The faculty, staff and students of the UW-Madison Department of Electrical and Computer Engineering continue to push boundaries and lead the nation in research, education and technological innovations that address our society’s critical needs.

Faculty and their graduate students are identifying how to make the electrical power grid smart and adaptive to the intermittent supply of solar and wind energy, predicting incredibly rare events that could cause a computer hard drive to fail, and developing methods to manage and sort through massive “big data” sets that continue to grow in an age of ever-expanding mountains of information.

But in addition to innovating in the lab, our faculty continue to innovate in the classroom: 21 of our courses have been adapted to online and blended formats, providing students with unprecedented flexibility to learn at their own pace while simultaneously freeing up class time for one-on-one instruction and coaching through difficult problems and concepts. Small, self-contained lab kits and student-built circuit boards have made it possible to give students hands-on experience with electrical and computer engineering concepts earlier than ever before. And unique design experiences—ranging from developing sustainable, high-yield agricultural and domestic living systems to real-world products for industrial partners like Microsoft—give our students the direct experience they need to succeed as working engineers.

Our alumni and corporate partners play a critical role in providing that experience to our students, donating time and resources that sustain our students’ exceptional education while enabling research that tackles national and global grand challenges.

On behalf of our students and faculty, I thank you for your continued support and pledge that we will continue our commitment to the tradition of excellence that your UW-Madison’s ECE department has long been known for.

On Wisconsin!
“The idea is that we’d be like consultants,” says Venkataramanan. “Electrical engineering has applications in so many different areas, that the potential for different projects here is pretty huge.” That freedom led the students to some interesting places. Calvin Cherry, an electrical engineering senior returning in the fall as a graduate student, often finds his email inbox is a clearinghouse for interesting community problems: a monitoring device for use of “little free libraries,” or a small wind turbine for the roof of a veteran’s home. “They just keep coming in,” says Venkataramanan.

While many don’t fit into established courses, the professor knows they could offer interested students a challenge to think outside the traditional boundaries of electrical and computer engineering. So Venkataramanan recruited eight students—freshmen all the way up to fifth-year seniors—looking for hands-on engineering opportunities, and gave them a chance to tackle projects of their choosing, with an emphasis on design related to sustainable living.

That allows the tank to be used to grow food—in this case, four kinds of lettuce, dill, swiss chard, two kinds of basil and marigold. “It’s mainly a way to grow vegetables, and fish are just along for the ride, helping us out in doing that.” Growing a garden indoors under artificial lighting can be complex; Tryon-Petith and Graeber spend a lot of time monitoring nitrate levels, pH and water levels at the aquaponics display in the lobby of the Wisconsin Institutes for Discovery. But in the design group, Tryon-Petith recruited freshmen Patrick Stoddard and Alexander Klintworth, electrical engineering majors who worked to design a lighting control system using a Raspberry Pi, a cheap hobbyist computer that could be embedded in future aquaponic systems. Tryon-Petith says that remote lighting control—and eventually, remote measurements of the overall health of the system—will make broader rollout of aquaponics displays to future sites like the Madison Children’s Museum much easier to manage. “Right now, it’s mostly through human observation and maintenance, but as we move forward, it would be cool to make everyone’s life easier with automated monitoring networks,” he says. Someday, the team envisions multiple aquaponics units across Madison, linked together in a sort of “living network” that can talk to one another over the web.

Miles and his team share an infectious enthusiasm for sustainable engineering, a spirit that flows from students who get to work on a personally meaningful design project so early in their engineering careers. “Being able to integrate myself into an environment where I’m immersed in sustainable engineering has done loads to help me learn more from the experience,” says Tryon-Petith. Their experience reflects everything Venkataramanan had hoped for: an early chance to work on real problems that require interdisciplinary thinking. “We’re making as close to a closed-loop system as we can,” says Tryon-Petith. “It’s mainly a way to grow vegetables, and fish are just along for the ride, helping us out in doing that.”

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Ideas in Action

From dorm room to delivery: Students launch successful businesses

Like any engineer worth his or her salt, Eric Martell can identify and analyze a problem when he sees it. Particularly when it’s sandwich-related.

One fateful lunch hour, a driver for Silver Mine Subs told Martell he’d save time and money by calling in orders instead of ordering through a clunky (and expensive) third-party ordering website.

“I just thought ‘It’s 2010. There has to be a better way to do this,’” says Martell, a 2012 computer engineering and computer science alumnus. “Why would I have to call in an order?”

Three years later, EatStreet—the food ordering website Martell and former roommate and business partner Matt Howard created as an answer to the hungry student’s dilemma—is being used by more than 1,000 restaurants in 23 cities.

