PRINCETON
INNOVATION

Accelerating impact *through* **innovation** *and* **entrepreneurship**

2022

PRINCETON
UNIVERSITY

IDEAS
INVENTIONS
IMPACT

It is my pleasure to welcome you to Princeton Innovation, the University's initiative to accelerate Princeton's service to humanity through innovation and entrepreneurship.

At the core of innovation is the desire to push knowledge and impact to new and higher levels. Our world-renowned faculty, research staff and students make discoveries, explore new ideas and invent new technologies. Princeton Innovation helps forge connections among University researchers and partners in industry and entrepreneurship to solve societal challenges.

It is a tremendous honor to lead Princeton Innovation into its next phase as it evolves into a thriving initiative. Since the program's inception in 2020, Princeton has created and expanded entrepreneurial training, grown efforts to promote entrepreneurship in a welcoming and inclusive manner, and become a regional leader in academic entrepreneurship with the establishment of the National Science Foundation Innovation Corps (I-Corps) Northeast Hub.

This year we are accelerating our pace, our programs and our impact in the region and beyond. We are expanding an academic environment at Princeton that rewards and encourages risk-taking to tackle the most difficult problems facing humanity, while providing the tools, partnerships and infrastructure for success. We are building bridges to industry, government, foundations and the entrepreneurial ecosystem in New Jersey and beyond.

We invite you to join us on this fast-paced journey. Throughout this publication, find out how Princeton research benefits society, explore startups with roots in Princeton science and engineering, and meet our innovators and view their groundbreaking technologies. We are excited to connect with you to celebrate Princeton Innovation.

Craig B. Arnold
Vice Dean for Innovation
Susan Dod Brown Professor of Mechanical and Aerospace Engineering

On the Cover: Our annual Celebrate Princeton Innovation reception features a range of Princeton-led discoveries with the potential to benefit society. From top, a nanosized camera produces images that rival cameras 500,000 times its size (page 16), artificial proteins produce quantum dots for use in electronics (page 12), and a new technology purifies water using low-cost solar power (page 17).

Collaborative
Bold
Open
Inspirational
Inclusive
Evolving

We are Princeton Innovation

> Princeton's human scale, research intensity and culture of collaboration across disciplinary boundaries create a rich environment where new ideas and ingenuity thrive.

Deborah A. Prentice,
Princeton University Provost

> As we confront global challenges, connections between world-class research and the innovation ecosystem are more important than ever. At Princeton, we are eager to cultivate those connections on campus, in central New Jersey, and beyond.

Christopher L. Eisgruber,
Princeton University President

> Research is at the heart of discovery, and is the foundation of tomorrow's scientific breakthroughs and technological innovations, expanding the frontiers of what is known and contributing to societal progress.

Pablo G. Debenedetti,
Princeton University Dean for Research

In the Nation's Service and the Service of Humanity

PRINCETON INNOVATION

ACCELERATING OUR IMPACT

Research

Nearly **$280M** in external funding spent on research in FY22*

Industry and nonprofits fund about **20%** of Princeton research projects

14%
increase in industry-supported academic research from FY19 to FY21

*Fiscal year 2022 starts on July 1, 2021 and ends on June 30, 2022.

Innovation

104 new invention disclosures filed in FY22

190 new patent applications filed in FY22

51 U.S. patents issued in FY22

28 license and options agreements in FY22

Princeton Innovation brings together Princeton faculty, students, staff and alumni to take their ideas and inventions to the next level.

Since the creation of Princeton Innovation in 2020, our innovation activity has soared.

Startup Activity

17

startups formed based on discoveries made at Princeton since 2020

Over $500M in funding raised by startups since 2020

40%

of new licenses went to startups since 2020

Entrepreneurship

10

I-Corps Hub teams qualified for $500K in NSF innovation training grants in 2021

43

faculty and postdoctoral researchers trained via the Princeton-Wharton Executive Education program since 2020

73

postdoctoral researchers and graduate students trained in the Princeton Startup Bootcamp since 2020

NSF I-Corps Hub Northeast Region

> "Seeing the enthusiasm and hustle of so many teams from universities across the Northeast who never saw themselves as entrepreneurs before is inspiring. The result is innovative researchers solving real-world problems."
>
> **— Christina Pellicane,**
> *Assistant Director of Innovation and I-Corps Northeast Hub Lead Instructor*

Addressing societal and customer needs:
The I-Corps Northeast Hub

Funded by the National Science Foundation (NSF), the **Innovation Corps (I-Corps) Northeast Hub** prepares scientists and engineers to boost the economic and societal impact of their discoveries and inventions.

The Hub launched on January 1, 2022. The Hub is centered at Princeton University and is open to researchers and mentors throughout the Northeast and beyond.

