovery of aluminum from scrap.

"The challenges of sustainable development are enormous," Apelian says. "It will take our collective ingenuity and collaboration across disciplines and national borders to achieve success. Through the CR^3, I believe we have established a model for collaborative, interdisciplinary research that can help point the way toward a more sustainable future."

Learn more: "Materials science and engineering's pivotal role in sustainable development for the 21st century," Diran Apelian, MRS Bulletin, April 2012; wpi.edu/academics/Research/CR3/2012pu035.html

Master's candidate Yuwei Zhai and Professor Lados inspect an aluminum sample undergoing a test in a machine that can stretch metal until it breaks. Knowledge gained by testing alloys can lead to better computational tools and greater use of light metals in cars, trucks, and airplanes.

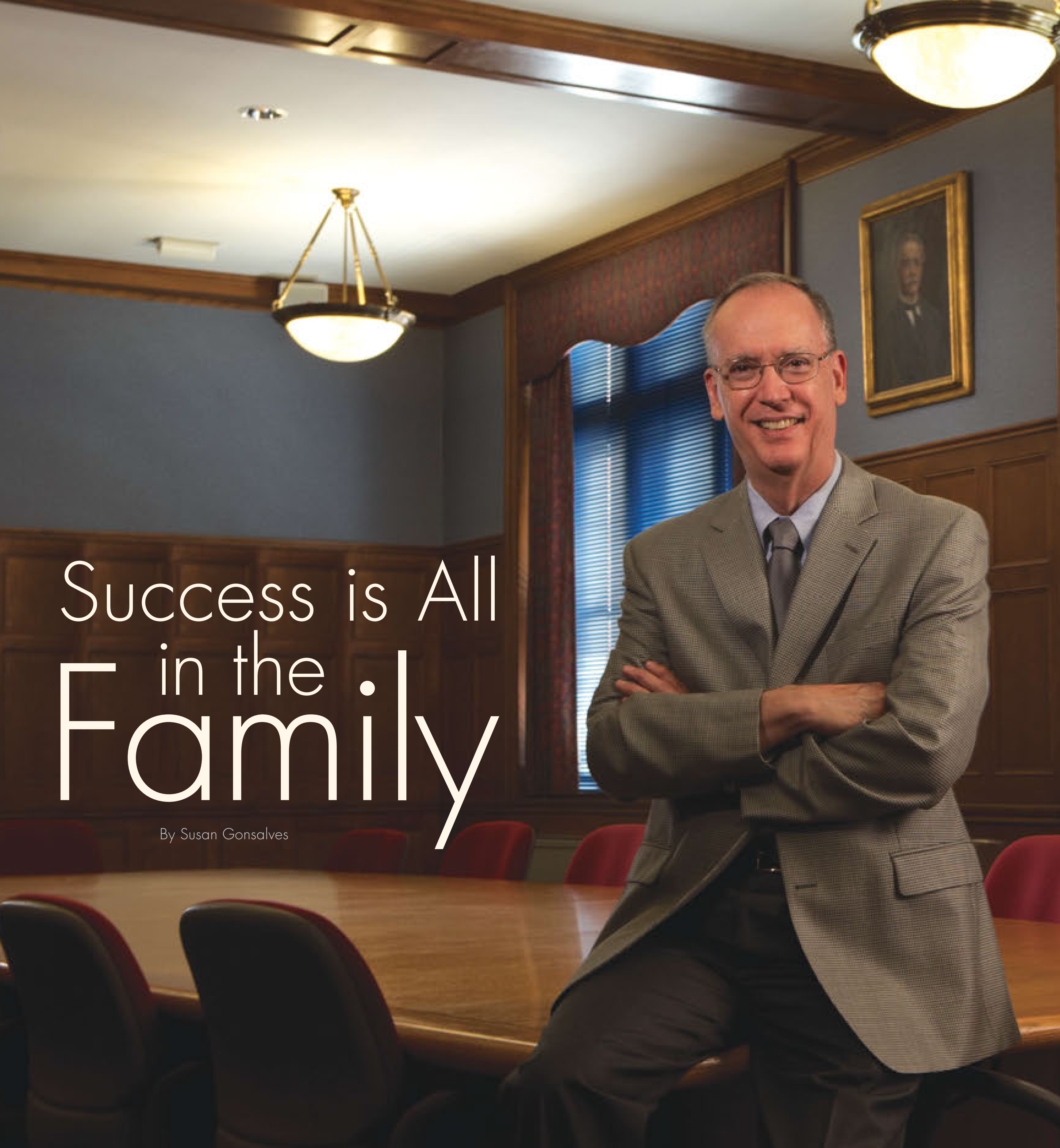
According to Lados, 90 percent of all mechanical failures are caused by fatigue. Yet despite years of research, scientists still don't fully understand how those cracks form at the nano-level, especially in complex alloys. Nor have they managed to combine what they do know about small cracks with their understanding of large ones. That knowledge gap presents a problem, because without a clear picture of what's going on at every level, designers can't accurately predict how susceptible a particular metal will be to fatigue and failure under real operating conditions. So they build excessive weight into vehicle parts just to be safe.

Using a combination of computational modeling and hands-on experimentation, Lados and her students plan to explore how small cracks form in the microstructures of metal parts, how they propagate and grow into larger fissures, and how all of this ultimately leads to failure. To gather data and validate their models, Lados and her team will prepare different light metal alloys, process them using novel techniques, then break them and examine the corpses.

The iMdc, whose mission is to advance the state of the art and practice in sustainable materials, materials design, and manufacturing, will play a critical role in that process. Member companies, which represent all the transportation industries, along with manufacturing suppliers and metals producers, will use the alloys in real-world applications and help validate the tools and methods developed in the study.

What Lados learns about the relationship between small cracks and big ones, how cracks form and spread, and how a material's properties influence fatigue will help metal manufacturers develop new and better alloys. It will also help designers more accurately predict the lifespan of their components. And that, in turn, should lead to increased use of lighter metals in everything from cars to boats to planes.

That's all thanks to a little creative destruction — and a generous application of the real-world wizardry at work in every corner of the Washburn Shops, magic that is transforming the field of modern metallurgy. ■



Success is All in the Family

By Susan Gonsalves

Frank Hoy, an authority on family-owned businesses, has spent many hours in corporate boardrooms as part of WPI's participation in a global project to learn from such firms.

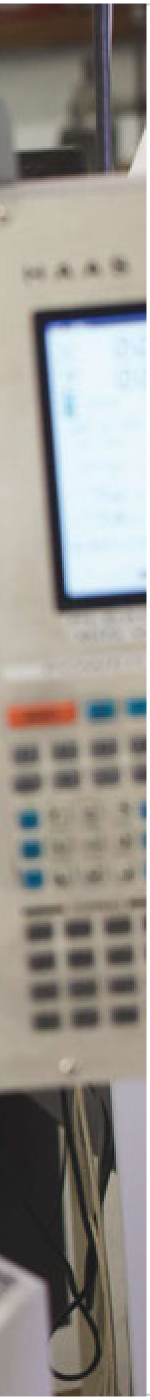
Students in the nation's business schools learn a bewildering range of facts about the realities of modern business life, but there is one word they are unlikely to hear in the classroom: family.

"Business schools tend to avoid talking about family-run businesses, or they screen out the family influence in family firms," says Frank Hoy, Paul R. Beswick Professor of Innovation and Entrepreneurship at WPI. "They try to focus on rational decision making, and they don't view family businesses as rational enterprises."

Hoy is a pioneer in the relatively young field of scholarship on family-owned businesses. Through several books, including *Entrepreneurial Family Firms* (2010) and *Small Business Management* (2012), dozens of articles, and collaborations with colleagues around the world, Hoy has explored how family businesses sustain themselves and thrive, and how they manage the transition from one generation to the next. He says this research is more than academic.

