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APS News

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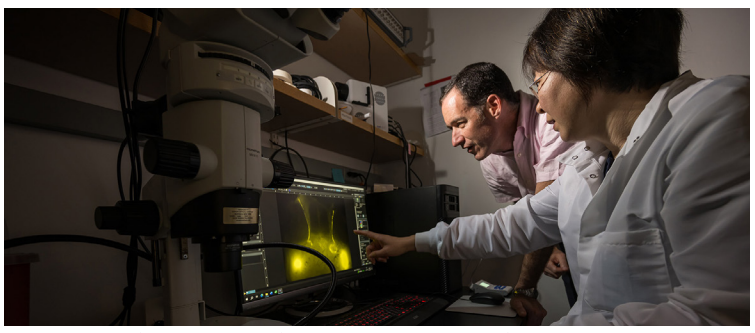
Physicists working on breakthrough medical treatments face an uncertain future

Cuts to federal funding could devastate biomedical research — but these impacts are not inevitable.

BY LIZ BOATMAN



Doug Kelley (left) and Ting Du, faculty at the University of Rochester, examine lymphatic vessels that drain cerebrospinal fluid from the brain. Such studies could help scientists "do a lot more with diseases like Alzheimer's," Kelley says — but funding cuts threaten the interdisciplinary research that bridges medicine and the physical sciences. University of Rochester photo / J. Adam Fenster

In a laboratory at the State University of New York at Albany, Carolyn MacDonald has been busy studying samples of human tissue, looking for the abnormal signatures of breast cancer. For years, her team has worked to develop new X-ray phase and scatter imaging techniques to catch these signatures. "We think this will lead to much earlier detection of cancer," she says.

But MacDonald is worried. Nearly five months into President Trump's second term, the administration has already canceled or withdrawn an estimated $8 billion in grants to higher ed. Her team's work, she says, "is not going to clinical [trials] without federal funding."

This spring, MacDonald received an initial review for a recent grant application to the National Institutes of Health, but "what's up in the air, of course, is whether [NIH will] actually have any money once the proposal is resubmitted," she says. With the university's help, she's "scraped together some barely adequate funding" for her own students, but fears other students across the country — facing an unstable path — will leave American universities.

MacDonald is one of countless researchers working at the intersection of the physical sciences and biomedicine, where some of today's most promising medical advances emerge, and which now faces an existential funding threat.

In May, the Trump administration released topline figures for its budget proposal for the 2026 fiscal year, which foreshadowed drastic cuts to science. In early June, the administration published a more detailed account of these proposed cuts — including a roughly 40% cut to NIH's budget and 57% for the National Science Foundation.

Biomedicine continued on page 6

First takes of the largest astronomical movie ever

The Vera C. Rubin Observatory has released its first images, a preview of a decadal survey that will help researchers tackle the biggest mysteries in cosmology.

BY MATTEO RINI

The Lagoon Nebula (center) and of the Trifid Nebula (top right). NSF–DOE Vera C. Rubin Observatory

On June 23, the NSF–DOE Vera C. Rubin Observatory unveiled a sample of images and videos acquired in its first testing run, offering a tantalizing glimpse of what's to come. Perched high in the Chilean Andes, the observatory is designed to capture the most expansive view of the night sky ever recorded — creating a vast, time-lapse 3D movie of the universe. The observatory will conduct a 10-year survey called the Legacy Survey of Space and Time (LSST). In its first year only, it will gather more data than have been collected in the entire history of astronomy. The imagery released on June 23 was obtained in just 10 hours of test observations, in which the observatory captured millions of galaxies and Milky Way stars, as well as thousands of asteroids.

"This observatory represents a giant leap in our ability to explore

Rubin Observatory continued on page 7

Congress passes reconciliation bill, with impacts for R&D

President Trump signed the bill into law on July 4.

BY CLARE ZHANG

AR Pictures/Adobe

Republicans passed their reconciliation spending bill in early July, codifying billions worth of tax breaks for private R&D and spending boosts for defense and NASA.

The bill raises the endowment tax rate for certain private colleges and universities to 8% and orders the auctioning of 800 megahertz of spectrum. It also adds funding for scientific AI models at the Department of Energy and reauthorizes the Radiation Exposure Compensation Act.

The bill reintroduces tax rules allowing companies to fully deduct domestic research costs in the year they occurred, reversing a rule that requires companies to spread the deduction of R&D costs over five years. The Joint Committee on Taxation estimates the provision will add more than $141 billion to the federal deficit over the next 10 years.

At DOE, the bill adds $115 million for the National Nuclear Security

Science Policy continued on page 6

How AI could shape the future of climate science

Some researchers are ready to create the next generation of climate models, with AI's help.

BY ERICA K. BROCKMEIER

Experimental, 3-kilometer global forecast from the NSF National Center for Atmospheric Research showing 60-hour accumulated precipitation in inches (validated June 1, 2025). Globe frame from Dragon Claws/Adobe.

While "artificial intelligence" might conjure thoughts of chatbots or streaming recommendations, AI has also made a name for itself as a weather forecasting tool — prompting climate scientists to ponder whether machine learning and other types of AI algorithms could bring about a similar revolution in their field.

"We saw the power of these algorithms, but we also saw the challenge of being able to roll them out for a long time because they accumulate error the same way a simulation can accumulate error," explained Laure Zanna, professor of mathematics at New York University, about the challenges of using AI to study a system as complex and dynamic as our climate.

Now, recent advances in the stability of machine learning models have allowed climate researchers to more thoroughly explore AI as a tool. During sessions organized by the APS Topical Group on the Physics of Climate at the Global Physics Summit, scientists shared achievements and discussed the future of research at the intersection of AI and climate science.

While AI might be new to this field, physics has long been an essential part of understanding Earth's weather and climate, said Francesco Ragone, assistant professor of applied mathematics at the University of Leicester, who highlighted this contribution during a tutorial at the summit. "There's a long history that has intersections with fields of physics which are not necessarily directly related to climate science — like statistical physics or dynamical systems theory — that are the backbone of our understanding of the climate system."

> "Some of the equations [in climate models] are known, and you can model them, but you don't have infinite computing [power]," said Zanna.

Building on this grounding in physics, what can AI do to make existing climate models better? One of AI's main advantages is speed, as a model for a system as complex as the climate requires a lot of detailed equations. "Some of the equations [in climate models] are known, and you can model them, but you don't have infinite computing [power]," said Zanna.

One strategy to tackle this complexity is to develop hybrid models that have a core physical model but can learn new patterns from data with the help of machine learning. This hybrid approach lets researchers take advantage of "data and tools that we didn't have decades ago," said Tapio Schneider, an environmental science and engineering professor at the California Institute of Technology. "I think the biggest opportunity [with hybrid models] is to drive the physics forward [by] learning from data," he added.

During the summit's two "AI applications in Weather and

Climate Science continued on page 4

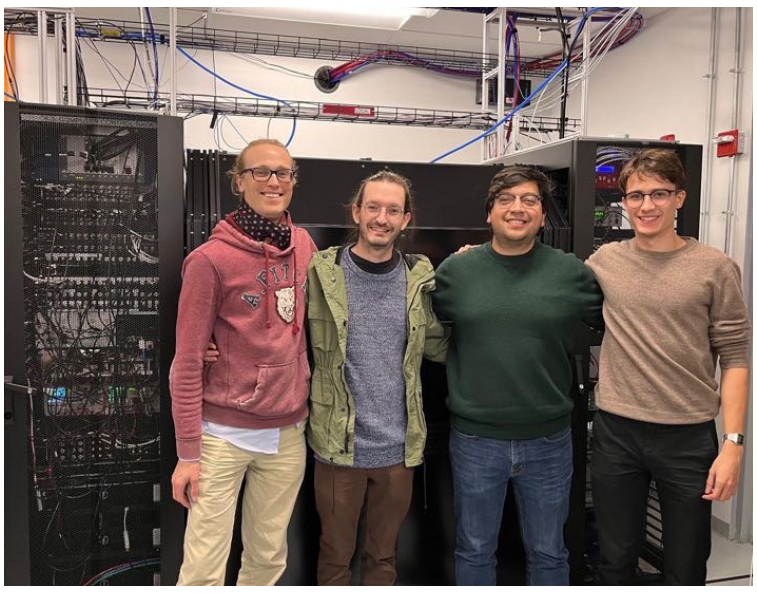
Building tomorrow's quantum computers, teaching tomorrow's scientists

Sergio Cantu's dual mission spans multiple continents.