In its first year the Hub has:

- Trained 89 academic teams from 18 institutions across seven states
- Taught 60 I-Corps instructors, many from groups underrepresented in the field, including 57% women and 32% underrepresented minorities
- Welcomed Drexel University as the newest member of the Hub

Icorpsne.org

Solving the microplastics problem

Princeton's **Project Plastic** team is building a device that removes microplastics, tiny pieces of plastic smaller than the size of a pea, from water. To explore the potential for this technology to succeed as a product, the team signed up for the I-Corps Northeast Hub's Propelus four-week training.

Project Plastic's device is a small raft that floats on the water and catches microplastics in a network of artificial root fibers.

During their I-Corps training, the team, led by Princeton School of Architecture graduates Yidian Liu and Nathaniel Banks, explored one of the primary reasons that startups fail: lack of demand for the product. With support from the Hub, the team met with more than 40 potential customers, discovering new unmet needs along the way.

Project Plastic will now advance to NSF's national I-Corps Teams program, a more intensive seven-week training to explore forming a startup to advance the technology.

projectplastic.site

Project Plastic, a Princeton-based team, is developing a device to remove microplastics from water.

Taking innovation to the next level:
Princeton Entrepreneurship Council

For Princeton faculty, students and alumni looking to develop and improve their skills, learn about new trends and industries, and connect with others in the ecosystem, the **Princeton Entrepreneurship Council (PEC)** offers educational programs, mentoring and connections to funding.

In addition to popular events held around the country, PEC runs several programs:

- **Princeton-Wharton executive entrepreneurship education for faculty**
- **VentureWell bootcamps for graduate students and postdocs**
- **OfficeHours mentoring/advisory platform, Startup Showcases and more**

entrepreneurs.princeton.edu

A solid START for inclusive entrepreneurship

Throughout all its programs, PEC supports inclusive entrepreneurship by facilitating connections between those who have historically not had access to entrepreneurship opportunities and the larger entrepreneurial ecosystem. This year, PEC launched **START Entrepreneurs**, Princeton's academic fellowship and startup accelerator, which encourages applications from scholars who contribute to entrepreneurial excellence and diversity, broadly defined.

START Entrepreneurs spend several months working on Princeton's campus, where they receive entrepreneurship education and curated mentorship to gain skills to launch a successful venture. They spend the second part of the program working to launch their startup.

start.princeton.edu

> **"We are encouraged by the promise and the enthusiasm of this first group of START Entrepreneurs. Our hope is that their work will result in viable startups with global impacts."**
>
> **— Anne-Marie Maman,**
> *Executive Director, Princeton Entrepreneurship Council*

The four inaugural START Entrepreneurs are (L to R): Maksim Mezhericher, Shelf-stable vaccines; Ebony Noelle Golden, Civic theatre; Tanyaradzwa Tawengwa, Digitizing cultural identity; and Sunxiang "Sean" Zheng, Sustainable lithium production.

THE NEXT BIG IDEA

Three-dimensional printing of building materials could revolutionize construction. The project is led by Reza Moini, Assistant Professor of Civil and Environmental Engineering.

Making the possible real:

Office of Technology Licensing

Through expertise, mentoring and resources, the **Office of Technology Licensing** helps faculty transform Princeton discoveries into innovative solutions to real-world problems. Our associates help University researchers to explore outlets for technology translation in collaboration with industry partners, investors and entrepreneurs.

Over the past few years, the office has expanded support for researchers looking to enhance impact through startups and new ventures. We also connect our researchers to our Executives in Residence, experienced mentors who can advise on a range of scenarios.

patents.princeton.edu

> **"Our team helps forge the link between promising discoveries and real-world solutions. The overarching goal is to help University research provide widespread positive impacts."**
>
> **— John Ritter,** *Director, Office of Technology Licensing*

Bridging the divide with the IP Accelerator Fund

Often, discoveries require additional research or development to demonstrate the ability to become a real-world product or service. The Intellectual Property Accelerator Fund provides funding toward proof-of-concept work, data collection or construction of prototypes. This support helps push forward technologies to the stage at which they can attract investment and licensing by a startup or existing company.

Among the 2022 awardees:

- **Light-controlled purification of pharmaceuticals**
  José Avalos, Assistant Professor of Chemical and Biological Engineering and the Andlinger Center for Energy and the Environment
- **New drug candidates against cancer**
  Yibin Kang, the Warner-Lambert/Parke-Davis Professor of Molecular Biology
- **Three-dimensional printing for buildings and construction**
  Reza Moini, Assistant Professor of Civil and Environmental Engineering
- **Better and brighter augmented reality systems**
  Paul Prucnal, Professor of Electrical and Computer Engineering

Featured startup: Barcelona-based SpliceBio forges gene-therapy solutions

Chief Business Officer Gerard Caelles, Chief Executive Officer and Cofounder Miquel Vila-Perelló, and Chief Technology Officer and Cofounder Silvia Frutos

SpliceBio, a company with research roots in Princeton's chemistry department, is generating cross-Atlantic excitement over its approach to tackling challenging genetic diseases.

