

**E** **EQuad News**

Winter 2015  
Volume 26, Number 2

**IDEA**

to

**IMPACT**



**PRINCETON**

School of Engineering  
and Applied Science

## ENGINEERING AND ENTREPRENEURSHIP

*The value of an idea lies in the using of it.*

–Thomas Alva Edison

**What is the connection between engineering and entrepreneurship?** On the surface, it may seem to be about inventing devices or Internet applications that burst onto the tech scene, the epitome being the select few that lead to companies worth billions of dollars. Those important accomplishments often require tremendous engineering talent. But I'd like to point to a deeper connection.

First, let us consider the nature of engineering. At Princeton, we emphasize engineering as a tool for making a positive difference in the world. It is a hub where fundamental knowledge, especially scientific insight, meets a societal need in all its messiness and complexity. We build teams across disciplines, solve problems, implement solutions – and repeat. What better vehicle for instilling and practicing that ethic than in starting a business or a social service organization?

That brings us to what we mean by entrepreneurship. Ed Zschau A.B. '61, who taught “High-Tech Entrepreneurship” at Princeton for 15 years, emphasized to his hundreds of students that entrepreneurship is not so much about starting companies as it is a way of life – the skills, audacity and drive to set one's own path and make a difference. If there is a theme of the many entrepreneurship courses now offered through the Keller Center, it is how to start with an idea and – within the constraints of time, resources and physical reality that engineers know so well – build something that has a positive impact.

Even the general news stories on the next few pages, though not about starting companies, demonstrate the variety of ways engineers take an entrepreneurial approach to problems arising in human health, physics and computer networks. How do you exhibit entrepreneurship in your life? Please join us on Facebook, Twitter and LinkedIn and share your stories.

Warmest regards,

**H. Vincent Poor Ph.D. '77**  
Dean and Michael Henry  
Strater University Professor  
of Electrical Engineering

(Photo by David Kelly Crow)

DEAN'S  
MESSAGE **E**

EQuad News  
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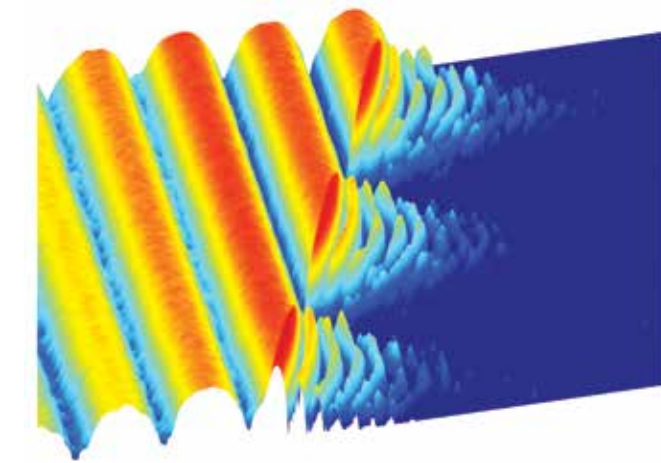
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### ‘SOLID’ LIGHT COULD COMPUTE PREVIOUSLY UNSOLVABLE PROBLEMS

Researchers at Princeton University have begun crystallizing light as part of an effort to answer fundamental questions about the physics of matter.

The researchers are not shining light through crystal – they are transforming light into crystal. In work that could lead to exotic materials such as room-temperature superconductors, the researchers have locked together photons, the basic element of light, so that they become fixed in place.

“It's something that we have never seen before,” said Andrew Houck BSE '00, an associate professor of electrical engineering and one of the researchers. “This is a new behavior for light.”

The results, reported Sept. 8 in the journal *Physical Review X*, raise intriguing possibilities for a variety of future materials. But the researchers also intend to use the method to address questions about the fundamental study of matter, a field called condensed matter physics.

“We are interested in exploring – and ultimately controlling and directing – the flow of energy at the atomic level,” said Hakan Türeci, an assistant professor of electrical engineering and a member of the research team. “The goal is to better understand current materials and processes and to evaluate materials that we cannot yet create.”

To build their machine, the researchers created a structure made of superconducting

materials that contains 100 billion atoms engineered to act as a single “artificial atom.” They placed the artificial atom close to a superconducting wire containing photons.