BY SOPHIA CHEN

Sergio Cantu, the vice president of quantum systems at QuEra, puts a sticker on the company's first quantum computer. Sergio Cantu

Sergio Cantu lives in Massachusetts, but this spring he is in Tokyo, where he and his colleagues are unpacking quantum computer parts that they've sent across the ocean. The core of the computer is a small glass cube filled with 30 grams of neutral rubidium atoms, 260 of which will serve as qubits at a time. "You hope that things didn't shake too much during shipping," says Cantu, the vice president of quantum systems at QuEra, a Boston-based quantum computing startup.



The science team for QuEra's Gemini class quantum computer, including Cantu (third from left). Sergio Cantu

Cantu's team is building the quantum computer at Japan's National Institute of Advanced Industrial Science and Technology. There, researchers will use the machine to develop quantum algorithms and work to integrate it with the institute's supercomputer. "It has been an opportunity of a lifetime," says Cantu, also an APS member.

This isn't Cantu's first international experience. Born as an American citizen in Texas, Cantu moved across the border as a child to Tamaulipas, Mexico, when his father got a job as state postmaster general. After attending high school in Mexico, he returned to the U.S. to study physics, first at the University of Texas at Brownsville, and later at the Massachusetts Institute of Technology for his Ph.D. "I always knew I wanted to do experiments," he says.

As a student, Cantu worked on instruments for gravitational wave detection for the LIGO collaboration. That led him to an interest in optics and lasers. In graduate school, he studied and built devices to study quasiparticles called Rydberg polaritons formed from atoms and photons, which paved his way toward his current job building quantum computers.

After earning his Ph.D. in 2021, he began working at QuEra, which had fewer than 10 employees at the time. The company has grown to a few dozen employees, with plans to expand to 130 by the end of the year.

But the path hasn't been easy.

Sergio Cantu continued on page 5

THIS MONTH IN PHYSICS HISTORY

June/July 1925: Werner Heisenberg pioneers quantum mechanics

Heisenberg's matrix mechanics fixed the holes in quantum theory by taking physics into the realm of pure abstraction and math.

BY KATHERINE BOURZAC

In 1925, quantum theory was in crisis. Physicists' understanding of the structure of atoms and the nature of light wasn't consistent with experimental observations. The great physicists of the day tried fix after fix, but they couldn't resolve the problem.

On June 6, a swollen-faced, stuffy-nosed Werner Heisenberg, then 23 years old and suffering from hay fever, left his home in central Germany for the fresh air of the North Sea island of Helgoland, hoping for relief. There, he had a breakthrough, becoming the first to articulate a mathematical framework of quantum mechanics and resolve the then-glaring contradictions of quantum theory — while raising uncomfortable questions about the nature of reality.

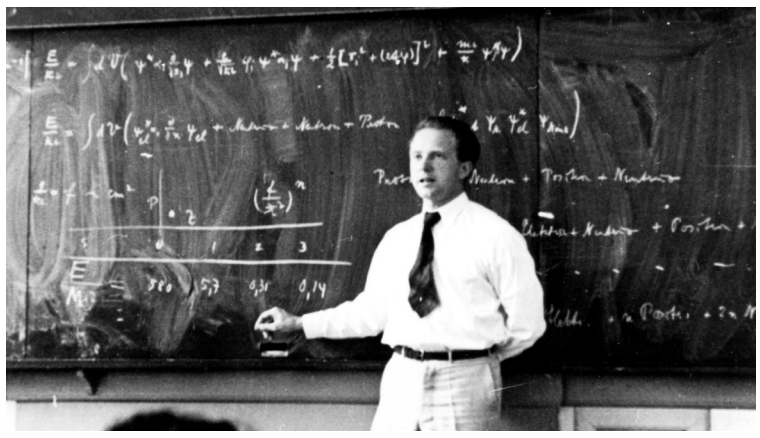
Heisenberg was born in Würzburg, Germany, in 1901. Growing up during World War I and disgusted by its aftermath, he became a leader in his local New Boy Scouts, which promoted nationalistic ideas and embraced German romanticism through poetry, music, and natural beauty. (Hitler banned such groups in 1933.)

Heisenberg was also a brilliant student. In the fall of 1920, he started his doctorate at the University of Munich, where he published well-regarded papers on quantum theory — but struggled in the lab. Despite his deep interest in the nature of light, he couldn't answer questions during his orals about microscopes, telescopes, and the interferometer he'd used in his lab course. He received the equivalent of a "C" grade, which humiliated him. While he was a skilled theoretician, he was no experimentalist.

Still, Heisenberg graduated in just three years' time. He then worked as an assistant to physicist Max Born in Göttingen, with an interlude during the school year of 1924-25 at Niels Bohr's institute in Copenhagen. By this time, the problems with quantum theory had become impossible to ignore.

Bohr had articulated the current picture of the atom, made up of electrons circling around a nucleus like planets around the Sun. "It was quite visual," says physics historian and CNRS research director emeritus Olivier Darrigol. "You could describe the shapes of their orbits, or at least try to."

Even Bohr knew this theory was inadequate. It couldn't predict the observed behavior of atoms, particularly their spectra — how they absorbed and emitted light. And physicists could not actually observe the orbits of electrons.



Werner Heisenberg lecturing in Copenhagen in 1936. AIP Emilio Segrè Visual Archives

Faced with this impasse, Heisenberg made a bold leap into abstraction. If the orbits of electrons could not be observed, why insist that they existed? "The genius of Heisenberg is that he was able to conceive a brand-new theory without picturing it," says Darrigol.

He decided to derive quantum mechanics based on observable quantities: atomic spectra. He focused his calculations on the frequency and intensity of light emitted by the simplest atom, hydrogen.

Heisenberg was working on his calculations in the months leading up to his allergy-driven escape to Helgoland in 1925, but he was stuck. So were his colleagues, collaborators, and correspondents. In May, Wolfgang Pauli wrote to Ralph Kronig, "Physics is at the moment once again very wrong."

According to Heisenberg's account decades later, it was during an all-nighter in his lodgings at Helgoland that he made his breakthrough. After writing into the early morning, he triumphantly climbed a rock at the edge of the island and watched the sun rise (although some historians have raised doubts about this romanticized story.)

Heisenberg's equation described quantum mechanics not based on electron motion, but on atomic energies and arrays of probabilities.

Accounting for electron motion required complex, abstract math. When an electron jumps from one state to the next lowest one, then to the one below that, "the two emitted frequencies must add together to produce the frequency that is actually observed," writes physics historian David C. Cassidy in his biography of Heisenberg, Beyond Uncertainty. "Heisenberg found that, mathematically, if the frequencies do add together, then the two amplitudes do not simply multiply together but are subjected to a new and strange multiplication rule involving all of the possible intermediary states — just in case the electron takes a circuitous route in getting from one place to another."

The new approach made the movement of the electron abstract. Heisenberg said as much, declaring in a July 9 letter to Pauli, "My entire meager efforts go toward killing off and suitably replacing the concept of the orbital paths that one cannot observe."

In July, Heisenberg submitted this work to the journal Zeitschrift für Physik, which published the paper in September.

Heisenberg provided "a theory without a picture," says Darrigol. "It's a discovery based on completely counterintuitive ideas." For that reason, though many of these ideas had been hashed out in letters and conversations with Bohr, Pauli, and others, Heisenberg may have needed time alone to make the leap. "The fact that he was isolated, not talking to other people, may have helped," says Darrigol.

Physicist Max Born recognized that Heisenberg's arrays resembled the matrices used in linear algebra, and worked with his assistant Pascual Jordan to expand the mathematics of what would come to be called "matrix mechanics." Heisenberg and Pauli also added to the theory to account for electron spin, which made it possible for matrix mechanics to account for the effects of magnetic fields on atomic spectra — previously a hole in the theory.