The 15-person company earlier this year secured the largest early-stage round of funding ever for a Spanish biotech firm, raising nearly $57 million from some of the biggest European and U.S. venture capital investors.

Company cofounder Miquel Vila-Perelló was a research scholar at Princeton when he envisioned the therapeutic potential for unique proteins known as inteins.

Inteins, short for "intervening proteins," can attach two molecules to each other, and could perform tasks such as fastening drugs to cancer cells.

Vila-Perelló teamed with Tom Muir, Princeton's Van Zandt Williams Jr. Class of 1965 Professor of Chemistry, who led the intein research, and another Spanish-born postdoctoral researcher, Silvia Frutos, to explore forming a company. He also called up a friend, Marc Montserrat, from his hometown of Barcelona who was earning an MBA at the Wharton School of the University of Pennsylvania.

With Muir, the team started conversations with Princeton's Office of Technology Licensing. They received support from Princeton's Intellectual Property Accelerator Fund, which provides initial sums for prototyping and experiments, and founded the company in 2013.

Vila-Perelló, the company's CEO, felt that the future lay in Barcelona. Over the past two decades, Barcelona has blossomed into a biotech hub.

"I wanted to return home and contribute to the biotech sector here," he said, and so the team relocated to the Barcelona Science Park, a health-sector incubator.

At first, the founders envisioned a company that provides technology to enable other researchers to develop intein-based therapies. However, they realized that they could have a bigger impact by becoming a drug-development company and tackling therapeutic targets themselves. "For us, it was exciting to think that we could be part of developing a treatment or a cure for patients," Vila-Perelló said.

The scientists pivoted the company to focus on inteins to help with a challenge facing the gene-therapy field: how to ferry large genes into cells. Researchers typically do this by replacing a virus's genetic material with the desired gene, then infecting cells with the virus. But today's commonly used viruses are too small to carry large genes.

With inteins, large genes can be split into smaller fragments, ferried into cells, and then reassembled.

One of the first diseases the company is tackling is a hereditary disorder called Stargardt disease, also called juvenile macular dystrophy, which manifests in the early decades of life and results in eventual blindness. More applications are to come. Said Vila-Perelló, "This funding puts the company in a very good position to accomplish the challenge of developing new therapies for currently untreatable diseases."

splice.bio

BUILDING CONNECTIONS

> **Whether you are a Princeton researcher or an external organization, we are eager to work with you to explore how collaboration can advance science, innovation and scholarship for societal benefit."**
>
> **— Coleen Burrus,**
> *Director, Corporate Engagement and Foundation Relations*

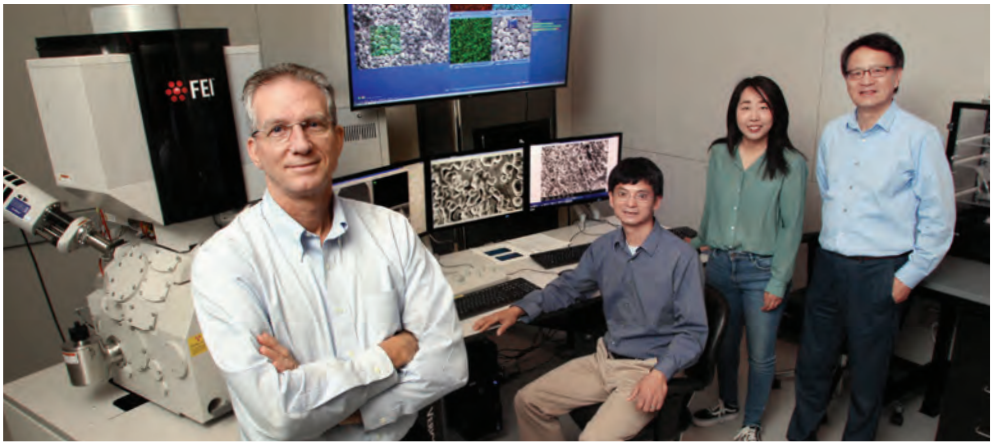
Welcoming partnerships to accelerate research, scholarship and innovation:

Corporate Engagement and Foundation Relations

Princeton's **Corporate Engagement and Foundation Relations (CEFR)** team works to build collaborations between Princeton researchers and external organizations that hail from across the U.S. and around the globe. Industry, foundations, nonprofits and government are all important partners in the exceptional work of Princeton researchers on the world's most pressing problems.

The universal key to successful research collaborations with Princeton is strong alignment with the University's core academic and research strengths. In addition to sponsoring faculty-led research, partners can support fellowships and student capstone projects. Membership in a corporate affiliate program allows companies to have deep, substantive and ongoing dialogue with Princeton faculty. Partners may also access Princeton's top-of-the-line scientific core research facilities.

partnerships.princeton.edu



Princeton's Imaging and Analysis Center offers high-end, state-of-the-art instrumentation and expertise to all qualified users, whether from Princeton or elsewhere.