By the rules of quantum mechanics, the photons on the wire inherit some of the properties of the artificial atom – in a sense linking them. Normally photons do not interact with each other, but in this system the researchers are able to create new behavior in which the photons begin to interact in some ways like particles.

“We have used this blending together of the photons and the atom to artificially devise strong interactions among the photons,” said Darius Sadri, a postdoctoral researcher and one of the authors. “These interactions then lead to completely new collective behavior for light – akin to the phases of matter, like liquids and crystals, studied in condensed matter physics.”

Türeci said that scientists have explored the nature of light for centuries, discovering that sometimes light behaves like a wave and other times like a particle. In the lab at Princeton, the researchers have engineered a new behavior.

“Here we set up a situation where light effectively behaves like a particle in the sense that two photons can interact very strongly,” Türeci said. “In one mode of operation, light sloshes back and forth like a liquid; in the other, it freezes.” –John Sullivan

Oscillations of photons create an image of frozen light. At first, photons in the experiment flow easily between two superconducting sites, producing the large waves shown at left. After a time, the scientists cause the light to “freeze,” trapping the photons in place. Fast oscillations on the right of the image are evidence of the new trapped behavior. (Image courtesy of Houck/Türeci groups)

## LASER DEVICE COULD END PIN PRICKS FOR DIABETICS



Princeton University researchers have developed a way to use a laser to measure people's blood sugar, and, with more work to shrink the laser system to a portable size, the technique could allow diabetics to check their condition without pricking themselves to draw blood.

of many diabetes sufferers who depend on frequent blood glucose monitoring.”

The researchers measure blood sugar by directing a specialized laser at a person's palm. The laser passes through the skin cells, without causing damage, and is partially absorbed by the sugar molecules in the patient's body. The researchers use the amount of absorption to measure the level of blood sugar.

Sabbir Liakat, one of the researchers, said the team was pleasantly surprised at the accuracy of the method. Glucose monitors are required to produce a blood-sugar reading within 20 percent of the patient's actual level; even an early version of the system met that standard. The current version is 84 percent accurate, Liakat said.

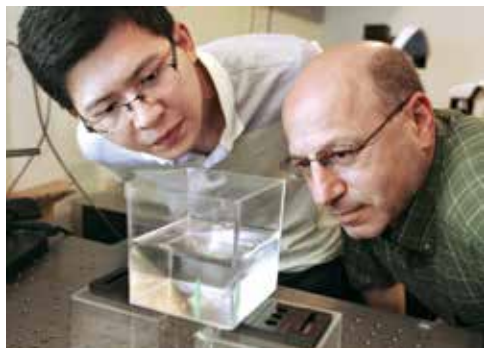
“It works now but we are still trying to improve it,” said Liakat, a graduate student in electrical engineering. **—JS**

“We are working hard to turn engineering solutions into useful tools for people to use in their daily lives,” said Claire Gmachl, the Eugene Higgins Professor of Electrical Engineering and the project's senior researcher.

“With this work we hope to improve the lives

A system developed by Princeton engineers could allow diabetics to check their blood sugar with a laser instead of pricking their skin. Members of the research team included, from left, Claire Gmachl, the Eugene Higgins Professor of Electrical Engineering; Kevin Bors, who graduated in 2013 with a degree in electrical engineering; and Sabbir Liakat, a graduate student in electrical engineering. (Photo by Frank Wojciechowski)

## BUBBLING DOWN: DISCOVERY SUGGESTS SURPRISING USES FOR COMMON BUBBLES



Anyone who has ever had a glass of fizzy soda knows that bubbles can throw tiny particles into the air. But in a finding with wide industrial applications, Princeton researchers have demonstrated that the bursting bubbles push some particles down into the liquid as well.

“It is well known that bursting bubbles produce aerosol droplets, so we were surprised, and

fascinated, to discover that when we covered the water with oil, the same process injected tiny oil droplets into the water,” said Howard Stone, the Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering and department chair.

The researchers used high-speed cameras and other experimental approaches to develop a detailed physical description of how bubbles

burst and how that affected the oil and water mix. The conclusions provide new insight into the mixture of non-soluble liquids – a process at the center of many fields from drug manufacturing to oil-spill cleanups.