Physicists were excited about the predictive power of matrix mechanics, but dismayed and even

Heisenberg continued on page 7

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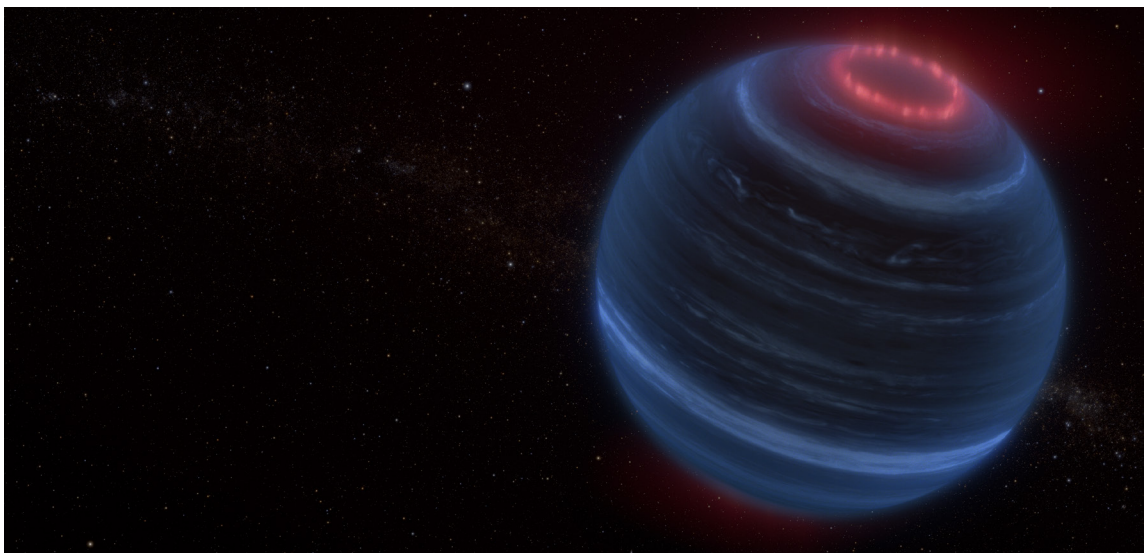
Nature's magnifying glasses can spot the northern lights on distant planets

To help researchers study exoplanets, radio telescopes and microlensing could work in tandem.

BY BRILEY LEWIS



An artist's rendition of brown dwarf W1935, 47 light-years from Earth, which scientists think may have aurorae, shown in red. A new method of gravitational lensing could allow scientists to observe radio waves from planets around other stars — and glimpse the magnetic fields that give rise to aurorae. NASA, ESA, CSA, and L. Hustak (STScI)

Einstein's famous description of spacetime as the fabric of the universe leads to some peculiar facts of nature. Among them: The universe makes its own magnifying glasses.

At the 2025 APS Global Physics Summit, astronomers shared how these cosmic magnifying glasses, known as gravitational lenses, could allow us to observe radio waves from planets around other stars. The technique they propose would combine the forces of two upcoming powerhouse telescopes, NASA's Roman Space Telescope and the international Square Kilometer Array, to double the number of new exoplanets Roman will find.

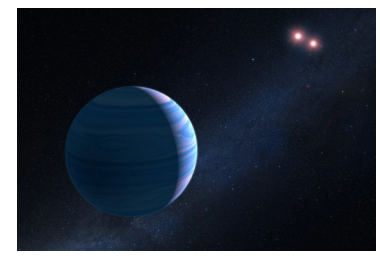
This technique is "a completely new way of detecting and studying exoplanets," says lead author and presenter Fatemeh Bagheri, an astronomer at NASA's Goddard Space Flight Center. "We are tapping into a new observational window that could provide more direct and detailed information about these distant worlds."

> A strong magnetic field is a prerequisite for a stable atmosphere — and as a result, the possibility of extraterrestrial life.

Bagheri's new technique relies on a well-established way of detecting exoplanets: gravitational microlensing. Gravitational lensing happens when light from a star has to bend around a massive object on its way to our telescopes, making the star appear magnified from our perspective. This natural magnification zooms in on distant objects that we otherwise wouldn't have any chance of detecting, because they'd be too faint and small without the lens. The James Webb Space Telescope has captured snapshots of the most distant galaxies ever seen, thanks to lensing.

Microlensing is essentially the same process on a smaller scale. When light from a background star is lensed by a star closer to us — and that nearby star has a planet around it — the planet's gravity will add an extra bend to the background star's light. In practice, the lensing planet adds a blip on top of the signal you'd expect from a typical lone star. The Roman Space Telescope, expected to launch by May 2027, will excel at this planet-hunting technique and is expected to find about 1,400 exoplanets with microlensing. (Roman is also going to be good at the transit method. Scientists predict it will make over 100,000 new transiting exoplanet detections — more than fifteen times the total number of exoplanets discovered to date.)

Typically, microlensing looks for indirect evidence of a planet around the star doing the lensing. But Bagheri's proposed method would directly record emission from a planet around the background star — "a distinct approach compared to the one used by the Roman team," she says.



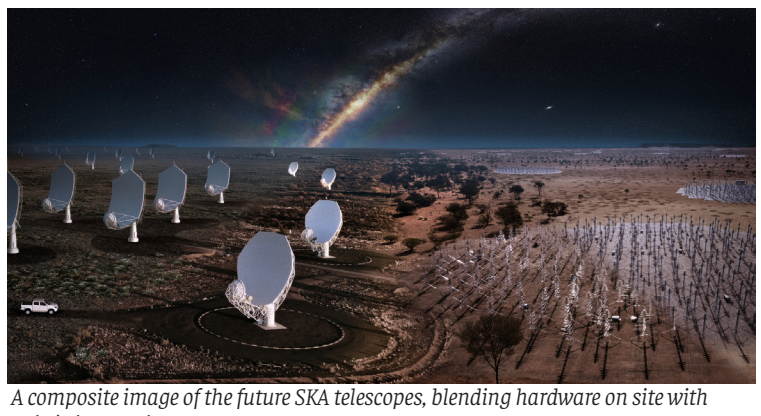
An artist's illustration shows a gas giant exoplanet circling a pair of red dwarf stars in the system OGLE-2007-BLG-349, located 8,000 light-years away. NASA, ESA, and G. Bacon (STScI)

When a background star is magnified by a gravitational lens, a planet's emission — whether infrared, radio, or any other part of the electromagnetic spectrum — is magnified, too. In Bagheri's plan, Roman will spot a microlensing event in the infrared, then trigger a notification for astronomers to point their radio telescopes at that target for follow-up.

Why look at a planet with radio waves? Radio waves are just long wavelengths of light, and stars simply don't emit a lot of them, making it easier to spot a planet amidst the light from stars.

Radio waves are also a unique window into a planet's magnetic

Exoplanets continued on page 7



A composite image of the future SKA telescopes, blending hardware on site with artist's impressions. SKAO

In turbulent times, physics department leaders share strategies for moving forward

Department representatives from nearly 80 institutions convened in Chicago for the inaugural APS Thriving Department Symposium.

BY KENDRA REDMOND

Attendees at the APS Thriving Departments Symposium. APS

In June, more than 100 physics department leaders and changemakers — from chairs to students — convened in Chicago for three days with one purpose: creating thriving physics departments.

The challenge has snowballed over the last several months, as executive orders have terminated federal science grants; dismantled diversity, equity, and inclusion initiatives; and moved to change the accrediting process for higher education institutions.

"It has felt a little bit like the end of the world," says Andrea L. Del Vecchio, chair of the physical sciences department at Rhode Island College. The symposium, she says, was a boost to the spirit — an optimistic forum for discussing how the community can best serve physics students and prepare the STEM workforce, despite growing threats.

APS and the American Association of Physics Teachers (AAPT) laid the groundwork for the new symposium last fall, with support from the National Science Foundation and University of Chicago. They designed it to reflect a holistic view of physics education, weaving together strands for physics department chairs, leaders of graduate education programs, and those dedicated to creating more welcoming and inclusive departments. These groups typically meet separately through events like the Physics Department Chairs Conference, Conference on Graduate Education in Physics, and APS-IDEA network.

This year, planning for the symposium took on a sense of urgency, says Kathryn Walters-Conte, Head of Innovation at APS. As early as the APS Annual Leadership Meeting in January, the community expressed a heightened need for departments to align and share ideas, she says, realizing that they would need to shoulder more of the efforts to support students, despite fewer resources.

Representatives from 78 institutions attended the symposium, meeting in interactive sessions on recruitment, retention, graduate enrollment, and mentoring.