Shared research facilities make discoveries happen

Princeton University is home to top-of-the-line scientific facilities that enable research, teaching, and the creation and dissemination of knowledge. To extend these resources to others who share Princeton's mission of service to humanity, and in support of the local innovation ecosystem, Princeton makes certain shared-use research equipment available to external users. Each facility has its own participation and training requirements. Contact Dean Edelman in Corporate Engagement and Foundation Relations at dean.edelman@princeton.edu for more information.

- **Proteomics and Mass Spectrometry**
- **Nuclear Magnetic Resonance**
- **Micro/Nano Fabrication Laboratory**
- **Macromolecular Crystallography**
- **Imaging and Analysis Center**
- **Genomics Core Facility**
- **Flow Cytometry Resource Facility**
- **Confocal Microscopy Facility**

Campus Partners

Keller Center eLab team MoVA moves art outside the museum

MoVA is a museum experience that uses augmented and virtual reality to deliver interactive education and entertainment. The team developed their startup in the Keller Center's eLab Summer Accelerator Program, which helps student-led teams explore entrepreneurial endeavors.

The product's target audience is users with accessibility constraints that may not be able to travel to museums or art installations.

"Our shared motivation in facilitating the psychosocial well-being of vulnerable populations with innovative technologies and designs was the driving force behind me joining this team," said Sophie Jiang, who earned her master's degree in Princeton's School of Architecture in 2022.

kellercenter.princeton.edu

MoVA brings art to users wherever they are via augmented and virtual reality.

Princeton Innovation Center BioLabs fosters early-stage startups

Located about three miles from main campus, **Princeton Innovation Center BioLabs** is often the first jumping off point for Princeton-led technology companies. As a premier coworking space for all science startups in New Jersey, whether affiliated with the University or not, Princeton Innovation Center BioLabs is a unique place where researchers can test, develop and grow their ideas.

princetonbiolabs.com

Startup Optimeos is developing a nanoparticle platform to deliver RNA medicines based on research led by Robert Prud'homme, Princeton Professor of Chemical and Biological Engineering.

Dean for Research Award for Distinguished Innovation

In recognition of the importance to society of innovative research and scholarship, the University created a new faculty honor, the **Dean for Research Award for Distinguished Innovation**.

The 2022 award will go to Zemer Gitai, Princeton's Edwin Grant Conklin Professor of Biology, for a drug-discovery platform that combines quantitative imaging and machine learning. The technology is being developed by a startup, ArrePath, which spun out from Gitai's lab to develop new antibiotics and treatments for other diseases.

FEATURED INNOVATORS

Meet the faculty members and researchers featured at our annual reception, Celebrate Princeton Innovation.

Life sciences

Britt Adamson: Accurate genome editing
Michael Hecht: Quantum dots from artificial proteins
Peter Jaffe: Bioremediation of persistent contaminants
Lindy McBride: Mosquito attractants that mimic human odor
Howard Stone and Maksim Mezhericher: Shelf-stable vaccines

Tech

Felix Heide: Nanophotonic camera
Rodney Priestley and Xiaohui Xu: Low-cost water purification
Xiaoxiao Shen: ReChat, an interactive chat tool
Barry Rand: Perovskite thin-film lasers
David Gates: Fusion power

Improvements to genome editing by manipulating DNA repair

Britt Adamson,
Assistant Professor of Molecular Biology

A new approach promises to improve precision genome editing by profiling how individual genes affect DNA sequences.

The ability to make programmed changes to the genomes of living cells has tremendous potential to address a host of unmet medical needs. Over the past decade, enzymes repurposed from bacteria (CRISPR-Cas) have enabled specific gene targeting and genome editing.

Despite recent advances, genome-editing techniques remain imprecise, and unwanted mutations frequently occur. Genome editing requires first damaging the DNA — for example, by making a break in the molecular strand — to permit the insertion, deletion or replacement of a gene sequence. Unwanted mutations typically arise from the same processes that make the desired changes, namely, host-cell mechanisms of DNA repair. These mechanisms are highly complex and thus the precision of sequence changes has been hard to control.

To address this challenge, Adamson, together with academic and biotechnology industry collaborators, developed a new experimental and computational approach called Repair-seq, which reveals in exquisite detail how genome-editing tools work.

Repair-seq allows researchers to probe the contribution of individual pathways to repair of specific DNA lesions at sites targeted by genome editors. It works by simultaneously profiling how hundreds of individual genes affect the DNA sequence. Adamson and colleagues have applied their method to three of the most common and promising genome-editing approaches. By understanding the biology underlying these tools, the team has pioneered significant improvements.