During oil spills, for example, it is important to understand how the oil moves from the surface into deeper water. This has generally been attributed to wave action, but the researchers' findings indicate that even in calm seas oil can gradually filter down because of tiny bubbles.

Graduate student Jie Feng said the approach could play an important role in industrial mixing systems.

“This system offers an energy-efficient route to produce nanoparticles, with the potential to increase in scale, in a variety of fields such as drug delivery, food production and materials science,” he said. **—JS**

Graduate student Jie Feng (left) and Professor Howard Stone observe bubbles in a tank as part of research that led to the discovery of an unexpected ability of bubbles to disperse particles within a liquid. (Photo by Frank Wojciechowski)



Graduate student Peng Sun (left) and Professor Jennifer Rexford worked with Microsoft to develop software that greatly improves the management of complex computer networks. The software, called Statesman, has been deployed in major data centers. (Photo by Frank Wojciechowski)

## STATE OF THE NETWORK: PROJECT WITH MICROSOFT MANAGES COMPETING DEMANDS

Global computer networks are immensely beneficial to many users but they also can be immensely difficult for network administrators. Running a modern data network – with thousands of computers spread across a wide area – requires juggling myriad systems including power regulation, maintenance and traffic management, not to mention security.

To meet the needs of ever-expanding systems, researchers at Princeton and Microsoft have created an automated tool that manages the network's needs. Called Statesman, the new software acts like an air traffic controller for large computer networks: it constantly monitors the needs of the system and coordinates actions of other tools involved in maintenance and operations.

“Companies that run these large clouds have a scale problem,” said Jennifer Rexford BSE '91, the Gordon Y.S. Wu Professor in Engineering and one of the developers of Statesman. “The size of the networks keeps getting bigger and bigger.”

Working with the team at Microsoft's Azure network, Rexford and graduate student Peng Sun set out to create a network management system that is reliable, adaptable and requires little or no human intervention. In order to manage multiple tasks that are running independently – like power manage-

ment and network traffic – the team created three states in a network: an observed state; a proposed state; and a target state. The Statesman program maintains a current view of a network, which is the observed state, and also is responsible for updating the network to a desired target state.

When a subordinate system wants to make a change in the network – say a traffic management system wants to send data requests to a different group of servers on the network – it develops a proposed state and sends this to Statesman. Statesman compares the proposed state to changes proposed by other programs and uses a set of rules to determine whether the change can be allowed. If, for example, the traffic manager wanted to use servers that a power management system needed to take offline, the traffic request would be denied.

“We wanted a system that could manage very large-scale infrastructure automatically and handle conflict and safety issues on its own,” Sun said.

Statesman began operating in Microsoft data centers last October.

“It is not a prototype,” Sun said. “It was built for use from day one.” **—JS**

# IDEA to IMPACT

by Mung Chiang

**What is entrepreneurship “the Princeton way”? Twelve months ago, Provost David Lee Ph.D. '99 created the Princeton Entrepreneurship Advisory Committee (PEAC), a group of faculty, students, administrators and alumni with expertise in this area.**

We were asked to develop a vision for how the University can best support our student, faculty and alumni entrepreneurs in a way that is rooted in Princeton’s strengths as a liberal arts institution and as a leading research university.

The committee thinks of entrepreneurship as activities that “initiate transformative changes and challenge conventions through risk-taking actions using a relatively small amount of resources.” The PEAC members

view “entrepreneurship” not merely as an occupation, but instead as a mindset. We see the goals of entrepreneurial thinking taking place not only in founding startups, but also creating social entrepreneurship organizations, joining early-stage companies, or innovating within large corporations, governments or NGOs. The common thread is taking actions to make significant, positive changes by pushing, pivoting and persisting. ▶

Multiple organizations across campus have already initiated entrepreneurship programs in recent years. An example in the engineering school is the Keller Center, which recently created eLab, a summer accelerator for student startups. The Keller Center also offers many courses in entrepreneurship, all of which are heavily subscribed by hundreds of students in and outside of engineering, and is building a mentorship network to engage talents of innovation with our alumni and the local ecosystem.