VIDEO EXTRA
Learn more about WPI's involvement with STEP.

Chick Kasouf and Adrienne Hall Phillips, faculty members in WPI's School of Business, have helped complete case studies of two multigenerational manufacturing companies with close ties to WPI. They say what they have learned will inform their work with students and their research on marketing.



"Some of the world's most successful companies are family-owned," Hoy says. "Among them are 30 percent of the Fortune 500 firms, including Fidelity, Marriott, and Wal-Mart. Business giants like Ford and IBM trace their roots back to family enterprises. As business scholars, we should be asking what these companies are doing that helps them prosper."

In 2011, WPI was offered an extraordinary opportunity to begin asking that question on a global scale. Thanks, in large part, to Hoy's reputation, the university was invited to become one of 10 North American universities to join the Successful Transgenerational Entrepreneurship Practices (STEP) project headquartered at Babson College. Through STEP, research teams from Europe, Asia, Latin America, and North America are creating a shared database that currently includes more than 95 case studies of multigenerational family-owned businesses worldwide.

In addition to Hoy, the STEP team at WPI includes fellow Business School faculty members Chickery "Chick" Kasouf, associate professor of marketing, and Adrienne Hall Phillips, assistant professor of marketing; Hansong Pu, a visiting lecturer who also directs an entrepreneurship and business center at China's Hangzhou University; and Kimberly Eddleston, associate professor of entrepreneurship and innovation in Northeastern University's College of Business Administration.

Case Studies in Success

The team has completed its first two case studies, both of which focus on companies with longstanding ties to WPI. Morgan Construction, a maker of rolling mills and other machinery for the steel industry, was founded in the 1880s by Charles Hill Morgan, the first superintendent of WPI's Washburn Shops. It was run by five generations of Morgans before the company agreed to be sold to Siemens VAI in 2008.

Spirol, which makes engineered fasteners, has ties to three families, including the Prym family, which started the oldest family-owned business in Germany. Located in Northeast Connecticut, Spirol has been led throughout its 60-year history by members of the Koehl family, including Hans Koehl, a 1956 WPI graduate, the recently retired CEO, and his son Jeffrey, the current CEO.

To prepare the case studies, WPI researchers spent several months conducting structured interviews with key corporate personnel, including family and non-family members, using a lengthy questionnaire prepared for the STEP project. The result of this exhaustive process was a detailed analysis of each firm's history, status, vision, governance, marketing practices, and more.

While the case histories, which are currently being reviewed by the Morgan and Koehl families, will remain confidential, Hoy says they will be available to members of the STEP consortium for research purposes. The database

"Through its global projects program and globally diverse student body, WPI already gives students a tremendous introduction to the global society in which they will live, work, and hopefully prosper." —Adrienne Hall Phillips

"By putting its name on the business, a family conveys a sense of integrity and trust to employees, customers, and creditors." — Frank Hoy

gives researchers access to information about more than 95 companies, which can be used to answer a wide range of questions about why some businesses survive from one generation to the next and succeed in the global marketplace.

"One thing we're finding is that good practices in family companies translate to non-family businesses as well," Hoy says. Although the research is still in its early stages, he says there is "solid evidence" that shows family businesses are more likely to prosper because they have the ability to make longer term decisions to achieve their goals.

While each company and its leaders are different, Hoy says evidence is mounting that an organization's culture is an important factor in its success. "By putting its name on the business, a family conveys a sense of integrity and trust to employees, customers, and creditors," he notes. "It is a way of saying they are going to deliver on their promises."

Kasouf says participating in STEP has enabled him to expand his research on small businesses to include perspectives from transgenerational family-owned firms. While he cautions that it can be difficult to find common ground among such a diverse group of organizations, he's observed that researchers can also learn a great deal from the mistakes that multigenerational companies make. "I've seen small companies fail to thrive because the second and third generations threw out the business model and treated the place as an annuity and not an investment," he says.

Family dynamics like these distinguish multi-generational family-run companies, Phillips says. "The complexities and pressures involved are different for family businesses," she notes. "There are issues of separating family ties with business decisions and absorbing personal risk. The dynamics affect viability over the long run."

Family businesses are also characterized by complicated governance structures, says Kasouf, who notes that family members from multiple generations often hold equal shares, and have equal votes, making it tricky to determine who will have the final say. And when some family members work for the company and others don't, they may face what Hoy calls "the predator versus parasite controversy."

"People outside of the business see their relatives getting salaries and nice benefits and say, 'they're sacking our inheritance,'" he says. "Company insiders feel entitled to the rewards they're reaping and may feel that family members who are not contributing to the business are sucking blood out of them."

Overcoming obstacles like these can make achieving intergenerational success a challenge. Kasouf recalls one Connecticut business that resorted to therapy to figure out how to transition the business. "They wanted to be sure everyone could deal with what was going on before moving forward," he says.

Hans Koehl, right, and his son Jeffrey represent the most recent generations to oversee Spirol in Danielson, Conn. Opposite, Herman Koehl, center, Hans's father, founded Spirol in partnership with Walter von Conta, left, and Hans Prym.

A Richer View of Business

One goal of WPI's participation in the STEP project is to strengthen the university's undergraduate and graduate programs in business by incorporating a greater focus on family enterprises, Hoy says. "Business schools have not done a proper job to this point of preparing students for their inevitable fate, whether that is starting a family business, working for a family business as a family or non-family member, or conducting business overseas, where family business are quite common. This research will help people understand that the most successful businesses are family-based—including in the engineering and technology realm."

Among the most valuable aspects of the STEP research, Hoy, Kasouf, and Phillips note, is the perspective it will offer on cultural differences in business practices and family dynamics. "Through its global projects program and globally diverse student body, WPI already gives students a tremendous introduction to the global society in which they will live, work, and hopefully prosper," Phillips says. "This global database will help us give students an even richer view of the world of business."

The researchers say they also look forward to using the STEP database to make cross-cultural comparisons and examine best practices across international boundaries. "Drawing distinctions between family businesses located in different regions of the world should be enlightening," Phillips says.