During a session on preparing students for diverse career paths, Christine Nattrass, a professor and director of the undergraduate program at the University of Tennessee, Knoxville, highlighted a low-cost, one-credit careers seminar at UT. The seminar largely consists of weekly one-hour Zoom sessions with recent physics graduates, who discuss their careers. Given the federal funding situation, conference attendees seemed especially drawn to lean but effective programs like this, Walters-Conte says.

Current and proposed federal science funding cuts are prompting many departments to prioritize career preparation. "Graduate admissions have been wild," Nattrass says. Many excellent undergraduate students who would have been accepted in a typical year weren't because of fewer openings, she says.

James Kakalios, head of the School of Physics and Astronomy at the University of Minnesota, says his department didn't cut graduate admissions this year. Still, the situation is uncertain for next year. Current admission numbers assume that students will become research assistants within a few years, he says, and whether that assumption remains valid depends on federal funding. Navigating the fluid situation "is like trying to build a house in a lava lamp," he says.

> Navigating the fluid situation "is like trying to build a house in a lava lamp," Kakalios says.

A new chair, Kakalios attended the symposium to get ideas for navigating the challenging environment and building a stronger department community, which he sees as essential to a thriving department. Echoing the words of the late Senator Paul Wellstone, Kakalios says, "We all do better when we all do better."

This is a longstanding value in the physics community, made evident by initiatives like the APS-IDEA network, which seeks to make the discipline more accessible and collaborative. However, in the face of recent anti-DEI orders and state laws, some institutions have begun eliminating programs designed to support students.

That's the main reason Jessica Burns, a University of Cincinnati graduate student, attended the symposium. "I was hoping to get a clearer idea of what can be done, and should be done, to make physics more equitable for our department," she says. The question of what can be done became more urgent this spring, when a new measure to support students in the College of Arts and Sciences was abruptly rolled back by administrators, she says.

Burns says the faculty members in her department have been supportive of equity measures but unclear about what they're allowed to do. She left the symposium more hopeful than she arrived, with new ideas and a better understanding of what her department can implement. She says she was especially encouraged when Art Coleman, a founding partner of EducationCounsel LLC, highlighted the growing pushback against many of the executive orders in his keynote.

Despite the challenging climate, the symposium had an optimistic and collaborative energy, says Marvin Jones, a graduate student at Indiana University and a member of the APS-IDEA Steering Committee. "People came genuinely ready to ask questions and engage in really tough conversations," he says. "It gave me a lot of hope."

Kendra Redmond is a writer based in Minnesota.

How one undergrad found career support through APS mentorship

To prepare for the private sector, Taylor Eskew learned from an expert.

BY AARON RAGAN-FORE

For many students and early-career scientists today, launching a career is a daunting prospect. The landscape has been shaken by funding cuts and job losses, and scientists are increasingly struggling to move, work, and live freely throughout the world.

Taylor Eskew, an undergraduate physics and computer science double major at Chapman University, is navigating these pressures ahead of her 2027 graduation. "It feels like you're just expected to figure it out yourself," she says.

She's interested in quantum physics and high-performance computing, and though she enjoys the leg-up of conducting research at the Institute of Quantum Studies, she has concerns about the job market in such "uncertain and transitional times," she says.

Earlier this year, she knew she needed "to make sure that my materials, particularly my resume, were competitive, professional, and field-specific." So Eskew registered for a one-on-one APS Career Mentoring Fellows coaching session at the 2025 Global Physics Summit in Anaheim.

Taylor Eskew, Chapman University physics student and APS mentee.

"A mentor who knows your field"

The Career Mentoring Fellows program connects students and early-career physicists with working physics professionals to discuss career trajectories and strategies.

Eskew knew she was interested in graduate school or an internship, and eventually a career in industry, so she was thrilled to meet with Neha Pachauri, a process engineering manager at Amazon and APS Career Mentoring Fellow.

Almost immediately, Pachauri offered "thoughtful, highly targeted feedback," says Eskew. "It really wasn't a list of corrections to make, but it was the type of comment you would expect from a mentor who knows your field inside out, and its requirements."

Neha Pachauri, Amazon process engineering manager and APS mentor.

For Pachauri, Eskew's desire to transition from academia to industry made the pair a good mentor-mentee fit. Pachauri hails from a small city in India and had no professional models for a career in physics. And as a former international student who earned her Ph.D. at the University of Alabama, she understood the anxiety that many entering the job market now feel.

"Some of them are theoretical physicists and they don't know how to transition into industry," Pachauri says of the students and early-career scientists she counsels. "They don't have insights into how the industry job market works. They don't have exposure to what kinds of different types of jobs exist."

Pachauri says that Eskew was already a strong communicator, "confident and clear" in person and on her resume, but that Eskew "didn't know how to tailor it for the industry audience," a gap Pachauri could address.

"A different journey"

Pachauri's desire to give back to the physics profession doesn't end with the Career Mentoring Fellows program. She regularly volunteers at APS meetings and has served as a panelist for careers sessions and at APS Conferences for Undergraduate Women and Gender Minorities in Physics (CU*iP).

But Pachauri was once hesitant to volunteer for APS. Her experience was too scattered between academia and industry, she thought, and made her "uncertain whether I could effectively relate to and contribute value to early physics professionals focused on core physics areas."

"Then I realized this is an asset," Pachauri says. "I have had a different journey compared to others, and it will be beneficial for people to understand how you can navigate your career and grow in different directions."

Eskew feels fortunate that Pachauri volunteered. "The [mentoring] session helped my approach not only with resumes, but with how I tell my story in applications and interviews," she says. "I have since had a string of successful conversations for fellowships, national labs, and research programs."

"It made a huge impact on how I came across in print, and really, how confident I was going after competitive opportunities," Eskew says of her meeting with Pachauri. "The Fellows are able to assist thoughtfully and graciously. They're people who understand, and they genuinely care."

APS tools for job-seekers

APS can help you land your next job or plan your career.

- Visit the Physics Jobs Board at go.aps.org/JobBoard for up-to-date job listings.
- Plan your journey with the APS Career Navigator tool at go.aps.org/careernav, which includes chapters on resume-writing, networking, and seeking informational interviews.
- Discover physics careers and trends in the annual Careers Guide at go.aps.org/careerguide.
- Join the Career Mentoring Fellows program at go.aps.org/CMF.
- Learn from APS' resource set for industrial physicists at go.aps.org/industry.

Aaron Ragan-Fore is a head of communications at APS.

Science funding decisions still to come, following passage of reconciliation bill

The recent spending bill is separate from federal science spending.

BY TAWANDA W. JOHNSON

The "One Big Beautiful Bill Act," signed into law on July 4, is different from the fiscal year 2026 budget process. The bill is slated to enact some policy changes that impact R&D, but it does not impact spending plans for most federal science agencies.

JHVEPhoto - stock.adobe.com

Passed under the special budget reconciliation process, the bill extends some tax cuts, reduces spending on Medicaid and other entitlement programs, and boosts funding for border security and defense, among many other provisions.

The bill touches on areas that impact research and development, including new tax breaks for private, domestic R&D and a tax increase on large university endowments.

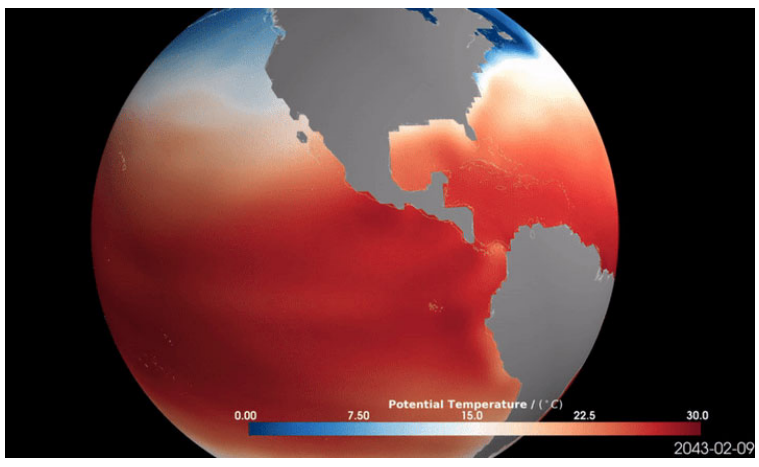
However, the bill does not reduce or cancel any existing research grants, and it does not reduce discretionary spending for the National Science Foundation, Department of Energy Office of Science, NIST, and NASA Science Directorate. That funding will be handled through the standard appropriations process, which is underway for fiscal year 2026. Decisions about research funding will happen in the coming months in the House and Senate.