Much more remains to be done in years to come. PEAC prepared recommendations along five dimensions: incubator spaces and programs to create dynamic hubs for entrepreneurs; multiple entrepreneurship funds for alumni, students and faculty; curricular and co-curricular programs for learning entrepreneurship by practicing it; policy updates and consistent branding; and effective mentorship through alumni and ecosystem connections.

Across the board, we believe that “Entrepreneurship the Princeton Way” will amplify what Princeton stands for: a broad-minded liberal arts education contributing to the common good and innovative research translating into societal impact. A common theme from the committee’s work is the idea that the University ought to focus not on just supporting the success of projects per se, but also on investing in the long-term entrepreneurial potential of our people. Providing outlets for entrepreneurial experiences can enhance our core mission – spurring creativity and innovation, while giving students opportunities to build the character and habits they need to take risks, follow their passion, and persist through the inevitable failures that are a necessary part of entrepreneurial activity.

Entrepreneurship is fundamentally about individuals who embrace uncertainty and bootstrap each step of the way. We realize the importance of building an ecosystem within our community of Princetonians, both on campus and beyond. We will draw upon the expertise of the experienced entrepreneurs among our famously loyal alumni to create an accessible network for our students, while they are here on campus and well after they leave.

The work of PEAC is itself entrepreneurial in nature. Creating an environment for entrepreneurship “the Princeton way” may have risks and will not be quick or easy. It is unlikely to go exactly as planned and will require experimentation and perseverance. But when properly executed, entrepreneurship at Princeton will expose our students to a different mode of thinking; enable those who choose to broaden their pathways toward serving the nation and all nations through entrepreneurship; and enhance Princeton’s ability to make a positive difference in the world through the creative energy of our faculty and students.

For more information on PEAC initiatives, visit the website at [www.princeton.edu/entrepreneurship](http://www.princeton.edu/entrepreneurship). **E**

*Photos by Victoria Sulewski*



*Mung Chiang (above) is the director of the Keller Center and the Arthur LeGrand Doty Professor of Electrical Engineering. He is also the director of the Program in Technology and Society.*

# STUDENT INITIATIVES DRIVE ENTREPRENEURIAL CULTURE

by Stacey Huang '16

Princeton seniors Vaidhy Murti (above left) and Michael Pinsky trace the beginning of a company they founded to a chance meeting at the Frist Campus Center and attribute their success in launching the venture to the Keller Center's eLab Summer Accelerator Program. (Photo by Victoria Sulewski)



**Vaidhy Murti and Michael Pinsky met freshman year when they sat down on adjacent couches in Frist Campus Center to watch a Yankees game.**

The two became fast friends, and this modest beginning gave way to the startup which is now Friendsy, a college-based social media site that is gaining traction among universities nationally.

"We got close quickly, but we realized things don't always happen this way," said Pinsky, a senior in psychology.

Murti and Pinsky, now roommates, found support for their budding company from the Keller Center's eLab Summer Accelerator, which provided a \$20,000 stipend and an office in the EQuad to help them develop their business.

Princeton might not be situated in Silicon Valley, but in recent years the University has come to offer an increasingly robust support system for entrepreneurial students.

The eLab accelerator is one example. In addition to a stipend, the 10-week program offers student teams coaching and support from veteran entrepreneurs. Murti, a senior

in computer science, said eLab helped the Friendsy team expand its working base from seven schools to 40 and its membership from 10,000 users to 23,000. "They did a very good job of catering to us, even though we were probably at a later stage than most teams," Murti said. "They allowed us to really use their resources and achieve what we've achieved so far."

Aside from formal programs such as eLab, students find an avenue for various levels of entrepreneurial pursuits through Princeton's student-run Entrepreneurship Club, or E-Club for short.

E-Club's events run throughout the year. For beginners, the club offers "Hack Classes" that teach skills in starting a business, web development and application design. More experienced students can attend the semi-annual Hackathon, in which hundreds of students gather from around the country to exchange ideas and create new apps and

devices. The club also sponsors a competition, TigerLaunch, with over \$50,000 in prizes. The competition involves three rounds in which participants pitch their ideas to judges, develop a usable prototype and finally present their idea to venture capitalists.