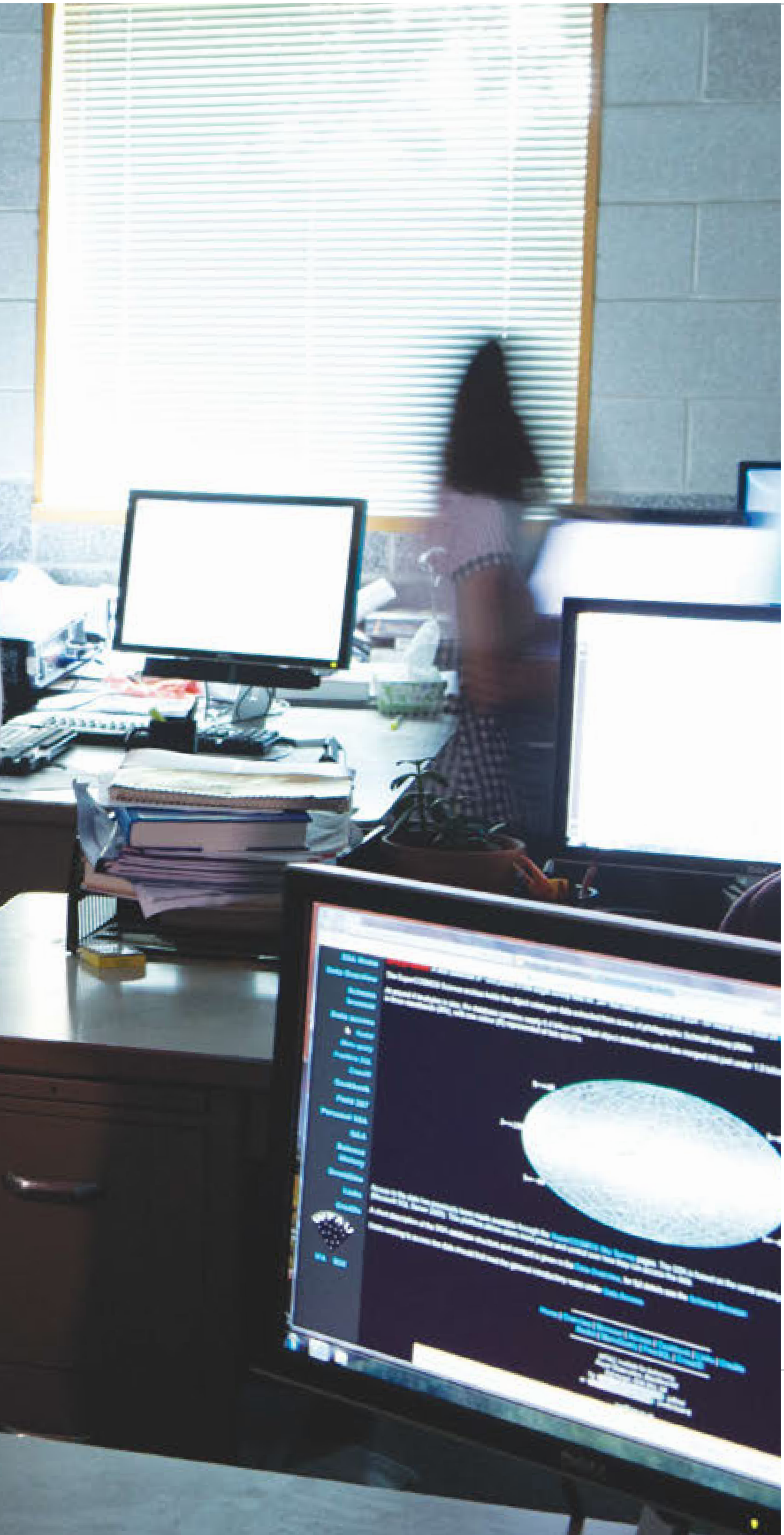
The team, which anticipates completing one or two new case studies a year, is also looking forward to tackling a new challenge together.

"We already have our eye on an interesting company," Hoy says. "Zildjian Cymbals in Norwell, Mass., is the oldest family-owned business in the United States. It is beginning its 15th generation of management and is being led by two women, who are its first female CEOs. Just imagine what lessons we can learn from a company with such a long and rich history." ■

CRUNCHING THE BIG NUMBERS

By Ami Albernaz

In her busy lab, Elke Rundensteiner pioneers ways to pull meaning—in real time—from streaming data to drive actions and decision making when time is of the essence.



By the end of this year, individuals and organizations will have generated nearly 3 zettabytes of digital data, a volume 3 billion times greater than the capacity of a terabyte hard drive. From emails and purchase transactions, to health measurements and Facebook posts, to cellphone calls and streaming movies, data fuels our technological world, and we are creating it at an ever-increasing pace and in a proliferating range of forms.

This vast, overflowing pool of information can be a gold mine for those with the right tools to comb it for telling patterns. Researchers at WPI are among those looking to harness this torrent of data to tackle problems as diverse as hospital-acquired infections to consumer fraud. From algorithms that pull insights from data on the fly to analytical techniques that draw on massive data sets to make useful predictions about the future, these researchers are helping advance the emerging science of "big data."

Insights in the Blink of an Eye

Elke Rundensteiner, professor of computer science, is a prime example of this forward-thinking research. She has been exploring ways to extract actionable insights in real time from the streaming data from sensors, smartphones, and social media platforms—a process she calls complex event stream processing. "Having access to the right information at the right moment, possibly fused together from numerous sources, can be a critical capability in many domains," she says.

While the innovative techniques she and her students are developing can be applied in many fields, including business, scientific discovery, and security, Rundensteiner is currently focusing on solving problems in healthcare. For example, she has been working for several years with doctors at UMass Memorial Medical Center on a pilot project centered on preventing infections within the hospital.

The system targets healthcare workers and their hand-washing habits. Using Rundensteiner's techniques, computers process data relayed from sensors attached to soap dispensers, doors, and other locations within hospital rooms. If the instantaneous analysis reveals that workers have failed to wash their hands or to perform other critical infection-control procedure, they receive an immediate reminder to take the appropriate action to remediate the problem.

More recently, Rundensteiner, in collaboration with colleagues at WPI and psychologists at UMass Memorial, has started work on a project that aims to deliver more cost-effective care to patients with addiction issues by tracking them between doctor visits through smartphones. The goal is to combine smartphone data with continuous measurements of stress levels, in real time, to identify situations that appear to put patients at risk of relapse, and to deliver appropriate interventions when they can be most effective. The system will transparently monitor how effective this assistive technology is in improving the patients' well-being.

"This is a promising new use of real-time analytics," she says, "one that opens the door to other types of applications that can address a wide range of problems with important societal impact."

Rundensteiner has received support from HP Labs' Innovation Research Program and the National Science Foundation in developing her data processing technology, which depends on a 20-computer cluster rapidly analyzing sequences of events. Along with gaining insights that can be acted on immediately, she analyzes the sequences to derive longer-range patterns. For example, in her work on infection control, she hopes to give doctors information they can use to improve processes at the hospital.

Rundensteiner is also working with Mohamed Eltabakh, assistant professor of computer science, to extend the capabilities of Hadoop, a system for processing large, static data sets on computer clusters, so that it can also handle streaming sources, such as Twitter. Combining static and streaming data in the same system, she says, can result in richer insights in a range of disciplines, not achievable when working with archival data only.

"To me, 'big data' doesn't mean just one type of data," she says. "It can include static data, and it can come from multiple dynamic sources. I want to develop new kinds of analytics that can pull together and learn from all types of knowledge."

Telling the Story of Data

Brenton Faber, professor of writing and rhetoric in the Department of Humanities and Arts, also works with large, health-related data sets, but his goal is to use the data to inspire new ideas. Having long studied human dynamics and organizational change, he is interested in how framing insights gained from big data can motivate process improvements, particularly within healthcare settings.

"How you present the data and how you tell the story has a huge impact," he says. "Once you gain insights from big data sets, you need to know how to make them persuasive and motivational."

Faber is bringing this approach to data into the new Analytics Lab, which he co-founded with Andrew Trapp and Renata Konrad, assistant professors in WPI's School of Business. The lab received a start-up grant of funds, training, and software valued in excess of $350,000 from Dimensional Insight, a business intelligence firm in Burlington, Mass. Working in the lab, students and researchers across

Brenton Faber directs WPI's new Analytics Lab, which will bring together faculty members and students from many disciplines who want to draw on huge data sets to gain insights that can drive process improvement, particularly in healthcare.

"How you present the data and how you tell the story has a huge impact. Once you gain insights from big data sets, you need to know how to make them persuasive and motivational." — Brenton Faber

VIDEO EXTRA
Professor Radzicki explores predictive analytics in trading.

> "Fraud is a huge and growing problem in healthcare. By helping reduce fraud, the system can potentially play an important role in lowering costs in the healthcare space." —Michael Radzicki

disciplines will analyze large data sets using The Diver Solution, Dimensional Insight's business intelligence software. Students will learn to find meaning in data and to place the insights gained into a larger context.

"By housing the lab in the humanities department, we hope to address the human dynamics issues, the narrative, and not just the technical issues," he says.