The site offers easy-to-use ordering tools and websites for locally owned campus staples in need of a turnkey web presence. “In a lot of ways, I think that we kind of keep money in our communities, wherever we are,” says Martell.

In its early stages, EatStreet was a project being pitched to judges in the G. Steven Burrill Business Plan Competition and NEST software competition, two of many UW-Madison opportunities for student entrepreneurs looking to test their innovative business ideas.

Even though they didn’t win in Burrill the first time, Martell says the feedback he and his partner received as part of the campus entrepreneurship community provided a first push toward realizing their business. “The judges and industry experts that were brought in offered us some really helpful advice; they’re advisors and partners that we continue to work with,” says Martell.

Another Burrill winner-turned-Madison-startup, C-Motive Technologies, seeks to shrink electric motors and build them from entirely sustainable materials, replacing steel and copper with aluminum plates to establish electric fields over an air gap. It’s a design conceived by four engineering students—electrical and computer PhD students Dan Ludois, Justin Reed and Micah Erickson as well as mechanical engineer Kyle Hanson—who leveraged the university community’s fertile ground for startups to grow a side project into a full-fledged business.

“Within ECE, the most instrumental individuals were our advisors, Professor Giri Venkataramanan and Grainger Professor of Power Electronics and Electrical Machines Tom Jahns,” says Reed, president and CEO of C-Motive and a current ECE graduate student. “From the very beginning, they have been very supportive of our venture, and that’s incredibly valuable when your time is spread so thin between your degree and your startup.”

Resources for early-stage companies like these abound on the UW-Madison campus. When the time came to protect its invention, the C-Motive team turned to the Wisconsin Alumni Research Foundation, which patented the design on its behalf. And when they needed to get the business down on paper, both C-Motive and EatStreet leveraged the Law & Entrepreneurship Clinic within the UW Law School as an invaluable legal resource. “For the first year or so, we didn’t have to pay a cent in lawyers’ fees,” says Martell.

Chris Beley says one benefit from participating in university competitions was learning about the resources that aren’t always advertised. The 2012 computer engineering and electrical engineering alumnus won the 2012 Qualcomm Wireless Innovation Prize for his data management system, Flextory.

Beley says staying connected with innovation competition organizers and campus resources helped him network with Madison-area mentors, including Merlin Mentors and Capital Entrepreneurs. “All these people are willing to help if you just ask,” he says.

Consultants at places such as Hybrid Zone X on campus, Gener8tor in Milwaukee and the Wisconsin Entrepreneurship Network (a partnership between UW Extension and the Wisconsin Economic Development Corporation) offer the final bits of wisdom engineers often need to launch a concept into the marketplace. “Cheryl Vickroy of the Wisconsin Entrepreneurs’ Network helped us shift focus from the technology itself to the business surrounding the technology,” says Reed. “Having been so focused on technology for so many years, making this change of mindset was quite challenging for us.”

Tangible resources aside, student entrepreneurs unanimously agree on the biggest asset available to electrical and computer engineers graduating from UW-Madison: other ECE alumni. “The prestige that goes along with the UW-Madison College of Engineering goes a long way, in my experience,” says Martell. “I’ve gone out to Silicon Valley and New York to raise money, and no one will close the door on a UW engineering grad. That’s a fantastic credential that the university continues to create.”

EatStreet founders Eric Martell (left) and Matt Howard at their office space in downtown Madison.
Computers serve as powerful tools for categorizing, displaying and searching data. They’re tools we continually upgrade to improve processing power, both locally and via the cloud. But computers are simply the medium for big data. “We really need people to interact with the machines to make them work well,” says McFarland-Bascom Professor Rob Nowak. “You can’t turn over a ton of raw data and just let the machine figure it out.”

Unlike computers, people cannot be upgraded. They work at a finite speed and at rising costs, so Nowak is improving interactive systems that can optimize the performance of both humans and machines tackling big data problems together.

Typically, human experts—people who categorize data—will receive a large, random dataset to label. The computer then looks at those labels to build a basis of comparison for labeling new data in the future. However, Nowak suggests the model should be flipped. “Rather than asking a person to label a random set of examples, the machine gets the set of examples, then asks a human for further classification of a specific set of data that it might find confusing,” says Nowak.

With support from the National Science Foundation and Air Force Office of Scientific Research, Nowak has been exploring an active learning model, in which the machine receives all the data up front. Initially, with no labels, the machine makes very poor predictions, improving as a human expert supplies labels for some of the data. For example, if a new data point is similar to one that a human has labeled, the machine can predict that this point should probably have the same label. The machine can also use the similarities and labels to quantify its confidence in the predictions it makes. And when the confidence for a certain prediction is low, it asks the human expert for advice.