"We have about 11 teams in charge of planning different types of events for students on campus," said Hansen Qian, a junior in computer science who ran HackPrinceton last fall and spring, and currently works on rebranding and advertising within the club. When Stephanie He, president of E-Club, approached a venture capitalist last summer for more ideas about how to promote entrepreneurship on campus, "she was told that no other school offers this much for students," Qian said.

The E-Club organizes collaborative sessions such as IdeaFactory, a gathering of students and mentors to discuss and develop ideas. E-Club's Speaker Series has featured presentations by business leaders including Fred Wilson, the co-founder of Union Square Ventures; Jack Dorsey, the co-founder of Twitter; and Walter Isaacson, the CEO of the Aspen Institute.

One of the most popular events offered by the E-Club is TigerTrek, in which about 20 students from a pool of more than 200 applicants are selected to meet with leading professionals in New York City and Silicon Valley. The program helps students gain awareness of career opportunities and expand their professional network. It also pairs them with mentors and allows them to interact with peers who share interests in entrepreneurship.

This year, Daniel Toro, a junior in operations research and financial engineering, led students on the Silicon Valley TigerTrek. They visited top entrepreneurs including Salman Khan, founder of Khan Academy; Peter Thiel, co-founder of PayPal and Palantir; and Meg Whitman, CEO of Hewlett Packard and a 1977 Princeton graduate.

"I went into TigerTrek with a clear mindset of my career plans, and left with the over-

whelming yet exciting feeling that career plans are overrated," said Lynn Nehme, a senior in mechanical and aerospace engineering.

Andrew Ng, a Princeton junior and a 2012 TigerTrek alumnus, founded Chesscademy, a free online platform that helps users learn chess. Ng landed a competitive spot at Silicon Valley's Y Combinator accelerator after meeting its founder during TigerTrek. "Meeting Sal Khan was also inspiring," he said. "I learned many things about the potential future of education during our meeting, and it definitely influenced the direction of Chesscademy."

As E-Club continues to expand its offerings, Stephanie He, the club president, hopes it will allow students at all stages of entrepreneurship to network, compete and challenge themselves. "The future has always been driven by innovators and those who are finding new, exciting ways to better the world around them," she said. "E-Club is a hub for those aspiring entrepreneurs who seek to make that impact on the world." **E**



A group of Princeton undergraduates traveled to Silicon Valley in California in October as part of the annual TigerTrek program run by the student Entrepreneurship Club. The group visited well-known entrepreneurs and funders, including PayPal co-founder Peter Thiel (center rear), who gave the group copies of his recent book "Zero to One." (Photo by Michael Kratsios A.B. '08)

# START. BUILD. TRANSFORM.

'Introduction to Entrepreneurship' examines elements of success and failure in new ventures

by John Sullivan

## John Danner moved across the auditorium, tossing questions at his students about a possible business startup.

What else? What next? What was the thing they were not thinking of? What was lurking to trip them up?

"It has to scale," said junior Rachel Leizman.

"Does it have to scale?" Danner asked raising his hand to punctuate his question. "What about a small flower shop, what about a bodega?"

"Well, that's a scale," Leizman shot back, drawing a laugh from the class.

Danner, a veteran entrepreneur with a booming voice and an easy presence, used fast-paced dialogue and some friendly banter to jar his students into thinking in new ways about what it takes to start a new venture. Proposals became epic stories; business plans were charts to guide an enterprise through hidden shoals waiting to sink an unwary new company.

"We want the students to develop their thinking and sophistication about how entrepreneurship plays out," Danner, an entrepreneurship specialist at the Keller Center, said after class. "We want them to



"Introduction to Entrepreneurship," a sophomore-level class introduced this year, drew more than 80 students from across the University. In a recent session (above), students collaborated on final projects. (Photo by Denise Applewhite)

see this as an option, whether their motivation is to launch a new technology or a new industry or to change the world."

The subject of the Keller Center's new class, "Introduction to Entrepreneurship," is "entrepreneurship writ large," said Derek Lidow BSE '73, another instructor.