Faber learned the importance of using the right language to frame data-driven initiatives while he was director of analytics and new project development at Canton-Potsdam Hospital in Potsdam, N.Y. He found that if he wanted to persuade the staff to act, he needed to use the terms they were accustomed to thinking in.

"While a lot of the language used at the hospital was quantitative—blood pressures, pulse rates, and so on—the staff didn't have a vocabulary for talking quantitatively about hospital operations," he recalls. "Quantifying everyday things like the infection rate and the readmissions rate seemed to motivate the staff to work toward process improvement."

Faber hopes the Analytics Lab will ultimately be a nexus for undergraduate projects, graduate research, and corporate-sponsored research. As a step in that direction, he and the other lab founders are working on a large-scale analysis of data related to medical visits by patients with congestive heart failure. They hope to learn the impact of preventative care on outcomes, explore which treatments seem to work best, and to even quantify how much money those measures can save. Faber is excited to bring these sorts of complex issues into the new lab.

"Through this new initiative we are building the capacity to examine all sorts of medical and health-related data," he says. "Ideally, we hope to eventually be able to cross-link disease, utilization, and finance data to get a more detailed description of medical practice."

Toward a Smarter Future

In addition to shaping behavior and driving change in the present, big data can be used make predictions about the future—for example, to investigate questions such as who is most likely to contract a particular disease, where the Euro will trade a minute or a day from now, or who is planning to commit healthcare fraud. Michael Radzicki, associate professor of economics, has long been immersed in this area, called predictive analytics. He recently built it into a new WPI program in currency trading system development and is using it in an innovative new project to reduce Massachusetts healthcare costs.

Radzicki's interest in predictive analytics dates back to the early 1990s, when he and a group of math and computer science professors developed a set of trading strategies based on analyzing years of trading footage from the Chicago Board of Trade. While their strategies performed well in computerized tests, they ultimately didn't hold up because they couldn't factor in trading lag time. Trades were conducted through a chain of hand signals, meaning that by the time the trade was finally executed, the market had usually changed.

"It wasn't until the Web and online trading that these barriers were eliminated," says Radzicki, who also started the system dynamics program at WPI. "Commissions were much lower, and though there were still latencies, they were nowhere near what they had been."

Michael Radzicki has been exploring the use of predictive analytic tools, which mine big data sets for patterns and trends that can help make predictions about future activities or behaviors, in areas as diverse as currency trading and medical fraud detection.

More recently, in partnership with Hossein Hakim, professor of electrical and computer engineering and an active currency trader, Radzicki has been developing an automated trading system. Using historical data on the Euro-U.S. dollar currency pair and other mathematical indicators, his machine-learning algorithm tests different values to find the combination that would have yielded the most profitable trades. The system essentially mines the data to find and exploit patterns that are so complex and so deeply woven in that humans cannot perceive them.

Radzicki has taught classes on trading system development and has had former students recruited by Goldman Sachs and Putnam Investments. He hopes leading financial services firms will increasingly recruit WPI students, particularly with the launch of the new trading system development program that he and Hakim have established.

Radzicki is also working with a Woburn-based startup to build predictive analytics into two software systems designed to link buyers' and sellers' payment systems to make transactions more efficient and transparent. In one, he is using predictive analytics to build an instant credit-scoring tool for companies wanting to join the system and access credit to pay their vendors. For the second, he is using predictive analytics to help detect fraud in health insurance payment data. An early version of his algorithm was able to identify cases of fraud in tests with a portion of the state's data set. He says the state could use this algorithm to prevent fraudulent claims from being paid.

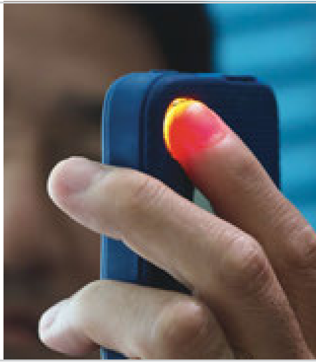
"Fraud is a huge and growing problem in healthcare," Radzicki says. "By helping reduce fraud, the system can potentially play an important role in lowering costs in the healthcare space." ■

Ki Chon develops algorithms that extract a wealth of physiological information, from vital signs to evidence of blood loss, from light reflected off pulsing blood. He has adapted a number of his tools for use on smartphones.

Engineers in the Clinic

By Michael Cohen

From robotic systems that enable more accurate biopsies and less invasive cancer treatments, to wireless sensors that can detect internal bleeding, to bioengineered materials that help the body regenerate damaged tissues, advanced technologies developed by WPI engineers are moving into clinical studies to help physicians diagnose and treat patients.



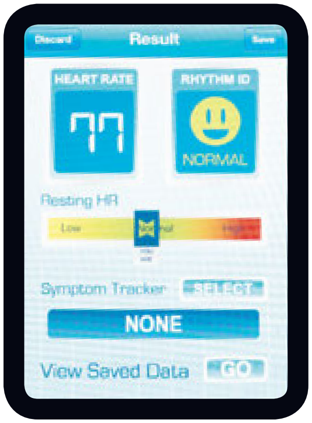
Shining Light on Blood Loss

An unconscious victim is extricated from the wreckage of her car and airlifted to the trauma center at UMass Memorial Medical Center in Worcester. Though there are no overt signs of injury, the EMTs know that blood loss from unseen internal trauma could soon send the patient into shock. Fortunately, tonight they have a tool for detecting early signs of hemorrhage: a prototype sensor developed by Ki Chon, professor and head of WPI's Department of Biomedical Engineering, and Yitzhak Mendelson, associate professor of biomedical engineering.

The miniaturized wireless sensors are being developed with the aid of a recent three-year, $1.9 million grant from the U.S. Army. They will ultimately be worn by soldiers in combat, but will first be tested in clinical trials in UMass Memorial's LifeFlight helicopters and emergency room. Embedded with mathematical algorithms, the sensors will simultaneously measure seven physiological parameters, including a novel way to detect bleeding. "The Army knows it can save more lives if it can detect hypovolemia much faster than is now possible under battlefield conditions," Chon says. "If we are successful, the technology will not only save soldiers' lives, but will also help civilian trauma patients."

The project builds on early work by Chon and Mendelson, who have developed wireless sensor hardware and signal processing algorithms that measure heart rate, heart rhythm, respiration rate, skin perfusion, and blood oxygen saturation. Mendelson's lab focuses on the hardware development while Chon's team works on the mathematical formulae that extract physiological data from the signals captured by the sensors.

Their technology platform shines infrared and visible light through the skin and then measures how different frequencies of light are absorbed by pulsing arterial blood. It is the same basic idea employed in the pulse oximeters that are clipped onto hospital patients' fingers to measure blood oxygen levels, but taken to a far more sophisticated level. Proof-of-concept studies with healthy patients donating blood have shown the light-based sensor system can detect early signs of a reduction in blood volume. Chon and Mendelson speculate that the same system may also be able to detect dehydration in patients not suffering from blood loss.



In addition to the wearable sensors, the WPI team will adapt the technology for use on a smartphone, with the built-in video camera providing light and then recording the reflections for processing. The UMass Medical team will develop decision-support tools to be embedded in the smartphone application, so when the device is deployed in the field it will not only measure vital signs, but also prompt the medic or civilian first-responder with information to guide treatment.

The blood loss sensor project, one of many collaborations ongoing between faculty at WPI and the University of Massachusetts Medical School, highlights the value of bringing engineers and clinicians together. "Having the opportunity to collaborate with the trauma team at UMass Medical is extremely important for our work," Mendelson says. "This is not a case of our developing the technology and handing it over for their use. It is a collaborative process. The physicians' clinical understanding and experience helps us refine the technology."