To explore these sorts of human-machine interactions, Nowak and his student Kevin Jamieson have applied the idea to a technology that’s a natural fit in Wisconsin—an iOS app that can predict which craft beers a user will prefer. In this case, the similarities between data points—beers—are based on flavor, color, taste and other characteristics defined by the spectrum of terms used to describe beers in reviews on Ratebeer.com. Using that existing data, the researchers’ algorithm can find the closest match for beers the user might enjoy, in much the same way that a bartender might: presenting the user with two beer choices, then using the user’s preference between the two to hone in on a specific point in the “beer space.”

“Basically, if I already know that you prefer Spotted Cow to Guinness, then I’m probably not going to ask you to compare Spotted Cow to some other stout,” says Nowak. “Because there are relationships between every beer, I don’t have to ask you for every comparison.”

These sorts of “this-or-that” determinations tend to be more stable than categorizations based on ranking scales or other more subjective measures, which are more vulnerable to psychological priming effects and can change over time. Finer point comparisons offer the machine more reliable data to improve its categorization and prediction over time.

And most importantly, it allows machines to process data much, much faster, since they require less human help to categorize the data. For example, pulling from thousands of possible beers, Nowak says the app can make a personalized beer recommendation based on only 10 to 20 comparisons. That sort of efficiency becomes important as data sets get bigger and human labor can’t keep up. In a collaboration with UW-Madison psychology colleagues, Nowak has applied his model to the relative emotionality of words; without the active machine learning model, learning the similarities between 400 words could require as many as 30 million total comparisons. “Even if you could recruit a cohort of 1,000 undergraduates, that would still be 30,000 trials apiece,” he says.

Understanding human judgments about similarity of word meanings is a fundamental challenge in cognitive science and absolutely crucial in order to make machines capable of understanding the subtleties of human language. Optimizing ways to apply machines and people toward problems like that could be key to making big data analysis economical and effective in many more situations.

“There’s no research to be done on the infrastructure side,” he says. “We have big data infrastructure. What we don’t understand is how to optimally yoke humans and machines together in big data analyses.”
Nick Hitchon: Predicting the unpredictable

There’s an elegance in math that can describe the churning heat at the cores of distant stars, the reactions within experimental fusion reactors, and the likelihood of failure in a computer’s hard drive.

Each of those scenarios relies on computationally analyzing kinetic equations to predict—within a reasonable degree of certainty—the unexpected places particles can end up over time.

“It’s a detailed description of where a lot of particles are and how fast they’re going,” says Professor Nick Hitchon, who specializes in computational modeling of charged particle behavior. “For instance, in fusion plasma reactions, kinetic equations allow predictions of where particles could end up with a distribution of energies.”

While fusion power might not be in the mainstream for several decades, Hitchon has been working with electronics manufacturer Hitachi to apply kinetic equation modeling to hard disk drives—something in every computer on the planet. Working on next-generation computer hard drives, Hitachi engineers have built devices with billions of tiny magnets, all flipping tiny sectors on the disk between the 1s and 0s that comprise files, photos and messages stored on each drive, all within an incredibly compact space. “It’s pretty staggering technology because the clearance between the head that’s writing and reading and the spinning disk drive is a matter of a few atoms, spinning at an incredible clip,” says Hitchon.

That means drives with unparalleled storage capacity and speed—given a reliable prediction of how often a drive might fail due to an erratic magnetic field. Studying whether drive can store data for 10 years or more while relying on that incredible design technology around it. “It’s an incredibly slow process compared to the timescale it’s bopping around on,” says Hitchon.

It all boils down to outliers beyond the standard set of mathematical possibilities. Author and scholar Nassim Nicholas Taleb describes these moments as “black swans.”

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It all boils down to outliers beyond the standard set of mathematical possibilities. Author and scholar Nassim Nicholas Taleb describes these moments as “black swan events;” moments that are inherently unpredictable, but need to be accounted for and explained somehow. “What I spend my life doing, in a way, is calculating the probabilities of black swarms,” says Hitchon.

The sudden failure of one tiny magnet among billions in a hard drive represents just one nearly impossible-to-know scenario that, nonetheless, needs to be considered so that engineers can design technology around it. “It’s a process of trying to think open-endedly about what do we need to put in to really get an answer,” he says.

Chris DeMarco: A nimbler, more responsive power grid

Frontlines, people focus on the “smart” end uses of electric power—for example, devices that intelligently use power when it will cost less for the user, or meters that track real-time consumer electricity usage. But for Chris DeMarco, it’s all about the grid.