The goal of the course, open to all University students, is to allow interested students to work with a team of veteran entrepreneurs: Danner, a business executive and professor at the University of California-Berkeley; Lidow, founder of iSuppli; Chris Kuenne A.B. '85, founder of Rosetta; and Ed Zschau A.B. '61, a founder or co-founder of numerous startups, including System Industries in the 1970s and Polyera Corporation in the last decade.

The four instructors trade off lectures focusing on various topics. Danner, for example, taught one session about business models; Lidow lectured on critical points for developing a startup enterprise into an ongoing business.

"We are trying to get at the core issues that inform students about success or failure," Lidow said. "If they only have time to take one course about entrepreneurship, then they can take this course and get a good understanding."

The idea for the course grew from a dinner among the instructors last year. Most entrepreneurship classes taught at Princeton target seniors, and they wondered whether it would be possible to involve students earlier.

"Its objective as a survey course is to expose Princeton students, particularly sophomores, to the range of flavors and concepts of entrepreneurship early in their college careers," said Zschau, who has taught entrepreneurship at Princeton for more than 15 years.

"We all had the experience of seniors saying, 'Gosh, I wish I had taken this earlier,'" Danner said. "We wanted to see if we could



"Introduction to Entrepreneurship" was co-taught in the fall semester by John Danner (shown at left), Chris Kuenne, Derek Lidow and Ed Zschau. (Photo by Frank Wojciechowski)

reach people earlier in their undergraduate careers; if they liked it, they would be able to pursue it."

The course was first offered this fall, and 86 students signed up. The course number has an engineering prefix, EGR, but 66 of the students are pursuing Bachelor of Arts degrees. Because of its large enrollment, the course is taught in an auditorium in Jadwin Hall. In addition to standard classwork, the students keep an entrepreneurship journal to track their growing understanding of the material and possible applications to the world. Toward the end of the class, the students split into groups to complete a project in which they flesh out an idea for a new venture.

"We don't require a formal business plan at this level; it's not about judging the idea the way an investor would," Danner said. "We want to see evidence that the students have developed their thinking and sophistication about how entrepreneurship plays out."

Leizman, a junior majoring in economics, said she enrolled in the class because it will allow her to gain a broad understanding of the subject before choosing one of the more specialized, upper-level entrepreneurship classes such as "High-Tech Entrepreneurship." She said she intends to start her own business in the future and she "thought taking a survey course taught by the four professors would allow me to explore the different areas of entrepreneurship to see what I liked best."

"One of the main things I've learned is that a great idea doesn't automatically turn into a successful enterprise," she said. "There are so many different factors – from funding to operations to the leadership – that make or break a good idea." ■

## ENTREPRENEURSHIP, INNOVATION AND DESIGN COURSES

The following courses are offered through the Keller Center in 2014-15.

Introduction to Entrepreneurship

High-Tech Entrepreneurship

Radical Innovation in Global Markets

Leadership Development for Business

Special Topics in Entrepreneurship – Building and Financing Technical Ventures

Entrepreneurial Leadership

Freshman Seminar: Can Entrepreneurial Innovation Cure What Ails America's Health System?

Special Topics in Social Entrepreneurship – Ventures to Address Global Challenges

Creativity, Innovation and Design

## FACULTY-STUDENT COLLABORATIONS SPARK BUSINESS VENTURES

by John Sullivan

Research with commercial value emerges continually from Princeton labs, and often students and postdoctoral researchers play key roles in bringing the ideas to market. In starting ventures and partnering with established companies, the University's Office of Technology Licensing facilitates connections between lab and industry. For more information about technology transfer and lists of technologies available for licensing, see [www.princeton.edu/patents](http://www.princeton.edu/patents).



Ilhan Aksay (right) and his former student John Lettow (left) co-founded Vorbeck Materials based on research conducted in Aksay's lab. (Photo by Frank Wojciechowski)

### FACULTY-STUDENT BOND IS MATERIAL FOR NEW COMPANY

**Vorbeck Materials sprang from a visit to a laboratory in the Engineering Quadrangle.**

John Lettow, who graduated from Princeton in 1995 with a degree in chemical engineering, returned in 2004 to the laboratory of his former professor, Ilhan Aksay, with questions about materials science. Lettow was looking for information on fuel cells, but his visit changed the course of his business.