> “We’ve known for a long time that to change the sequence of DNA, you first have to break it. We're now so much closer to improving the accuracy of that process.”
>
> **— Britt Adamson**

Co-inventors:
Jeffrey Hussmann, University of California-San Francisco; Peter Chen and David Liu, Broad Institute of MIT and Harvard

Collaborators:
Mandana Arbab, Broad Institute of MIT and Harvard; Luke Koblan and Jonathan Weissman, Whitehead Institute for Biomedical Research, MIT; Max Shen, Genentech; Cecilia Cotta-Ramusino, Tessera Therapeutics

Team members:
Postdoctoral Research Associate Jia Ling; Research Specialist II Purnima Ravisankar; Graduate Student Jun Yan, Princeton University

Development status:
Patent pending. Princeton is seeking outside interest in developing this technology.

Funding:
National Institutes of Health, National Science Foundation

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> “What I find exciting is how this discovery marries two completely different fields that nobody would think of combining in the same lab.” **— Michael Hecht**

Michael Hecht,
Professor of Chemistry

Leah Spangler,
Postdoctoral Research Associate

Sarangan Chari,
Senior Chemist

Semiconductor quantum dots using artificial proteins

A new method uses novel synthetic proteins to create semiconductor quantum dots, particles that have useful electronic and optical properties.

Quantum dots are tiny crystals that have unique properties that make them valuable for a variety of applications, including in biomedicine, solar energy and electronics. However, these nanometer-scale semiconductor particles are expensive to produce and require use of toxic solvents that are harmful to the environment.

Now, researchers have uncovered a cost-effective and environmentally sustainable method of producing quantum dots using artificial proteins. The idea came from combining two seemingly unrelated fields.

Michael Hecht and his team are interested in imagining how life forms could evolve differently from how life evolved on Earth. To explore this question, the team creates artificial DNA from which they produce artificial proteins. In another lab, Professor Gregory Scholes leads work on quantum dots.

Postdoctoral researcher Leah Spangler, now an assistant professor at Virginia Commonwealth University, drew a connection between the two projects. Spangler discovered that one of the artificial proteins could catalyze a reaction to create quantum dots using water rather than toxic chemicals.

Quantum dots are fluorescent and may help cancer researchers visibly trace cancer growth. Another application could be in solar energy production. Since the dots are cheaper to produce than silicon solar cells, they have the potential for wider applications, such as in window films that capture sunlight and generate solar energy.

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Collaborators:
Gregory Scholes, William S. Tod Professor of Chemistry; Nan Yao, Senior Research Scholar, Princeton Institute for the Science and Technology of Materials and Director, Imaging and Analysis Center

Team members:
Graduate Student Yueyu Yao; Associate Research Scholar Guangming Cheng

Development status:
Patent pending. Princeton is seeking partners for further development of this technology.

Funding:
National Science Foundation

Bioremediation of persistent contaminants

Peter Jaffé,
William L. Knapp '47 Professor of Civil Engineering

Researchers have discovered a bacterium that can biodegrade chemicals that are persistent in the environment and that may cause harmful effects in humans and animals.

Often referred to as "forever chemicals," PFAS (perfluoroalkyl and polyfluoroalkyl substances) are persistent in global water supplies, soil and air, as well as in the blood of a large majority of people and animals in the United States.

A number of the compounds have been linked with harmful health effects. Although some of the chemicals have been phased out of products by U.S. manufacturers, the substances were widely used for decades in a variety of products from nonstick pans to fire-fighting foam. Until now, researchers thought that breaking down these chemicals was impossible due to the strength of the carbon-fluorine bond.

Princeton researchers have discovered a new bacterium, Acidimicrobium A6, that is able to break this bond and biodegrade these chemicals. Technologies that harness this bacterial activity could remove PFAS from soil and water in locations where they are highly concentrated, such as airports, naval facilities and wastewater-treatment plants.

The biggest challenge is that these bacteria are extremely slow growing. The team is looking at ways to speed up bacterial production through various means, such as novel bioelectrochemical reactors and new ways of supplying required nutrients. Ultimately, the researchers hope to create a highly effective approach to remediating contaminated soil and water.

> "This is the first time that an organism has been shown to break down these chemicals, and we think that it could be a highly effective means of cleaning up these contaminated sites."— **Peter Jaffé**

Co-inventor:
Shan Huang, Professional Specialist

Collaborators:
Z. Jason Ren, Princeton Professor of Civil and Environmental Engineering and the Andlinger Center for Energy and the Environment; Mohammad Seyedsayamdost, Princeton Professor of Chemistry; Daniel Steingart, Columbia University; Larry Wackett, University of Minnesota; Mengyan Li, New Jersey Institute of Technology; Charles Schaefer, CDM Smith

Team members:
Graduate Students Camila Llerena-Olivera, Jinhee Park, Matthew Sima, Chiara Smorada and Joel Strothers, Princeton University; Melany Ruiz-Urigüen, Ph.D. '19; Arianna Sherman, Ph.D. '20; Weitao Shuai, Ph.D. '21

Development status:
Patent pending. Princeton is seeking outside interest for the development of this technology.