APS continues its advocacy efforts to support robust budgets for the science agencies, and APS members and non-members can play a key role. To learn more about this work, and to help directly, visit the APS in Action campaign at go.aps.org/APSinAction. If you are facing financial hardship, you can also request a membership fee waiver.

Tawanda W. Johnson is the senior public relations manager at APS.

Climate Science continued from page 1

Climate" sessions, many talks focused on using AI to learn from climate data, said Ching-Yao Lai, an assistant professor of geophysics at Stanford University and session co-chair. "We still rely heavily on existing physics-based models," said Lai. "[But now], there are emergent examples of leveraging all the observations we have, then directly learning new physics from those observations."



Samudra, an AI emulator, models the global ocean. Samudra — created by M²LInES, a research collaboration led by Laure Zanna — is trained on data from an ocean climate model. M²LInES/Laure Zanna

AI can also help with model parameterizations — the process of replacing small-scale or complex processes with simplified versions — by allowing researchers to "integrate large amounts of data with preexisting physics-based models [to parameterize] processes that are still poorly understood," said Lai. One example, presented by Schneider, was CliMA, a hybrid physics-AI model that runs on the cloud and can incorporate up to 100 terabytes of data.

There's also been progress in using AI for climate emulators, or models designed to mimic a specific system by "machine learning the whole dataset," said Zanna, who presented Samudra, an emulator that can model physical interactions of the ocean, atmosphere, and sea ice.

Along with sessions on statistical physics, dynamical systems, and more traditional climate physics research, the AI-focused climate talks at the summit covered a broad spectrum of topics, including advances in machine learning algorithms, methods for predicting sub-seasonal weather patterns, and climate modeling with quantum computing algorithms.

Researchers have more work to do to realize AI's full potential in climate science. "The challenge for AI/machine learning models is still to predict climate change — the new dynamics and patterns, with more extreme events, that the models have not seen before," said Jörg Schumacher, professor of mechanical engineering at Technische Universität Ilmenau and session co-chair, in an email.

But it's a challenge that scientists are motivated to tackle, as this research could lead to faster, more precise climate models that use less computing power and enable the "discovery of physics we have not seen before," said Lai.

Schneider is hopeful that advances in AI could vastly increase both the precision and speed of existing climate models. "We've seen something like a 10% improvement per decade in key metrics," he said. "I want to see 50% improvement — so five decades worth of progress realized in a much shorter time."

Zanna believes that AI can continue to bolster the field if researchers continue to use a multi-pronged approach. "It's [going to be] a combination of physics, data, and simulations that are going to be one of the breakthroughs," she said.

Ragone added that while AI's future impacts look promising, he's also hopeful to see continued research on more precisely quantifying uncertainties in models, which can lead to better predictions.

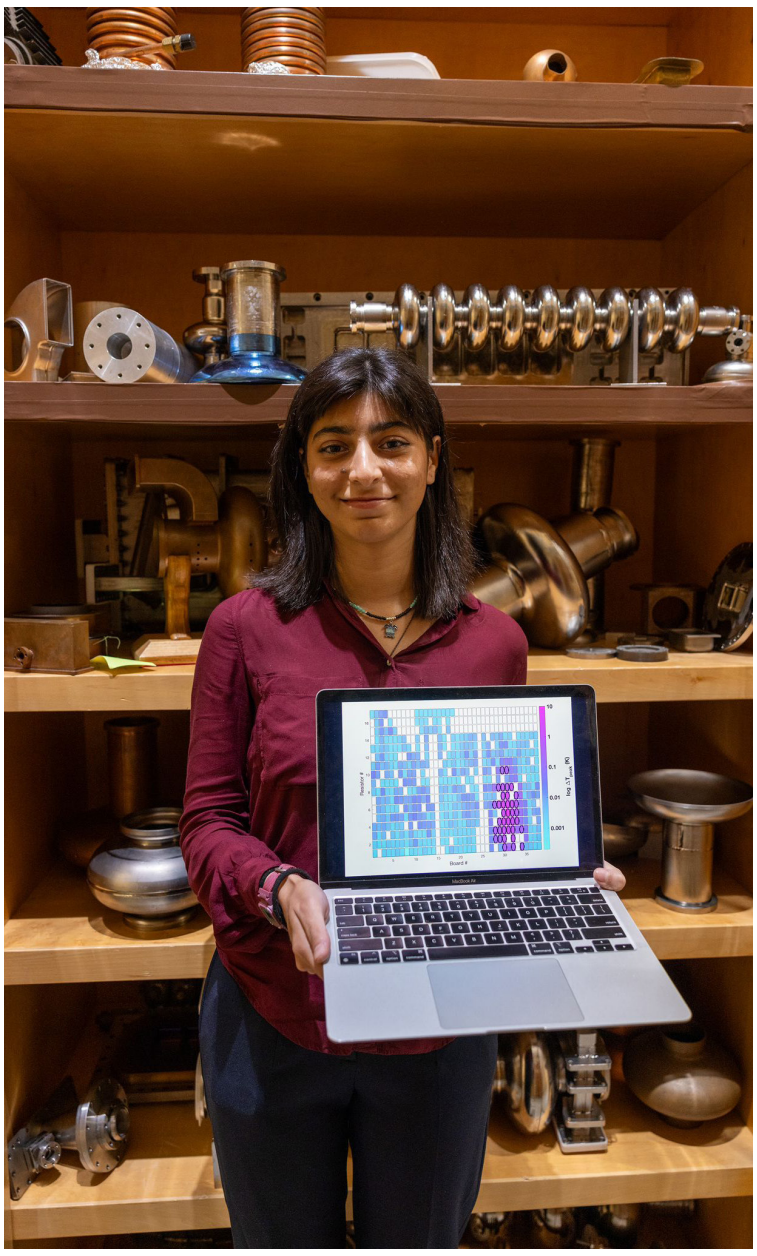
"The presence of [GPC] this year at the [Global Physics Summit] has been the largest to date — there has always been a niche group of people working on these things, but in the past few years, with the recognition of the Nobel Prize and of course with the emergence of AI applications, I think this [field] is trending upward quite a lot," said Ragone.

Erica K. Brockmeier is the science writer at APS.

From watching physics videos in Pakistan to supporting fellow physics students in Wisconsin

For Laraib Irfan, the APS Student Ambassadors program was "the perfect way to get connected with the community."

BY KENDRA REDMOND



Irfan displaying her research. Laraib Irfan

As a high school student in Lahore, Pakistan, Laraib Irfan wasn't sure what field of science she wanted to study — until she got hooked on YouTube videos about the Big Bang and other physics. "This entire idea of where we come from" interested her, she says. She decided to major in the field and headed to Beloit College in Wisconsin to start her first year of college.

It was an adjustment. "Back at home, [physics] was mostly rote learning," she says. At Beloit, a liberal arts college, physics classes were rooted in creative problem-solving. Irfan is grateful for that approach, but it felt new. And the physics department was small, with only a few professors. She felt isolated.

That began to change when a new professor, Carlos Cartagena-Sanchez, joined the department. The small community became more cohesive. They started a physics and astronomy club, hosting social activities and campus stargazing nights. Irfan started to get to know and rely on her classmates.

To hone her research skills, Irfan applied to a program at the U.S. Particle Accelerator School. As part of the application, the organizers had students sign up for APS publications. Soon after, she got an email from APS seeking APS Student Ambassadors.

"I thought this was the perfect way to get connected with the community," she says.

As an ambassador, Irfan is the APS point of contact for her campus community. She keeps her department informed about APS meetings, scholarships, grants, and other opportunities, encouraging students to apply and stay active in the larger physics community. It's a role she's happy with.

Laraib Irfan (right) with physicists Christine Darve (left) and Talat Rahman, who she met at the APS Annual Leadership Meeting in January 2025. Their conversations "made me feel a lot more comfortable with the process of enrolling in a doctoral program," Irfan says. Laraib Irfan

"Before I joined APS, I did not know of any physics students [on campus] who had gone to any conferences," she says. But when she became an ambassador in January 2024, she started hearing about the upcoming April Meeting in California. She shared the details with fellow undergraduates and, a few months later, four of them — all first-time conference attendees — arrived in Sacramento. Beloit's Physics and Astronomy Club now prioritizes sending students to conferences.