Helping Physicians Target Cancer

With cancer, early detection is often the key. The sooner a malignancy is found and characterized, the better the chances are for effective treatment. For many cancers, a needle biopsy is the first invasive step in the diagnosis, but results can be inconclusive when the targeted tissue is small or otherwise difficult to access through the skin.

Researchers at WPI are helping to improve those odds by developing a robotic system that will allow doctors to precisely position a biopsy needle as it is guided by live MRI images. The system, designed to work inside the bore of an MRI machine, will soon be tested in a clinical trial at Brigham and Women's Hospital (BWH) in Boston.

"Our first clinical goal is to improve the efficacy of needle biopsies for prostate cancer diagnosis, but we know there are many other applications for this technology," says Gregory Fischer, assistant professor of mechanical engineering and director of the Automation and Interventional Medicine (AIM) Lab at WPI. "The system gives a surgeon real-time images and the control to move the needle through and around tissues in ways that cannot be done so accurately by hand and without image guidance."

To build a robot capable of working within the small confines and intense magnetic field of an MRI machine, Fischer and the AIM team had to use materials without ferrous metal parts and with components designed to not emit electrical signals that could interfere with the quality of MRI images. Years of testing and development have yielded a system composed of specialized robot control electronics, fiber-optic sensors, ceramic piezoelectric actuators, engineered robot modules, and other components that are compatible with the MRI environment.

Fischer worked closely with the Advanced MRI Center at UMass Medical School in Worcester to test prototypes of his robotic system using tissue analogues and non-human biologic samples. "We have answered the tough engineering questions," Fischer says. "The system works. We can put a needle or a probe wherever the surgeon wants it."

In addition to the needle biopsy trial, Fischer and his colleagues at BWH hope to use the system for prostate brachytherapy, which is the placement of small radioactive particles within tumors to kill the cancer. Colleagues at Harvard Medical School are testing one of Fischer's systems for kidney cryoablation. Fischer is also working with a medical device company that builds high-energy ultrasound systems that ablate cancer cells. They are planning to adapt the robotic system to position an ultrasound probe in the brain and attack otherwise inoperable brain tumors.

"Our key contribution, I believe," Fischer says, "is that we have built a modular system, one that can be rapidly assembled and configured for a variety of applications so the clinical team can focus on treating the patient and not worry about the devices being MRI compatible."

Research That Tugs at the Heartstrings

Once confined to the realm of science fiction, tissue regeneration is among the most rapidly emerging areas of basic and applied biomedical research. Despite that awe-inspiring reality, the notion of literally stringing together cells to grow a beating human heart seems incredible, indeed. But that is exactly what Glenn Gaudette, associate professor of biomedical engineering at WPI, will be attempting to do in the year ahead with a colleague at Massachusetts General Hospital in Boston.

Gaudette is collaborating with Harald Ott, MD, a cardiothoracic surgeon and a world leader in the field of whole organ regeneration. "This is an exciting partnership," Gaudette says. "The technologies in our laboratories complement each other nicely."

Ott has broken new scientific ground with a process to strip away the cells from cadaveric hearts, leaving ghostly shells made of the collagen and elastin framework that shapes the heart's walls, chambers, and vasculature. In theory, this decellularized heart should make a perfect scaffold for engineered stem cells, which can repopulate the framework and regenerate a functional organ. In practice, successfully seeding the decellularized heart with new cells has proven to be a serious challenge.

Gaudette, an expert on the mechanical aspects of cardiac function, is well acquainted with the difficulty of placing stem cells where you want them. For several years, his lab has been using stem cells derived from bone marrow

Greg Fischer, right, and PhD student Gregory Cole work on a modular control system designed for use with surgical robots that can operate inside an MRI scanner. Fischer's MRI Compatible robots allow surgeons to perform activities that require high precision while guided by real-time imagery.

to regenerate cardiac muscle and improve the heart's ability to pump blood. When placing the cells on traditional biological scaffolds produced mixed results, he decided to try seeding the cells on biopolymer microthreads first developed at WPI by George Pins, associate professor of biomedical engineering.

Made of collagen, fibrin, and other biologic materials, the hair-thin microthreads can be braided into cable-like structures that mimic muscles, ligaments, and tendons. They can be seeded with engineered cells to promote regrowth of specific tissues. Pins developed the microthreads with the hope that they could be used to repair damaged ACLs (anterior cruciate ligaments). They have since been used by Gaudette and other researchers at WPI and elsewhere for a variety of tissue engineering and regeneration projects, with remarkable results. Gaudette says 60 percent of stem cells engraft in the heart when he uses the threads, a substantial improvement over the success rate for traditional scaffolds. "It's been exciting to see how this work has evolved into a platform technology with many clinical applications," Pins said.

At Mass General, Gaudette will use the microthreads as biological sutures to stitch stem cells into the decellularized heart and analyze their impact. "Our studies have shown that using the microthreads to deliver cells to a rat heart dramatically increases the successful engraftment rate compared to injection or perfusion," Gaudette says. "Working with Dr. Ott's team, we'll use the threads on the decellularized heart and study how the cells perform, how they migrate, and if they will develop into contracting heart-muscle tissue."

Once made painstakingly by hand, the microthreads are now produced by an extrusion system designed by WPI faculty members and graduate students. Earlier this year, Pins and Gaudette founded a new company, VitaThreads, to commercialize the microthread technology and the extruder. The company, now based at WPI's Life Sciences and Bioengineering Center, is focusing initially on tissue regeneration in the veterinary market as a precursor for human product development. ■

VIDEO EXTRA

Learn about a machine that extrudes microthreads.

George Pins, left, and Glenn Gaudette examine a machine that mass produces biopolymer microthreads that can serve as scaffolds for stem cells.

E. Scagnetti

"It's been exciting to see how this work has evolved into a platform technology with many clinical applications." — George Pins

RESEARCH HIGHLIGHTS

Major Research Awards

Here is a small sample of the many notable awards from federal agencies, corporations, and entities that have supported research at WPI in recent months.

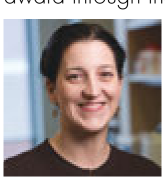
New Metallurgical Tools for the Army

WPI is the lead institution on an 18-month, $4 million project funded by the Army

Research Laboratory to develop computational tools that can be used to predict the microstructure and mechanical properties of engineering alloys. The project will help the Army, as well as the aircraft, automotive, and electronics industries, develop new nanostructured alloys for specific applications. **Richard Sisson**, Diran Apelian, Nikolaos Gatsonis, Jianyu Liang, and Makhlouf Makhlouf (Mechanical Engineering) are leading WPI's research efforts. Researchers at Northeastern University and Temple University are collaborating.

Driving Innovation with Biofabrication

WPI has received a five-year, $3 million award through the National Science



Foundation's Integrative Graduate Education and Research Traineeship (IGERT) program to launch an innovative graduate program in biofabrication that will combine interdisciplinary research, translational engineering, and industrial and international experiences to prepare a new cadre of researchers who can translate their discoveries into solutions for societal problems. The program is being directed by an interdisciplinary team consisting of **Terri Camesano** (Chemical Engineering), Kristen Billiar, Ki Chon, and Glenn Gaudette (Biomedical Engineering), and Frank Hoy (School of Business).

Sensors That Can Save Wounded Soldiers

Ki Chon and Yitzhak Medelson (Biomedical Engineering) have received a three-year,

$1.9 million award from the U.S. Army to develop wearable wireless sensors and a smartphone application that detect the early signs of hypovolemia (loss of blood volume). The research will be conducted in collaboration with the University of Massachusetts Medical School, where Chad Darling, MD (Emergency Medicine), and David McManus, MD, (Medicine) are co-principal investigators. The sensor and blood loss detection algorithm will make use of light transmitted through the skin. The technology could be used to help save the lives of soldiers and civilian trauma patients.