Funding:
Princeton Intellectual Property Accelerator Fund, Gordon and Betty Moore Foundation, National Science Foundation, National Institutes of Health, U.S. Department of Defense, and industry funding

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Lindy McBride,
Assistant Professor of Ecology and Evolutionary Biology and Neuroscience

Synthetic blends for manipulation of mosquito behavior

A specific blend of chemicals mimics the distinct human odor that attracts mosquitoes, suggesting a method for luring mosquitoes into lethal traps.

> Despite the complexity of human odor, mosquitoes have evolved a surprisingly simple mechanism for recognizing us."
>
> **— Lindy McBride**

In some regions, the mosquitoes that spread Zika, dengue and yellow fever have evolved to bite humans almost exclusively.

Human odor is composed of dozens of different compounds, and those same compounds are present in most mammal odors, but in slightly different ratios. None of those compounds is attractive to mosquitoes by itself, and the goal of the initial research was to determine the exact blend of components — and by extension the exact combination of neural signals — that mosquitoes use to recognize human odor.

The neural mechanism these mosquitoes use to recognize human odor is unexpectedly simple. Mosquitos have two nerve centers that respond strongly to human odor at moderate concentrations, and only one of these responds to human odor but not animal odor.

The team further found that two chemicals, decanal and undecanal, are enriched in human odor and activate human-specific neurons. The researchers have patented a blend featuring decanal that could lead to the development of baits that attract dengue- and Zika-carrying mosquitoes to lethal traps.

Additional testing would need to be done to confirm that this blend of compounds is effective in real-world scenarios. The team hopes that their discovery will plant a seed for other researchers to develop and test effective mosquito attractants.

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Co-inventor:
Zhilei Zhao, Ph.D. '21

Collaborators:
Stephan Thiberge, Director, Bezos Center for Neural Circuit Dynamics, Princeton Neuroscience Institute; Annika Hinz and Rickard Ignell, Swedish University of Agricultural Science; Martin Strauch, RWTH Aachen University

Team members:
Graduate Students Jessica Zung, Princeton University; Alexis Kriete, North Carolina State University; and Azwad Iqbal, Cornell University

Development status:
Patent pending. Princeton is seeking outside interest for the development of this technology.

Funding:
National Institutes of Health, New York Stem Cell Foundation

> We believe this technology has tremendous potential to ensure that vaccines and therapeutics reach the people who need them." **— Maksim Mezhericher**

Shelf-stable vaccines and biopharmaceuticals

Howard Stone,
Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering

Maksim Mezhericher,
Research Scholar

A new rapid dehydration technique converts liquid drugs and vaccine formulations into dried powders with improved stability at room temperature.

The technology could lower the cost and improve the stability and reliability of vaccines and biological medications, including several cancer therapies. The new approach uses a proprietary liquid atomization process to evaporate solvent from droplets at room temperature, generating a dry powder that could eliminate the need for the maintenance of a "cold chain" in which therapeutics and vaccines must be refrigerated or frozen during transportation and distribution.

The powdered formulation provides improved product quality and safety, enhanced versatility, increased production capacity, longer shelf life, lower operating costs and decreased carbon footprint. By cutting the need for energy-intensive refrigeration, providers can make vaccines and therapies available to patients in areas lacking adequate infrastructure. The technology could reduce or eliminate the maintenance costs and space requirements associated with freezer equipment.

The team has also invented a technique that enables microencapsulation of sensitive biological materials for storage, protection and gradual release. This simple, scalable and cost-effective method produces micron-sized particles consisting of a solid core and a porous exterior shell. The technology enables encapsulation of various materials via a proprietary liquid atomization process to generate droplets that have a layered core-shell structure. The diameter of the core-shell droplets can be tailored in the submicron-to-micron-sized range.

Collaborators:
Rina Dukor and Yelena Pyatski, BioTools Inc.; Sadegh Poozesh, AstraZeneca; Shurik Yatom, Princeton Plasma Physics Laboratory

Team member:
Postdoctoral Research Associate Zehao Pan

Development status:
Patent pending. A startup company, Inaedis Inc., has been created to develop this technology.