In January 2025, Irfan attended the APS Annual Leadership Meeting and met other student ambassadors, APS leaders, and a physicist from her home country, Talat Rahman. By coincidence, Rahman had earned her Ph.D. from the University of Rochester, where Irfan had just been accepted for graduate school. The chance conversation " made me feel a lot more comfortable with the process of enrolling in a doctoral program," Irfan says. She'll be starting at Rochester this fall.

"Talking to people and networking is really a very strong form of encouragement," Irfan says. She credits the APS Student Ambassador program for helping her make new connections — and helping her peers do the same. "It has been a really enriching experience."

Kendra Redmond is a writer based in Minnesota.

Sergio Cantu continued from page 2

He found it particularly difficult to navigate the American higher education system, as someone who grew up outside of it. "It was just not very clear," he says. "How do you apply to college? How do you apply to do science? What's a Ph.D.? How do you apply to a Ph.D.? What's a GRE?"

These gaps became evident when Cantu applied to attend university in the U.S. For the first application, he sent his awards and medals he'd received, along with the original and only copy of his high school diploma, to a university. In Mexico, universities commonly ask for original copies as a measure against fraud. "I thought that I would get them back to send to the next school," he says. "I kept waiting and waiting."

He finally contacted the university, which returned his materials. He had enough time to apply to other schools, but it was a stressful lesson to learn.

In graduate school at MIT, Cantu wanted to find a way to share his knowledge of American universities with other Mexican students. He found that opportunity in a new nonprofit named Clubes de Ciencia.

Clubes for short, the group organizes weeklong science workshops for high school students and undergraduates over the summer in multiple cities in Mexico. For each workshop, they pair a Mexican academic with a non-Mexican academic as instructors to teach subjects ranging from physics to biology to climate change. "We want to empower and inspire a new generation to pursue a career in science and technology," says Carla Marquez-Luna, a geneticist and a current co-director of the nonprofit. Clubes has about 100 volunteers and one full-time and one part-time employee.

Cantu joined a few months after the group formed in 2013. The program has taken off. Since then, Clubes has hosted more than 7,500 students in Mexico, 51% of whom are women.

The workshop began in just one city in Mexico, Guanajato, and now operates in 10. Cantu started the workshop in Monterrey, which is near where he grew up. "Because I'm from the border, I wanted to have an option in the northeast of the country," he says. Clubes has also expanded to seven more countries, including Brazil, Colombia, Bolivia, and Spain.

The workshops emphasize hands-on activities. Cantu, for example, has taught workshops on laser encryption, where students build their own lasers using diodes and Raspberry Pis. In 2023, he taught his students to perform experiments using Aquila, a QuEra-built quantum computer available on the cloud that he named and helped to build. The interactive approach contrasts with his early science education in Mexico, where the curriculum prioritized textbook learning. "I didn't see a multimeter until I got to college," he says.

The workshops have given Cantu the opportunity to mentor students from a similar background. In 2015, Grecia Castelazo met Cantu when she attended Clubes de Ciencia in Monterrey as a high school sophomore. Having participated in international physics competitions, she knew she was interested in physics and sought Cantu for advice.

Cantu excels as a science communicator, says Castelazo. "He finds the language to make a lot of these concepts accessible, and he's just very kind," says Castelazo. "I'm sure there's a million computations going in his head, but when you talk to him, he's so calm."

Cantu's example made her ambitions of studying physics at a U.S. university more real. "He had already gone through the things that I wanted to do," she says.

Castelazo got into MIT in 2017. In 2019, Cantu recruited Castelazo to work as a teaching assistant for that summer's Clubes workshop in Ensenada. Now, Castelazo is a first-year Ph.D. student at the University of California, Santa Barbara, studying quantum algorithms for near-term machines — perhaps future upgrades of the machine that Cantu is installing in Japan.

For Cantu, cultivating community has always been part of his scientific career. Prior to his work in Clubes, as an undergrad member of APS' Texas Section, he would travel around high schools in Texas performing demos in a show called The Physics Circus. And now in Japan, he's met a new group of people excited about physics. "The Japanese community has been very welcoming," he says. "It's nice to work in an environment where people are excited about what you're doing."

Sophia Chen is a writer based in Columbus, Ohio.

APS president elected to National Academy of Sciences

In April 2025, APS President John Doyle, the Henry B. Silsbee Professor of Physics at Harvard University, was elected to the prestigious National Academy of Sciences. The academy recognizes scientists for "distinguished and continuing achievements in original research."

Doyle has served as the APS president during a milestone year for APS, which has included the International Year of Quantum Science and Technology and the inaugural APS Global Physics Summit.

APS celebrates this well-deserved recognition of Doyle's outstanding contributions to science.

Science Policy continued from page 1

Administration to accelerate missions through AI and $150 million for DOE to take steps toward developing "self-improving artificial intelligence models for science and engineering," mainly by cleaning and preprocessing scientific data for use in such models. The bill directs the national labs to partner with industry to curate that data. DOE launched its Frontiers in AI for Science, Security, and Technology initiative last year, which includes efforts in AI for science and AI for national security.

Those AI models will be provided to the research community via a cloud computing service called the "American science cloud" dedicated to scientific research, data sharing, and computational analysis. The bill notes two possible uses for the preprocessed data: rapidly developing next-generation microelectronics and discovering new energy technologies.

The bill reauthorizes the Radiation Exposure Compensation Act and expands eligibility for those seeking compensation, including adding affected areas and modifying qualifying cancers. RECA, which expired one year ago, provides compensation for people exposed to radiation from nuclear weapons testing and manufacturing.

The bill restores the Federal Communications Commission's authority to auction spectrum through 2034 and requires the FCC to auction at least 800 megahertz within eight years. It specifies some bands with military uses to be excluded from consideration for auction, but does not include carveouts for radio astronomy or meteorology.

The bill includes nearly $25 billion for the "Golden Dome" missile defense shield proposed by President Trump in January, including space-based sensors and phase intercept capabilities as well as directed energy research. It also provides nearly $4 billion for NNSA, much of which goes toward nuclear weapons and facility upgrades.

The bill also includes $250 million for the Defense Advanced Research Projects Agency's Quantum Benchmarking Initiatives. The bill provides nearly $4 billion for the National Nuclear Security Administration, including $200 million for concept studies of new nuclear weapons, $1 billion to accelerate construction of facilities, $540 million for deferred maintenance, and $100 million to accelerate domestic uranium enrichment.

The bill provides nearly $10 billion for NASA programs, including funds for the Gateway lunar space station, Space Launch System rockets, and a telecommunications orbiter for use in a Mars Sample Return mission, all of which would be terminated under the president's 2026 budget request.

Clean energy and climate funds are hit hard by the bill, as it rescinds billions of dollars in unobligated Inflation Reduction Act funding from DOE and phases out the clean energy production tax credit.

Clare Zhang is a science policy reporter at FYI, published by the American Institute of Physics.

Biomedicine continued from page 1

A nurse works with a volunteer undergoing a study in a metabolic chamber at NIH in 1957. Federal funding for the NIH and other research agencies expanded significantly after World War II. National Institutes of Health

The president's budget request is not set in stone; Congress must ultimately approve a budget, and both the House and Senate typically propose their own spending bills that can differ significantly from the president's proposal. But the risks are dire. "For decades, the United States has been regarded as premier in graduate education," says MacDonald. "That's something we could be on the cusp of losing."

The U.S. government's support of research dates back decades. When the U.S. entered World War II, the government bankrolled over $9 billion in defense-related research and development. These investments helped defeat the Axis Powers, and in the war's aftermath, they inspired a powerful realization in Washington: Scientific discovery can determine a nation's fate.

A new paradigm was born, and the government adopted a fresh identity as the primary financier of the scientific enterprise. In 2023, the U.S. government spent nearly $190 billion on research and development, with roughly $60 billion directly supporting research in higher education. In 2020, U.S. institutions of higher education awarded nearly 42,000 STEM doctoral degrees, surpassed only by China.