Helping Students Develop Inquiry Skills

Janice Gobert and Ryan Baker (Social Science and Policy Studies) received a three-year, $1.5 million award from the U.S. Department of Education to develop an intelligent pedagogical agent that can help teach middle school students science inquiry

skills while drawing on educational data mining techniques to seamlessly integrate assessment with instruction. The project will build on 12 inquiry microworlds (interactive simulations) developed by Gobert and her team for physical science. In the project, she and Baker will develop a pedagogical agent and a set of detectors to assess students' inquiry skills and behaviors; the system will tutor students in real time as they engage in inquiry with the microworlds.

Protecting Firefighters from Toxic Gases

David Cyganski and James Duckworth (Electrical and Computer Engineering) and

Kathy Notarianni (Fire Protection Engineering) have received a $1 million award from the Federal Emergency Management Agency (FEMA) to develop a sensor that firefighters can wear to warn them that they are in the presence of carbon monoxide or hydrogen cyanide, both colorless toxic gases. Exposure to these toxins can cause serious short- and long-term health problems, and the gases can be present even outside a burning building, where firefighters may not be wearing protective breathing apparatus. While toxic gas detectors exist, none are able to function reliably in the extreme environment in and near the fire ground.

Sensing Gas Concentrations from the Air

With a four-year, $515,000 award from the Air Force Office of Scientific Research, **Michael Demetriou** and Nikos Gatsonis (Aerospace Engineering) will investigate the use of unmanned sensing aerial vehicles (SAVs) to estimate the concentration of a gas emitted by an unknown source. The ability to make such predictions is important in efforts to mitigate the deliberate or accidental release of contaminants, and in rescue missions that involve the release of gases. The research will combine theoretical estimation, controls, and aerospace vehicle dynamics with computational fluid dynamics.

Visual Tools for Assessing Risk in Streaming Data

Matthew Ward and Elke Rundensteiner (Computer Science) and Huong Higgins (School of Business) received a $500,000 award from the NSF to develop visual analytical techniques that can help spot important patterns in high-volume streaming data, patterns that can help in risk assessment. The tools are expected to have a significant impact on a wide range of fields that rely on extracting meaning from the real-time flow of digital data, including the military, the financial sector, and medicine. In particular, they will play an important role in the assessment of financial risk and the detection of fraud.

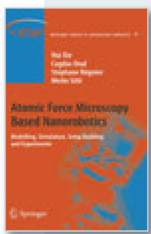
Can Online Tutoring Transform Homework?

WPI is collaborating in a study led SRI International and funded by a $3.5 million award from the U.S. Department of Education to evaluate the effectiveness of using ASSISTments, an online tutoring and assessment system, for mathematics homework. **Neil Heffernan** (Computer Science), who developed ASSISTments, is leading WPI's portion of the research. The research team, which includes faculty at the University of Maine, will study the use of ASSISTments by seventh-grade students and teachers in more than 50 schools in Maine. ASSISTments aims to transform homework by giving students instant feedback and tutoring adapted to their individual needs.

Gift Helps WPI Keep Its Eye on User Experience Research

The emerging research area of user experience is playing an increasingly important role in the development of websites, mobile apps, and video games. Central to this work is eye-tracking, in which researchers monitor what users look at as they take in and process information, including words and images on a printed page, a web page, or a smartphone screen. The new User Experience and Decision Making laboratory at WPI, established with the help of a five-year, $263,000 gift from Dynamic Network Services Inc. (Dyn) and directed by **Soussan Djamasbi**, associate professor of MIS, will support a host of research that makes use of state-of-the-art eye-tracking technology and other physiological measures.

NEW BOOKS by WPI Faculty



Atomic Force Microscopy Based Nanorobotics

Hui Xie, Cagdas D. Onal, Stéphane Régnier, and Metin Sitti
Springer, 2012

Co-authored by Onal, assistant professor of mechanical engineering, this book presents the latest progress in the use of the atomic force microscope as a nanorobot to manipulate nanoscale entities such as particles, nanotubes, and nanowires.

Engineering Design: Representation and Reasoning, 2nd Edition

Clive L. Dym and David C. Brown
Cambridge University Press, 2012

Arguing that symbolic representation and related problem-solving methods can help clarify and articulate concepts of design, this book, co-authored by Brown, professor of computer science, adopts the vocabulary and paradigms of artificial intelligence to enhance the presentation and explanation of design.

Faculty Achievements

International Honors for Inorganic Membrane Pioneer

Yi Hua "Ed" Ma, James H. Manning Professor of Chemical Engineering and director of WPI's Center for Inorganic Membrane Studies, received two significant international honors in 2012. In May he was recognized for his distinguished contributions to adsorption science and technology at the Sixth Pacific Basin Adsorption and Technology Science and Technology Conference in Taipei. In July he was one of four scientists honored as "Fathers of Inorganic Membranes" in a special session at the 12th International Conference on Inorganic Membranes at the University of Twente in the Netherlands.

Distinguished Professional Honors

Jim Cocola, assistant professor of literature,

film, and media, was named a fellow at the MacDowell Colony in Peterborough, N.H., the nation's leading artists' colony, where he was on a writing residency.

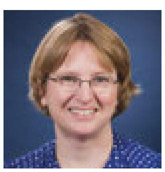
Robert Connors, professor and associate head of the Department of Chemistry and

Biochemistry, was named to the 2011 Irish Education 100 by the *Irish Voice* newspaper. The annual list honors leading educators of Irish descent.

Nicholas Dembsey, professor of fire

protection engineering, has been named to a three-year term on the governing council of the International Association for Fire Safety Science.

Kathi Fisler, associate professor of

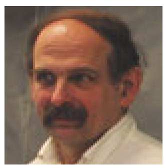


computer science, is a member of the SIGPLAN Education Board that is designing the programming languages component of new undergraduate curriculum guidelines for computer science being developed by the Association for Computing Machinery and the Institute for Electrical and Electronics Engineers.

Janice Gobert, associate professor of

social science and policy studies, delivered a keynote address at the 15th Biennial EARLI Conference for Research on Learning and Instruction, in Bochum, Germany, in August 2012.

John Goulet, coordinator of WPI's Master of Mathematics for Educators program, has

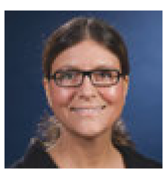


been named one of the best 300 college professors in the nation by The Princeton Review. A profile of Goulet is included in the 2012 book *The Best 300 Professors* (Random House/Princeton Review).

The New England Historical Association (NEHA) has named its book award in honor

of **James Hanlan**, professor of history. With 720 members, NEHA is among the largest academic professional societies in New England. Hanlan is the association's executive secretary.

Diana Lados, associate professor of

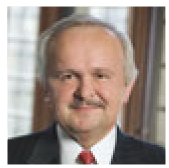


mechanical engineering, received a 2012 Women to Watch Award from the publication *Mass High Tech*. The award honors women who are leaders in various technical fields and in their communities.

James O'Shaughnessy, professor of

civil and environmental engineering, received the 2012 Clair N. Sawyer Award from the New England Water Environment Association. It honors outstanding service to the profession and the association.

Ryszard Pryputniewicz, K. G. Merriam Professor of Mechanical Engineering, has been elected to the Academy of

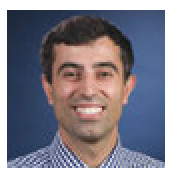


Distinguished Engineers at the University of Connecticut. The academy honors UConn School of Engineering alumni for "sustained and exemplary contributions to the engineering profession."