Funding:
Princeton Intellectual Property Accelerator Fund, University City Science Center's QED Proof-of-Concept Program, National Institutes of Health, New Jersey Alliance for Clinical and Translational Science, New Jersey Health Foundation, and Foundation for Health Advancement

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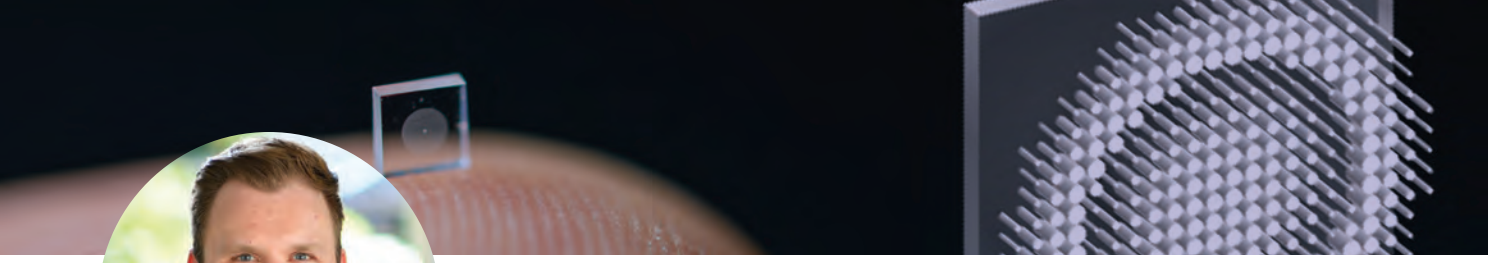

Felix Heide,
Assistant Professor of
Computer Science

Nanophotonic camera that produces high-quality images

An ultra-compact camera can produce crisp, full-color images on par with a conventional compound camera lens 500,000 times greater in size.

> By letting computers learn lenses, computer science can bring unprecedented possibilities and an entirely different design space into the field of optical design."
>
> **— Felix Heide**

Micro-sized cameras have tremendous potential to spot problems in the human body and enable sensing for super-small robots, but previous approaches captured only fuzzy, distorted images with limited fields of view.

This new system, the size of a coarse grain of salt, combines the camera's hardware and computational processing to create powerful imaging capability.

While a traditional camera uses a series of curved glass or plastic lenses to bend light rays into focus, the new optical system relies on a technology called a metasurface, produced much like a computer chip. Just half a millimeter wide, the metasurface is studded with millions of cylindrical posts, called nanoantennas, each roughly 300 times thinner than a strand of human hair. These metasurfaces are more cost-effective to produce than conventional lenses, and they take up significantly less space.

To design such a large array of nanoantennas, the research team developed an AI method that would efficiently handle the design and characterization of all of these elements.

The new lens could enable minimally invasive endoscopy with medical robots. Arrays of thousands of such cameras could create full-scene sensing, turning surfaces — such as the back of a smartphone — into cameras. The device could also have applications in privacy, for example by capturing images of optically coded information.

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Co-inventors:
Graduate Student Ethan Tseng, Princeton University; Graduate Students Shane Colburn, Luocheng Huang and James Whitehead, University of Washington; Arka Majumdar, University of Washington; Seung-Hwan Baek, POSTECH Computer Graphics Lab

Development status:
Patent pending. Princeton is seeking partners for further development of this technology.

Funding:
National Science Foundation, Defense Advanced Research Projects Agency, University of Washington Reality Lab

> “Sunlight is free, and the materials to make this device are low-cost and nontoxic, so this is a cost-effective and environmentally friendly way to generate pure water.” — **Xiaohui Xu**

Solar-driven system for water purification

Rodney Priestley,
Dean of the Graduate School, Pomeroy and Betty Perry Smith Professor of Chemical and Biological Engineering

Xiaohui Xu,
Postdoctoral Research Associate

A temperature-sensitive gel harnesses the sun to provide fast and inexpensive clean drinking water.

Most solar-powered approaches to water filtration use sunlight to evaporate water, which is a time-consuming process. Other water-filtration methods require electricity or another source of power to pump water through a membrane. Passive filtration via gravity, as with typical household countertop filters, requires regular replacement of filters.

Now, researchers have developed a water-purification device that uses sunlight, but does not require waiting for the water to evaporate, condense and evaporate again.

At the heart of the new device is a gel that changes depending on temperature. At room temperature, the gel can act as a sponge, soaking up water. When heated to 33 degrees Celsius (91 degrees Fahrenheit), the gel does the opposite and pushes the water out of its pores.

The gel resists absorption of contaminants in the water, leaving the user with clean, filtered water. This filter delivers the highest passive solar water-purification rate of any competing technology.

The device can operate off-grid at large and small scales. One way to use the gel would be to place it in a water source in the evening and the next day place it in the sunlight to generate the day’s drinking water. The technology has the potential to work anywhere to provide low-cost, non-powered water purification.

Collaborators:
Sujit Datta, Assistant Professor of Chemical and Biological Engineering; Z. Jason Ren, Professor of Civil and Environmental Engineering and the Andlinger Center for Energy and the Environment; Howard Stone, Donald R. Dixon '69 and Elizabeth W. Dixon Professor of Mechanical and Aerospace Engineering.

Team members:
Graduate Student Nehemie Guillomaitre; Associate Research Scholar Navid Bizmark

Development status:
Patent pending. Startup company AquaPao Inc. is developing this technology.