This research investment has returned dividends — more than $5 in social benefit for every dollar spent, according to a 2020 paper from the National Bureau of Economic Research — and made U.S. science and technology the envy of the world.

But this engine of innovation is imperiled. The administration's proposed cuts would affect researchers in every STEM discipline, including scientists who work at the intersection of physics and medicine, developing new therapeutic techniques and diagnostic tools.

Amanda Peiffer, a postdoctoral researcher in chemical biology at MIT, is also funded by NIH. "All the work I do — the experiments, the training of graduate students — is supported through federal grants," she says.

Peiffer focuses on developing novel compounds to treat antimicrobial-resistant infections, which are on the rise. Major pharmaceutical companies seldom fund this line of research, she says, because it's viewed as financially "risky." So academic labs, largely supported by federal funding, have become the de facto home for fundamental research in the biomedical sciences, where "you have the freedom to explore new ideas."

The administration's proposed R&D funding cuts also include caps on indirect costs for grants issued by the Department of Defense, Department of Energy, NSF, and NIH. 'Indirects,' a type of overhead, allow institutions to recoup a range of expenses associated with research support, such as handling of biohazardous waste. For universities with biomedical research programs, the proposed 15% cap could leave entire centers without sufficient funds for the simplest expenses, like electric bills, says MacDonald.

"The whole machine stops without the federal funding mechanism in place," says Peiffer, who is waiting to hear from NIH about multiple grants. "If we cannot get funding in, it will be absolutely devastating to the graduate students. The postdocs will inevitably have to leave," including Peiffer.

While she had planned to pursue a career at an American university, she plans to exit academia for the private sector. "This is not the environment I'd been hoping to start my career in," she says.

Kate Chain, a graduating physics major who plans to begin a Ph.D. program this fall, says that, fortunately, her future research advisor still has access to internal funds from his university. And Chain has a head start in her research area: stimuli-responsive elastomers, which could underpin a new generation of orthopedic support devices, like knee braces.

But her best hope for financial security during her doctoral studies would have been NSF's Graduate Research Fellowship Program, she says. Recently, the GRFP has awarded roughly 2,300 new fellowships each year, valued at about $53,000 annually per student. This April, the program extended just 1,000 awards for the next class.

Without the award, Chain says her advisor can only guarantee funding for three years. The typical STEM doctorate takes at least four years to complete.

Federal funding also set Chain on her current path: In college, she participated in two summer Research Experiences for Undergraduates (REUs). In 2024, NSF allocated $85 million to the program, which helps roughly 10,000 undergraduate students access research labs each year.

As an undergrad, "I wasn't sure what I wanted to do career-wise," says Chain. But her first REU experience solidified her love for physics, and the second set her on a course for graduate school. Now, "quite a few of my peers aren't able to do REUs because the funding was cut," she says. "We're going to lose a generation of scientists."

One national lab staff scientist, who asked not to be named, shares a similar sentiment. "Virtually all of my funding has been federal," he says. Like Chain, he was first exposed to research through NSF's REU program.

Today, he develops new methods for measuring nuclear properties, which could shape novel therapies for cancer. Figuring out patient dosage is "a major bottleneck with cancer therapeutics in clinical trials," he says. His current work, supported by a federal grant, offers a promising approach for targeted therapies.

But he fears that the odds of future funding are shrinking. And if the research groups with whom he could collaborate on clinical trials — the natural next step — are dismantled by federal cuts, it would create a major "choke point."

"I assume it would set this area of cancer research back by 10 to 15 years," he says.

At a medical imaging company based in the U.S., one R&D scientist, who asked to remain anonymous, is similarly worried about the "long-term implications" of the Trump administration's cuts to research.

After NSF funded his doctorate in physics, he completed a postdoc at a federally funded national lab before moving into the private sector. "A big part of the reason that our R&D division is located here, as opposed to anywhere else in the world, is that the U.S. has always been a really fertile location to hire people with Ph.D.s in STEM," he says. But if the proposed budget cuts hit U.S. doctoral programs, "then five years from now, when we need to start hiring new people, there just won't be any."

"Eventually, it could get to the point where the company says we need to move our research group to a country where there are actually scientists who can work for us," he says.

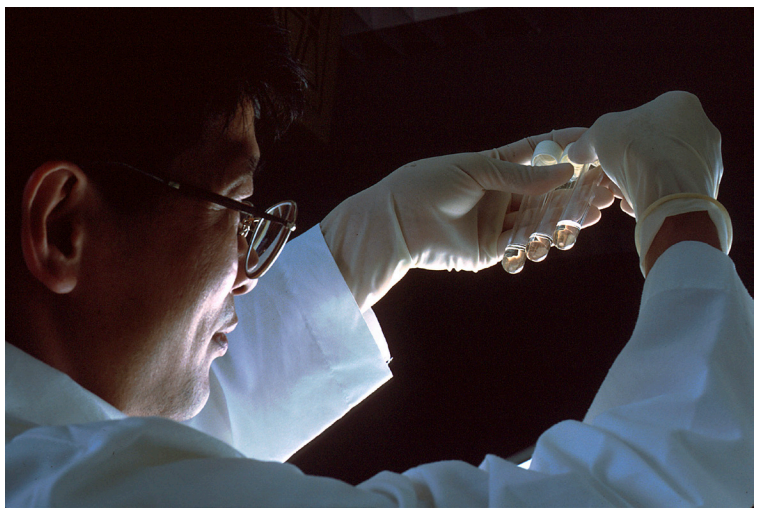
Findings like this could be revolutionary for the treatment of certain diseases, he says. For example, "we could do a lot more with diseases like Alzheimer's, with stroke and traumatic brain injury," he says. That's why Kelley's research has received funding from the U.S. Army Research Laboratory, which is interested in its implications for U.S. combat veterans, as well as from NIH.

But today, Kelley is fearful of the Trump administration's proposed budget cuts. And as of May 21, NSF and NIH — top funders for biomedical research — had already collectively canceled more than 3,000 awards, according to Grant Watch. Of NIH grants canceled, Grant Watch reports the tallies by keywords: HIV (206 grants canceled), cancer (133), brain (130), and aging (88), among others.

All the terminated awards amount to an estimated $1.9 billion from NIH and just over $1 billion from NSF. On May 28, the Department of Energy announced it had terminated $3.7 billion in clean energy projects. These canceled grants represent a savings of just 0.09% of the budget, given the $7 trillion in federal outlays in 2025 tabulated by the U.S. Congressional Budget Office.

"All of these things we've been building with the federal research funding, we're just losing — all of that infrastructure, the capital of being regarding as the place to go to do research, all of these health studies that are in progress — in order to save this relatively tiny amount of money," says MacDonald. "That's absurd."

These impacts are not inevitable, however. Many of the administration's actions, including its cancellation of billions of dollars in NIH grants, have successfully been challenged in court. Other lawsuits are still moving through the legal system.



A scientist at NIH working on HIV research. As of May 21, NSF and NIH had collectively canceled more than 3,000 awards, according to Grant Watch. John Crawford (photographer), National Cancer Institute, NIH

Doug Kelley, faculty at the University of Rochester since 2013, says the partnership between the federal government and U.S. universities has led to "a really great, well-trained [scientific] workforce" and "discovery after discovery."

"America is an unreasonably innovative place," says Kelley. "People debate about why, but almost everybody's list of reasons includes the fact that we have the best university system."

In Kelley's research lab — home to scientists at every step of the career pipeline, from undergraduates to staff researchers — his team is studying the mechanisms that pump cerebrospinal fluid around the brain. Last year, they discovered that lymph flow in the neck slows with age in mice — suspected to be one of the reasons that the clearance of brain waste slows over time. The team also found that drugs that make lymph vessels pump faster can restore some fluid flow and waste clearance.

And the Trump administration's budget proposal cannot take effect unless Congress approves. The final budget will emerge from negotiations between both congressional chambers, and it can look very different from what the president initially requested.

As a result, APS is mobilizing opposition through a 50-state advocacy campaign, aiming to reach legislators with a clear message: If enacted, the sweeping cuts would impact research in every state, and, in turn, the communities those institutions support.

APS members and non-members can play a key role in this advocacy campaign. To learn more about this work, and to help directly, visit go.aps.org/APSinAction.

Liz Boatman is a materials scientist living in Minnesota.