Richard Quimby, associate professor

of physics, has been named a senior member of the Optical Society of America and appointed associate editor of the journal *Optical Engineering* in the area of lasers and applications.

Nima Rahbar, assistant professor of



civil and environmental engineering, received a 2012 Young Leader Award from the Structural Materials Division of the Minerals, Metals & Materials Society (TMS). He was also chosen to represent TMS in the 2012 Emerging Leaders Alliance.

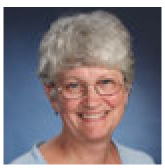
Vadim Yakovlev, research associate professor of mathematical sciences, was elected to the board

of governors of the International Microwave Power Institute, the leading global association dedicated to the exchange of information on all aspects of microwave and radio-frequency heating technologies.

Bogdan Vernescu, professor and head of the

Mathematical Sciences Department, has been elected to a second term as president of the National Professional Science Master's Association, which represents more than 245 professional science master's programs offered by 115 U.S. colleges and universities.

Yan Wang, assistant professor of mechanical engineering, received the 2012 Young Investigator Award at the 16th International Meeting on Lithium Batteries, in Jeju, Korea.

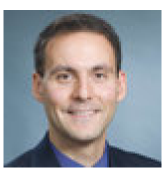


Pamela Weathers, professor of biology and biotechnology, received the 2012 Distinguished Service Award from the Society for In Vitro Biology.

Vance Wilson, associate teaching professor in

the School of Business, was elected to a two-year term as president of the Association for Information Systems (AIS) Special Interest Group on Information Technology in Healthcare, one of the largest AIS special interest groups.

Alexander Wyglinski, associate professor of electrical and computer engineering and



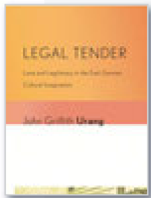
founder of the Wireless Innovation Laboratory, has been appointed to a two-year term as a distinguished lecturer by the Vehicular Technology Society of the Institute of Electrical and Electronics Engineers (IEEE).

NEW BOOKS by WPI Faculty

Leadership Craft, Leadership Art

Steven S. Taylor
Palgrave Macmillan, 2011

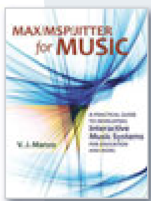
Taylor, associate professor of business, argues that leadership is a creative process, not unlike painting or acting. He explores the nature of creativity, with examples from the arts, and applies lessons learned to create a theoretical and practical understanding of the craft and art of leadership.



Legal Tender: Love and Legitimacy in the East German Cultural Imagination

John G. Urang
Cornell University Press, 2011

A 2011 *Choice* magazine "Outstanding Academic Title," this book by **Urang**, assistant professor of German, offers an eye-opening account of the ideological stakes of love stories in the culture of the German Democratic Republic, seemingly one of the most dour and disciplined of socialist states.



Max/MSP/Jitter for Music: A Practical Guide to Developing Interactive Music Systems for Education and More

V. J. Manzo
Oxford University Press, 2011

Manzo, assistant professor of music technology, provides a user-friendly introduction for music teachers at all levels to a powerful programming language that can be used to write custom software for musical interaction.

Principles of Security and Trust

Pierpaolo Degano and Joshua D. Guttman, editors
Springer, 2012

Co-edited by **Guttman**, professor of computer science, the book constitutes the refereed proceedings of the first International Conference on Principles of Security and Trust, which Guttman co-organized. The papers cover such topics as the foundations of security, authentication, and privacy and anonymity.

Faculty Achievements

STEM Education Pioneer Honored at the White House

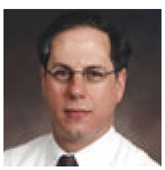
Chrysanthe Demetry, associate professor of mechanical engineering and director of the Morgan Center for Teaching and Learning, accepted the Presidential Award for Excellence in Science, Mathematics, and Engineering Mentoring at a White House ceremony in 2011; the award was for Camp Reach, a summer enrichment program for seventh grade girls that she co-founded in 1997. Also in 2011, she became the fourth WPI faculty member to be named Professor of the Year for Massachusetts by the Carnegie Foundation for the Advancement of Teaching and the Council for the Advancement and Support of Education.

Conference Organizers

Joel Brattin professor of literature and authority on Charles Dickens, served as academic advisor for the exhibit "Dickens and Massachusetts: A Tale of Power and Transformation," installed in the Lowell National Historic Park. WPI's Robert D. Fellman Dickens Collection, which Brattin directs, was an institutional partner in the exhibit, part of a global commemoration of the author's 200th birthday.

Mark Claypool, professor of computer science and director of the Interactive Media and Game Development program, was the general chair for the 2012 ACM (Association for Computing Machinery) Multimedia Systems Conference in Chapel Hill, N.C.

Michael Gennert, professor of computer science, and **Taskin Padir**, assistant professor of electrical and computer engineering, co-chaired the technical program for the 4th IEEE International Conference on Technologies for Practical Robotics Applications in April 2012.



Wesley Mott, professor of literature, recently completed an unprecedented second term as president of the Ralph Waldo Emerson Society, which, with the Nathaniel Hawthorne Society and the Poe Studies Association, organized the international conference Conversazioni in Italia: Emerson, Hawthorne, and Poe, in Florence, Italy, in June 2012.

Kaveh Pahlavan, professor of electrical and computer engineering, was general chair of the 2011 IEEE International Symposium on Personal, Indoor, and Mobile Radio Communications in Toronto and of the 3rd Invitational Workshop on Opportunistic RF Localization for Next Generation Wireless Devices held in New Orleans in May 2012.

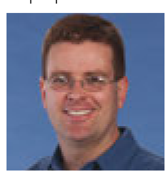
Elke Rundensteiner, professor of computer science, served as sole program chair for the 15th International Conference on Extending Database Technology, in Berlin, Germany, in March 2012.

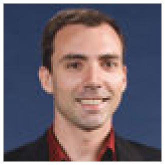
John Sanbonmatsu, associate professor of philosophy, organized a symposium titled "The Future of Critical Animal Studies" as part of the annual Minding Animals Conference, in Utrecht, the Netherlands, in July 2012.

Albert Simeoni, associate professor of fire protection engineering, was on the organizing committee of the 2012 Mathematical and Physical Modeling of the Dangerous Natural Phenomena and Technogenic Accidents Conference, in Tomsk, Russia. He is also helping organize the 4th Fire Behavior and Fuels Conference. Co-organized by International Association of Wildland Fire and the International Association for Fire Safety Science, it will be held in the United States and Russia in 2013.

Best Paper Awards

A paper co-authored by **Shawn Burdette**, assistant professor of chemistry and biochemistry, and Dhammika Bandara, a 2011 PhD recipient, was featured on the back cover of *Chemical Society Reviews* (Issue 5, 2012).

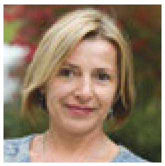




Stephen Nestinger, assistant professor of mechanical engineering, and PhD student Mahdi Agheli received the Best Paper in Theory award at the 8th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications, in Suzhou, China, in July 2012. The paper was titled "Study of the Foot Force Stability Margin for Multi-legged/Wheeled Robots Under Dynamic Situations."

Editorial Honors

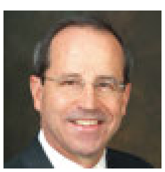
Tanja Dominko, associate professor of biology and biotechnology, has been named to the editorial boards for two journals, *Disruptive Science and Technology* and *DNA and Cell Biology*.