“End-consumer concepts have good potential,” says DeMarco, the Grainger Professor of Power Engineering. “But I think the bigger impact in being able to use renewable energy sources and ultimately reduce environmental impact is happening at the grid scale.”

Working as part of the Power Systems Engineering Research Center, with support from the U.S. Department of Energy, DeMarco seeks to increase the viability of renewable energy sources as part of the overall power infrastructure in the United States. He aims to make intelligent use of data gathered via phasor measurement units—remote electrical sensors installed, with federal funding, throughout the power grid over the past few years.

Those sensors paint a real-time picture of how changes in energy consumption and production are affecting the grid’s stability, which could allow for a more adaptive power grid that dynamically shifts between types of energy sources as they are needed. Allowing real-time switching among stored energy and less consistent sources of power, like solar and wind, could give renewable energy a more prominent role in the overall picture of where electricity comes from when we plug into an outlet. “What we recognized was that often, the amount of storage you need can be very modest, provided that it’s complementing the rapid variation in production from wind and photovoltaic energy caused by changes in weather,” says DeMarco.

Stabilizing the load capacity of renewable energy via smart controls and energy storage could push renewable energy usage from 20- to 30-percent market penetration closer to 50 percent, according to DeMarco.

Smarter, more adaptive power grids also will be instrumental for emerging and future technologies—such as electric cars—we’ll want to be able to plug in. Engineers like DeMarco are working toward a grid that can accommodate the enormous power demands of such devices; in the meantime, consumers will have to adapt to the fact that the grid also is a dynamic system and on-demand charging might cause undue strain on the current infrastructure. That’s a problem vehicle engineers likely will work around as devices improve, and the grid itself becomes smarter: “schedulers.”

“With plug-in electrics, you have a resource where you have this flexibility in time—by being able to control the moment-by-moment consumption, but still achieve a certain amount of charging over several hours—that gives you a lot of attractive features that we hope can help complement control of the grid,” says DeMarco. “While you can pump 20 gallons into your tank over a few minutes, you wouldn’t want to be around the equivalent transfer of electrical energy performed that fast.”
Throwing them in the deep end:
How student-built circuit boards improve freshmen education

Final project time at the end of a semester doesn’t tend to be punctuated with a lot of fun and games for engineering students, but ECE 210: Introductory Experience in Electrical Engineering bucks that trend. Battleship? Tic-Tac-Toe? Simon Says? Students play all the classics in the final days of the course, provided they’ve learned enough about writing programs for the ARM-powered circuit boards they’ve built and tested over the course of the past semester.

“When we thought of this course, I never thought the students would be doing the kinds of projects they’re doing now,” says Professor Giri Venkataramanan, instructor of the new course. “I had no idea they’d be building games around the boards, particularly games that they can play against each other.”

The idea? To give young engineering students an early chance to experience software and hardware engineering. With input from Venkataramanan and Faculty Associate Mark Allie, graduate student Joseph Bomber designed a relatively inexpensive “pre-authenticated” model for a circuit board with wireless communications, PWM LED lights, dip switches, push buttons, a battery charger, a small display and other components, all powered by a Cortex-M3 ARM processor donated by Texas Instruments. Each week, students follow that design as a model, soldering in and testing new components on the board, learning electrical concepts as they go. “It’s a very quickly paced, ‘here’s the water, now jump in’ approach. We show them the capabilities of the board, just to give them a feel for these components and what you can do with them,” says Venkataramanan.

Ultimately, the course shifts into writing software that takes advantage of the features students have been adding, with the freedom to pursue whatever they like — but the safety of having help to diagnose their missteps along the way. “They learn a lot about how you even go about writing a program. Do you write it block by block, or all at once? How do you test things? Where are natural places to test?” says Bomber. “Even now they’re still surprising me.”

That tactile, hands-on learning approach is something the hobbyist community has embraced with tools like Arduino and the Raspberry Pi, but ECE 210 takes young engineers’ drive to run before they walk and channels that energy into a platform robust and complex enough to allow them to build upon what they learn for years to come.

“If you’re looking to build something at a larger scale, you’re going to be looking at something like the ARM platform,” says Bomber. “This actually has an ARM processor.”

Apart from games, students have built wireless car trackers and pre-programmed wireless messaging devices, as well as ideas the boards technically aren’t even capable of. “The students wanted to see if they could charge an iPhone with it. You couldn’t, because it doesn’t have something that you need, but they decided to hack it anyway,” says Venkataramanan. “A couple of students figured it out, just a few weeks into the course.”