"Ilhan had been working on several different technologies," Lettow recalled. The conversation quickly moved to graphene – a sheet of carbon that is just one atom thick. "The breadth of graphene technology is enormous."

Over the next year, the pair formalized a new company that would become Vorbeck Materials. The idea was to develop Aksay's insights

### SENSING AN OPPORTUNITY

**Kelly Caylor and Adam Wolf couldn't find a cheap, compact sensor for their environmental research, so they decided to make one themselves.** The result, several versions and years of work later, is the Pulse Pod.

"Adam and I were both working on problems that required high-resolution, high-quality environmental data, but there were no companies producing the kind of sensors that we wanted to use," said Caylor, an associate professor of civil and environmental engineering. "Most environmental sensors are expensive and difficult to use. We wanted something that was cheap, easy and smart."

Wolf, an associate research scholar in ecology and evolutionary biology, had been tinkering with a prototype for some time before he and Caylor began teaching a class together on low-cost environmental sensors.

"From the class, we found students who were really interested in working on this,"

Caylor said. One, Ben Siegfried, graduated in 2012 but has continued as a hardware engineer for the Pulse Pod. The team received funding from the Engineering School's Project X program, which supports promising but somewhat unorthodox scientific ventures.

Pulse Pod, about the size of a household smoke detector, is solar powered and supports a variety of sensors depending on the need – it can measure the productivity of a field based on the shade of green or track moisture in soil. It transmits data on the system commonly used for telephone text messages.

After receiving multiple requests for the sensors from fellow researchers, Caylor and Wolf are working to lower costs and increase production. Ultimately, they believe they not only have a business opportunity but a chance to capture data about climate change, while improving farm production.

"We think the value of this is in the scale," Caylor said. "A few hundred out there would be great, but thousands across Africa measuring climate and crop conditions – that would be fabulous."



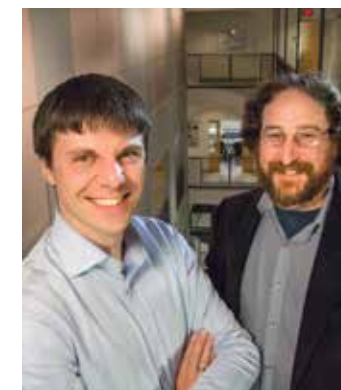
Kelly Caylor (left) and Adam Wolf (right) are producing compact, low-cost environmental sensors to answer questions about climate and crop conditions. (Photo by Frank Wojciechowski)

into graphene into a variety of industrial and commercial uses.

"I remember saying to John that this is like standing at the edge of a cliff and we will either succeed or fall off," said Aksay, who is a professor of chemical and biological engineering. "He said, 'Have you ever seen anyone accomplish something big without taking risks?'"

Today, Vorbeck's manufacturing facility in Maryland makes products ranging from advanced batteries to wearable circuitry. The company also has a research and development lab outside of Princeton that frequently consults with Aksay's research group.

"Ilhan has contributed to the company all the way through," Lettow said. "We would have had a very difficult time without him."



Craig Arnold (right) worked with Christian Theriault A.B. '07 MSE '08 to build a business around Arnold's research on high-tech lenses that use sound waves to shift focus with incredible rapidity. (Photo by David Kelly Crow)

### UNIVERSITY SUPPORT FOCUSES PATH FOR OPTICS COMPANY

**Tag Optics, an award-winning tech firm with customers around the globe, did not start as a business. It began as a senior thesis.**

"We were never thinking of commercializing it," said Craig Arnold, a professor of mechanical and aerospace engineering and one of the company's founders. "We were just trying to understand the physics."

In 2005, Arnold and undergraduate Adam Hopkins were intrigued by the possibility of using sound to rapidly focus optical lenses. They knew that light bends as it enters liquids of different densities, in effect turning liquids into lenses. They also realized they could change the density of a liquid – and thus refocus their lens – by blasting it with sound waves.

"I asked Adam to do some mathematical modeling to see what was going on," Arnold said. Hopkins graduated that year, and went

on to earn a Ph.D. from Princeton, and Arnold continued to work on the technology.