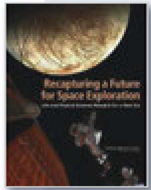
Christopher Brown, professor of mechanical engineering, and Torbjorn Bergstrom, operations manager for WPI's manufacturing laboratories, edited a special issue of the journal *Scanning* titled "Diverse Applications of Surface Metrology III." The papers were drawn from the 3rd International Conference on Surface Metrology, held in Annecy, France, in 2012.

David Brown, professor of computer science, completed a 10-year run as editor of the journal *Artificial Intelligence for Engineering Design, Analysis, and Manufacturing* in 2011. He has been appointed to the steering advisory board for the new *International Journal of Design Creativity and Innovation*, which will debut in 2013.

David DiBiasio, associate professor and head of the Department of Chemical Engineering, has been named to the editorial board of the journal *Chemical Engineering Education*.



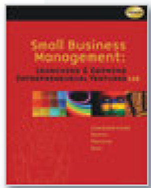
NEW BOOKS by WPI Faculty



Recapturing a Future for Space Exploration: Life and Physical Sciences Research for a New Era

Nikolaos Gatsonis and the members of the National Research Council Committee for the Decadal Survey on Biological and Physical Sciences in Space
National Academies Press, 2011

Gatsonis, professor of mechanical engineering and director of WPI's Aerospace Engineering Program, was a member of the committee that conducted this review, which expressed deep concern about the state of NASA's life and physical sciences research, and optimism about achieving the next significant phase of human space exploration.



Small Business Management: Launching and Growing Entrepreneurial Ventures, 16th Edition

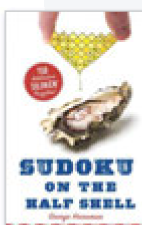
Justin G. Longenecker, J. William Petty, Leslie E. Palich, and Frank Hoy
Cengage, 2012

Co-authored by Hoy, Paul Beswick Professor of Entrepreneurship and Innovation, this popular textbook covers the fundamentals of business management with an emphasis on how to start a business as well as how to manage, grow, and harvest one.

Software Receiver Design: Build Your Own Digital Communication System in Five Easy Steps

C. Richard Johnson Jr., William A. Sethares, and Andrew G. Klein
Cambridge University Press, 2011

Through this step-by-step guide, co-authored by Klein, assistant professor of electrical and computer engineering, readers learn about wireless communications and software radio by building a complete digital radio that includes every element of a typical, real-world communication system.



Sudoku on the Half Shell: 150 Addictive Sujiken Puzzles

George Heineman
Sterling Publishing, 2011

Heineman, associate professor of computer science, sliced the popular Sudoku puzzle in half along the diagonal to create a new puzzle, which he calls Sujiken. The book contains 150 puzzles in five levels of difficulty.

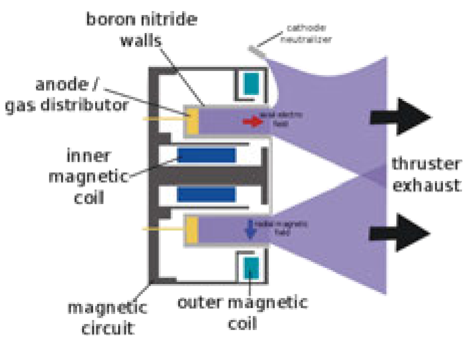
Pulling Knowledge Out of Thin Air

By Amy Crawford

The stainless steel cylinder in the basement of Higgins Laboratories is big enough for two adults to climb inside. Surrounded by industrial-strength pumps and blowers, it resembles a high-tech furnace. But it is actually the best tool researchers at WPI have for simulating outer space right here on Earth.

"It's a unique facility," says John Blandino, associate professor of mechanical and aerospace engineering, who came to WPI a decade ago from NASA's Jet Propulsion Laboratory in California. "It opens up a whole range of possibilities."

As Blandino explains how the chamber works, Zachary Taillefer, a PhD student in mechanical engineering, flips a switch to start a mechanical pump that will begin the process of removing the air. The machine whirs and the numbers on the readout fall from 790 torr (a little over one atmosphere of pressure) to 8 torr within just a few minutes. Then a second pump kicks in, and the pressure within the chamber falls even lower. Once Taillefer is sure there are no leaks, he can turn on the third pump, called a cryopump, which uses temperatures close to absolute zero to freeze out most of the remaining gas molecules.



"We get down to about 10^{-7} torr, or less than a billionth of an atmosphere," Blandino says.

While it may not look much like the far reaches of space, the vacuum chamber is a vital tool for Blandino's current research, which seeks to improve the durability of the cathodes used in electric propulsion systems designed for spacecraft.

In contrast to explosive chemical rockets, electric propulsion systems use streams of electrically charged particles to create thrust. They have higher exhaust velocities than chemical rockets, and can therefore deliver a heavier payload for a given mass of propellant. But they generate far less thrust, and they only work in a near vacuum, so they can't be used to propel spacecraft into Earth orbit. They are typically used for delicate operations, such as keeping satellites in geosynchronous orbit, and for deep space missions that require thrusters to function for a long time. "It takes you longer to get there," Blandino says, "but you use a lot less fuel along the way."

The most commonly used electric thrusters rely on hollow cathodes to generate electrons, which in a vacuum help ionize gaseous fuel into plasma. Cathodes also neutralize the stream of positive ions that the thruster emits, so the spacecraft does not become too negatively charged. But NASA has found that after years of use—the mission timeframe for spacecraft such as Dawn, which is currently exploring the asteroid belt—these cathodes wear out under the bombardment of countless energetic ions, a phenomenon scientists call "sputtering."

"Sputtering happens when an ion hits the surface with enough energy to knock out some of the material," Blandino explains. "So over time, the ions will erode part of the cathodes completely away and they'll fail."

Inside the vacuum chamber, Blandino and Taillefer have set up a cathode on loan from NASA's Glenn

PhD student Zachary Taillefer, left, and John Blandino work inside the vacuum chamber in WPI's aerospace engineering laboratories, preparing a test of an electric thruster, like the one illustrated on page 40. They are trying to find ways to extend the life of cathodes used in spacrcraft electric propulsion systems.

Research Center. To understand how the cathode might wear out, they use a tiny probe to measure the properties of the plasma that the thruster emits. Analysis of the data gathered from the experiments may help engineers create a more durable cathode, or identify more optimal operating conditions, resulting in a more reliable thruster.

"As you look at more and more ambitious missions, to the outer planets, to comets and asteroids, you need to be looking at increasing reliability," Blandino says.

Bruce Pote directs an electric thruster program at Busek, an aerospace engineering company in Natick, Mass., that has worked with Blandino and Nikolaos Gatsonis, head of WPI's Aerospace Engineering Program, on federally funded research. Busek's thrusters have been installed on satellites launched by the U.S. Air Force, and the company has received research grants and contracts from NASA, which is interested in using electric thrusters for missions to asteroids and the outer planets, or possibly a round trip to Mars.

"It's almost what you would call an enabling feature of some of the work that they do," Pote says. "You just simply can't do those missions with a chemical rocket."

While Busek focuses on applied research and developing new products, Blandino and other WPI scientists conduct more basic research, what Pote calls the theoretical underpinnings of electric propulsion.

"It's a really nice relationship that we have," he says, adding that a side benefit to the partnership is helping train potential recruits, since nearly one in four Busek employees is a WPI graduate.

Taillefer, who stayed on for graduate work at WPI after completing his BS in aerospace engineering in 2011, spends much of his time these days depressurizing the vacuum chamber and analyzing data gathered from the cathode. While he might be working in a basement, he knows his research could be important for the future of space exploration.

"Electric propulsion in general will be the link to longer duration missions," he says. "I'm glad to be making a small contribution to that."

It is a contribution being pulled, quite literally, out of thin air. ■

WPI

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