Funding:
Princeton Intellectual Property Accelerator Fund, New Jersey Health Foundation

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Xiaoxiao Shen,
Graduate Student in Politics

An integrated and interactive chat suite for online discussions

A new chat tool allows users to administer, monitor and analyze live conversations and gather data from discussions among study participants.

ReChat is a tool that will allow users to manage multiple live chat sessions using an automated moderator. The approach can improve the ability to study interpersonal communications while lowering costs and expanding the number of participants in a study.

Xiaoxiao Shen, a graduate student in politics, came up with the idea for ReChat when she wanted to conduct an online chat experiment as part of a research project. She noticed that there was no online tool available to help her moderate the conversation, so she decided to develop one herself.

With ReChat, study participants click a link to join an online chat room that is moderated by an intelligent bot, which the researcher can pre-program with questions and instructions to guide the conversation. The tool includes multi-language support, and can be embedded into common survey platforms or used as a stand-alone interface.

ReChat may be useful for academic researchers in the social sciences, who often conduct studies that involve discussion among participants. Researchers typically run in-person studies that involve low sample sizes and high costs of recruiting participants and moderating conversations.

Along with its viability in research studies, the tool may be of use to marketing companies that want to host product focus groups.

> “A lot of innovations come from STEM [science, technology, engineering and mathematics]. It is not as common for social scientists to develop an innovation, but I think that’s something that we may see more of in the future.”
>
> **— Xiaoxiao Shen**

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Funding:
National Science Foundation I-Corps Northeast Hub

Development status:
Patent pending. Princeton is interested in exploring investment and partnership opportunities.

> Developing a technology that can be seamlessly integrated into silicon microelectronics, and converting these chips into systems that can emit light, would be a game changer for a considerable number of applications." — **Barry Rand**

Barry Rand,
Associate Professor of Electrical and Computer Engineering and the Andlinger Center for Energy and the Environment

Perovskite lasers for optical communications

The world's first electrically pumped thin-film laser could be transformative for a range of applications including self-driving cars, facial recognition and emerging communication technologies.

An unconventional class of materials called metal-halide perovskites could become a cost-effective light source in optical devices, providing brightness in phone displays and televisions alongside well-established organic light emitting diode (OLED) displays.

Now, researchers have uncovered further applications for metal-halide perovskites by coaxing the light-emitting devices to function under high-intensity conditions, pushing capabilities toward the operating conditions of a laser. While optical communications in the form of lasers would not fully replace the standard fiber-optic cables required for long distances, the new technology could serve as a more efficient means of short-distance communication, currently supported by copper wiring, by transmitting large quantities of information at the speed of light.

The technology would have implications for the Internet of Things (IoT), the growing network of objects embedded with sensors and software to exchange data with other devices in the network. Other applications include self-driving cars and facial recognition technologies, which employ laser beams to create 3-D representations of surveyed environments and objects.

Metal-halide perovskites have demonstrated the ability to function for these purposes as a high intensity emitter, but more work needs to be done. If the materials can operate reliably at high intensities, this new technology could have significant prospects.

Collaborators:
Claire Gmachl, Eugene Higgins Professor of Electrical Engineering; Noel Chris Giebink, Ph.D. '09, Penn State University

Team members:
Graduate students William B. Gunnarsson and James Loy; Kwangdong Roh, Ewha Womans University; Lianfeng Zhao, Ph.D. '19, Clemson University

Development status:
Patent pending. Princeton is seeking outside interest for the development of this technology.

Funding:
U.S. Air Force Office of Scientific Research, Defense Advanced Research Projects Agency

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Advanced concepts for stellarator fusion energy

Three new inventions could unlock the production of clean and plentiful fusion energy.

Researchers at the U.S. Department of Energy Princeton Plasma Physics Laboratory (PPPL) have developed improvements to a type of fusion reactor known as a stellarator. The advances help trap atomic nuclei and force them to fuse in a process that releases large amounts of energy. The innovations are a step toward harnessing fusion energy to replace or supplement our reliance on carbon-emitting fossil fuels.

> We believe our new design concepts will help make the dream of fusion energy a reality."
>
> **— David Gates**

The first invention is a procedure for designing arrays of permanent magnets that produce a magnetic field, which the stellarator uses to confine a superheated ionized gas, or plasma, that contains the atomic nuclei. The innovation involves a small number of unique magnet parts consisting of identically shaped cubes, each polarized along one of three unique orientations.

The second invention is a stellarator that utilizes a large number of small magnetic coils. The large number of coils, each with its own adjustable parameters, enables precise control of the plasma.

The final invention is a neutron source to improve the confinement of energetic particles in the plasma, thus boosting the likelihood of fusion reactions. The concept involves using negative-ion neutral beams to accelerate deuterium to high energies and then injecting the beam into the optimized stellarator.

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Development status:
Patent pending. License discussion in progress.

Funding:
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