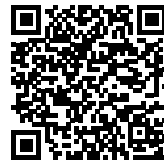
Arnold eventually teamed up with Princeton graduate Christian Theriault to commercialize the lens. The fledgling company received key boosts from the Keller Center's Innovation Forum and the University's IP Accelerator Fund.

In 2011, the company shipped its first product. Today, TAG Optics produces lenses that can completely shift focus 700,000 times per second. The lens is so rapid that it can create a full, three-dimensional image in the time in which a standard lens takes a single snapshot. The technology is currently used in microscopy, laser focusing and manufacturing.

"In terms of spinning out the technology, I can't overstate the importance of good relations with the University," Arnold said, noting direct support from Princeton and a general environment that encourages innovation. "They really want to see you succeed." ■

# PRINCETON ENTRE- PRENEURS

The entrepreneurs featured on these pages took at least one course at the School of Engineering and Applied Science – now offered through the Keller Center – on how to grow an idea into a viable venture. Their quotes are drawn from a series of videos produced for the opening session of a new sophomore-level course that began this year (see page 8). To watch the videos, scan the QR code or visit [www.youtube.com/princetonengineering](http://www.youtube.com/princetonengineering). A library of the videos also is available through iTunes University. Tell us your entrepreneurship stories through Facebook, Twitter or LinkedIn, or email us at [entrepreneurs@princeton.edu](mailto:entrepreneurs@princeton.edu).



## PHIL INAGAKI A.B. '04

*Polyera, a company that creates flexible electronics*



“Princeton is a great place to find mentors. I also sought them out in the summer jobs I took. So rather than doing consulting or investment banking internships, I worked for entrepreneurs and startups.

You talk to your mentors and they give you advice, but one of the greatest ways they helped me is just being a source of inspiration. Seeing what they had done with their careers just made me all the more excited about being an entrepreneur.”

## JASON ARAMBURU A.B. '07

*Edyn, manufacturer and seller of garden monitoring hardware and software*



“My first real experience with entrepreneurship, or first big experience, was Ed Zschau’s class at Princeton. It was really influential to me. It taught me that anyone could be an entrepreneur. You didn’t have to have all the details figured out, and that interest and persistence were really important.

Starting a company is really hard. It’s the hardest thing you could possibly do. And it’s in those difficult times, it’s really your personal passion that keeps you afloat and keeps you going.”



## ROBERT J. MOORE BSE '06

*RJMetrics, a data analytics platform supporting growing businesses*

“Do entrepreneurship now. Get exposure. It doesn’t always mean starting your own company. Come work for an amazing startup, whether it’s RJMetrics, whether it’s someone in New York or on the West Coast. Get exposure to what it’s like, and it’ll definitely pay off.”



## CARTER CLEVELAND BSE '09

*Artsy, an online resource for art collection and art education*

“The first time when I ever considered the possibility of entrepreneurship – up until that point, I figured I was going to be a theoretical physicist or something – was when I took Ed Zschau’s entrepreneurship course, my junior year. I just thought it was so fascinating how you could build something out of nothing.”



## BRIAN O’KELLEY BSE '99

*AppNexus, real-time online advertising platform*

“Going from failure to failure to failure was the only way to really quickly learn and build skills that would allow me, once I was in the right place at the right time, to actually be successful. I think the biggest risk for an entrepreneur is often that if you’re successful for the wrong reasons, like if you get lucky, then when hard times come, or the business grows, you don’t have the next set of things that you need to overcome those challenges.”



## ARIELLE SANDOR A.B. '12

*Duma Works, online job recruiting*

“One of the best aspects that we got from eLab was the incredible network that it provided us.

Get to know about the opportunities that are out there – the competitions, the accelerators, or what have you. Even just studying abroad, you never know when you’re going to stumble upon a good idea. So make sure you’re informed about the types of funding opportunities, or competition opportunities, or opportunities outside of Princeton.”



## CHRISTINE BLAUVELT A.B. '12

*Duma Works*

“It wasn’t until senior year, when Arielle and I were in the same social entrepreneurship class, that I started to really see more of the startup side, and got really interested in technology, and fusing those technology elements together with social issues to address the issues that I was already interested in.” ■





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