In a conference room in Engineering Hall, five seniors prepare to demo their data visualization application on a Microsoft Surface for a small audience: their professor and a webcam connected to an entire team of Microsoft engineers in Fargo, North Dakota.

Thankfully — since the students have, for the past semester, participated in regular virtual meetings with the team, comparing notes and swapping ideas for their senior design project — no one breaks a sweat.

“The Microsoft goal is to try to involve undergraduates in extensive design projects related to their products,” says Professor Parmesh Ramanathan, who leads the senior design course that for two semesters has brought Microsoft engineers and students together to collaborate.

UW-Madison serves as the latest in a series of university partnerships the software giant has formed to establish early connections between young engineers and the software industry. “Students benefit from having access to individuals who actually do software engineering as a vocation,” says Jeff Hensel, principal engineering manager for Microsoft.

(Continued on next page)
Real-world software (continued)

“They can ask questions, get a better understanding of how an entire project comes together over time, and how the different aspects of software development need to work together.”

Projects developed through the partnership can span software for consumers to enterprise and business intelligence, the area that student teams for the past two semesters have opted to pursue. Using a set of financial data provided by Microsoft and underlying technology like the Azure cloud computing platform, students worked to develop backend server software and a tablet interface that a financial analyst can use to easily generate charts and graphs of business performance over time. “They use the financial data as a representation, but the goal was to do this for any kind of data, take it at a very high level, and be able to drill down into details and view the same data from many different perspectives,” says Ramanathan.

But more broadly, Ramanathan says students learn about real-world software engineering while still within a classroom. “These are good experiences for them to have: to set milestones, and to work to achieve them as a team,” he says. “They really had to work hard and carefully plan out their time each week to get this accomplished.”

The final software design stands as a visible product for business consumers—a nice resume-booster for students, particularly since they retain intellectual property rights for what they’ve developed.

Computing and Information Technology department chair and professor John Booske notes that “the software his team envisioned, coupled with the generous access to Microsoft rights for what they’ve developed. “The software his team envisioned, coupled with the generous access to Microsoft

students working in research areas vital to material science and mathematics. Palfhaman was selected for his work designing reliable, power-efficient computer systems, particularly for the realm of web servers, where the scale involved makes reliability and power savings a paramount concern.

Computer engineering PhD student Kevin Jamieson received Sandia National Laboratories/UW-Madison Excellence in Engineering Graduate Research Fellowships for 2013-14. The program's goal is to encourage innovation in science-based, multidisciplinary research through support of outstanding doctoral candidates in engineering.

Jamieson's research focuses on material science and mathematics. His work involves creating automatic classifiers. These are used to label data, such as sonar data, to design comparison queries, using sonar data to analyze material that could lead to lower cost solar panels and image sensor arrays.

Highlighted on the cover of Advanced Functional Materials, Professor Zhenqiang Ma and his students put forth a concept for combining p-type and n-type organic semiconductors on a flexible substrate, forming one multifunctional material that could lead to lower cost solar panels and image sensor arrays.

The cover of the December 2012 issue of the Journal of Applied Physics featured a new study on the interaction of vacuum ultraviolet radiation with low energy electrons. The study, conducted by Harvey Spangler of the University of Michigan College of Engineering, was honored with the 2013 Bode Prize, which recognizes contributions to control systems science and engineering.

The IEEE Control Systems Society honored Professor B. Ross Barmish with his 2013 Bode Prize, which recognizes contributions to control systems science and engineering.

The UW-Madison Graduate School selected Hongrui Jiang and Zhenqiang Ma as Distinguished Vilas Professors in 2013. In addition, Jiang, Ma and Associate Professor Suman Banerjee were selected as Vilas Associates, who receive support to advance new and ongoing projects.

ACADEMIC EXCELLENCE

With 10,416 citations, Computational Electrodynamics: The Finite-Difference Time-Domain Method, a text co-authored by Philip Dunham Reed Professor Susan Hagnes (right) and Northwestern University Professor of Electrical and Computer Science Allen Taftove, ranks as the seventh most-cited physics publication in Google Scholar. Now in its third edition, the 2005 book relates the application of finite-difference time-domain computational modeling of the interactions between electromagnetic waves and physical objects, work that has broad applications in engineering and physics.

Suman Banerjee, Professor of Electrical and Computer Engineering, was honored with the 2013 Bode Prize, which recognizes contributions to control systems science and engineering. Banerjee's research focuses on multiple aspects of computing, such as the design and implementation of software systems for consumer and enterprise environments. His work has led to the development of new algorithms and techniques for improving the efficiency and scalability of software systems.

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