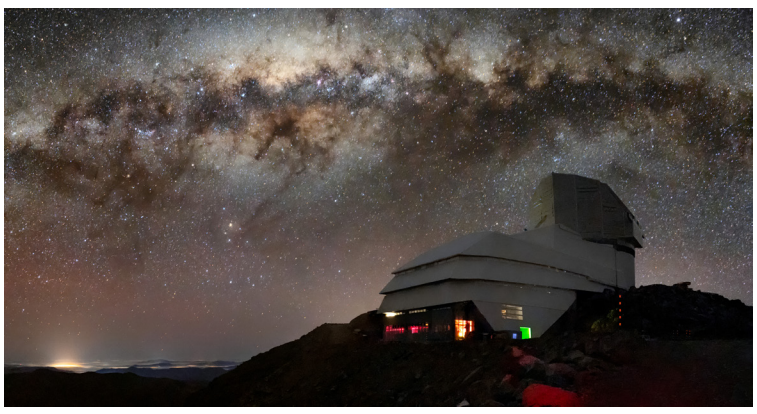
Rubin Observatory continued from page 1

The Rubin team in the control room on Cerro Pachón reacts to seeing the first on-sky engineering data captured with the LSST camera on April 15, 2025. RubinObs/NOIRLab/SLAC/DOE/NSF/AU

the cosmos and unwrap the mysteries of the universe," said Kathy Turner, U.S. Department of Energy physicist, at the "First Look" press conference.

The Vera C. Rubin Observatory, named after the scientist who provided early evidence for dark matter, sits in one of the world's most privileged locations for astronomy — at the summit of Cerro Pachón in Chile, offering exceptionally clear skies, low levels of atmospheric turbulence, dry air, and little light pollution. With an 8.4-m-diameter primary mirror, Rubin won't be the world's largest telescope, but it will be unmatched in the ability to quickly observe large swaths of the sky. Each of its images will capture an area equivalent to 45 moons. By comparison, the JWST space observatory's field of view is slightly less than a full moon.

What's more, the telescope moves quickly with little wobbling, allowing it to wheel within a few seconds to a new observing spot — moving 10 to 100 times faster than any existing telescope. This combination of speed and field of view will allow the observatory to cover the whole Southern Sky every three to four nights. To acquire that bounty of images, the observatory is equipped with the largest camera ever built, a 3.2-gigapixel, car-sized camera whose output would require 400 ultra-HD TV screens to be displayed in full detail. With such resolution, the camera will deliver 20 terabytes of data every night — an information content comparable to that of all the books ever written.



The Vera C. Rubin Observatory with its dome open during "First Look" observation activities in April 2025. M41, the Little Beehive Cluster, can be seen over the telescope. RubinObs/NOIRLab/SLAC/NSF/DOE/AURA/P. Horálek (Institute of Physics in Opava)

The repeated full-sky coverage will produce an ultra-high-definition, time-lapse record of the night sky, revealing a changing cosmic landscape. Astronomers expect to detect a vast range of transient events, such as supernova explosions, pulsating stars, and passing comets or asteroids. The observatory will issue alerts — potentially millions per night — notifying the global scientific community about anything in the sky that moves, pulses, or flashes. These alerts will trigger observations from other telescopes that could further dissect those events through spectroscopy or higher-resolution imaging. Rubin's observations will be relevant to many scientific areas in astronomy, astrophysics, and cosmology, with eight independent international collaborations focusing on different areas. These areas include probing dark energy and dark matter, mapping the Milky Way, imaging dynamic events in the sky, and conducting a census of Solar System objects, such as asteroids that could threaten Earth and a "planet 9" that might lie beyond Neptune.

Among the first unveiled images is a hauntingly beautiful picture of the Lagoon Nebula and the Trifid Nebula, residing in the Milky Way at a distance of 5,000 and 4,000 light-years from Earth, respectively. The picture results from the combination of almost 700 images that the Rubin Observatory captured in just over seven hours of observing time.

Rubin, however, is primarily a survey observatory, so don't expect that it will engage in a competition with the JWST and other telescopes for building spectacular cosmic galleries. The JWST excels at zooming in on specific targets such as distant galaxies and exoplanets, which it can inspect through spectroscopic analysis. Conversely, the Rubin Observatory maps the "big picture," thanks to its ability to observe an unprecedented number of astrophysical objects.

The videos released in June showcase this surveying power. One video, also obtained within the several-hour initial testing window, reveals about 10 million galaxies — roughly 0.05% of the 20-odd billion galaxies that the observatory is expected to capture during the 10-year LSST survey.

But arguably the most mesmerizing materials were videos showing Rubin's ability to bring the sky to life by observing transient events. One video shows a swarm of asteroids — seven of which are in near-Earth orbits — that were discovered in the telescope's testing phase. Millions of new asteroids might be found within a couple of years of the LSST run. Another video shows observations of the subtle pulsations of 46 variable stars.

After almost two decades of preparation, "it's absolutely amazing how quickly things just turned on and worked," says Telsa Jeltema of the University of California, Santa Cruz, who serves as the deputy spokesperson for the Dark Energy Science Collaboration. The Rubin Observatory will employ several strategies to probe the dark energy that drives the universe's accelerating expansion. For example, astronomers will measure distances using "standard candles" (supernovae), "standard rulers" (baryon acoustic oscillations), and subtle galactic distortions induced by dark matter (weak lensing), and those data will help constrain models of dark energy. Previous observations, including those from the Dark Energy Survey and the Dark Energy Spectroscopy Instrument, have delivered intriguing hints of a breakdown of the standard cosmology model, suggesting, for instance, that dark energy may change with time.

"But we are not convinced yet," says Jeltema. LSST will "get us to the point where we know for sure if there is something unusual going on or not," she says.

Gabriela Gonzalez from Louisiana State University and the LIGO Scientific Collaboration is excited about the synergies between Rubin and gravitational-wave observatories. The LIGO-Virgo-KAGRA Collaboration has extended its ongoing fourth observing run so that it overlaps with Rubin's observations for at least a few months, she says. Rubin would be particularly suitable to quickly follow up on gravitational-wave events such as neutron-star mergers, possibly getting "video coverage" to accompany the chirps and hums that gravitational-wave observatories are recording.

Gonzalez is particularly excited about surprising detections that cannot be anticipated. "We never know what will happen when a new window of observation is opened."

Matteo Rini is the editor of APS' Physics Magazine, *from which this article is republished.*

Exoplanets continued from page 3

field, which can generate radio waves in aurorae. Planetary aurorae, like Earth's northern lights, emit radio waves when high-energy particles from a nearby star interact with a planet's magnetic field. By observing radio emission from a planet, astronomers can infer the strength of the planet's magnetic field. A strong magnetic field is a prerequisite for a stable atmosphere — and as a result, the possibility of extraterrestrial life.

"A strong magnetic field helps protect the planet's atmosphere from being stripped away by the star's radiation, so the nature of the radio signals could tell us whether the planet's atmosphere is stable or subject to erosion," says Bagheri. And because magnetic fields are generated from a planet's molten metal core, these radio signals can also shed light on a planet's internal structure and composition.

Astronomers will need one more tool to record the faint radio signals of distant exoplanet aurorae: the SKA. This observatory consists of a vast forest of over 100,000 radio antennae in Australia and South Africa, and is set to come online around 2027 alongside Roman's launch. It will be "the most advanced radio telescope we will have in terms of frequency range and sensitivity," says Bagheri.

Roman and the SKA's similar launch date makes Bagheri's plan possible, a stroke of serendipity. Better still, the stars sometimes literally align to magnify the faint emissions of exoplanets. According to her calculations, radio follow-up observations from microlensing will double the number of exoplanets Roman expects to reveal, adding another 1,300 discoveries to the list.

"This approach could drastically improve how we discover exoplanets," says Bagheri. "Not only could it help us identify exoplanets that we might otherwise miss, but it could also give us insights into their environments, their potential for supporting life, and their magnetic properties — important factors for understanding how planets evolve and interact with their stars."

Briley Lewis is a science writer based in Southern California.

Heisenberg continued from page 1

Heisenberg and Bohr in Copenhagen. Photograph by Paul Ehrenfest, Jr., courtesy AIP Emilio Segrè Visual Archives, Weisskopf Collection

repulsed by its abstraction. Einstein called matrix mechanics "a true witches' multiplication table."

Many were drawn to Schrödinger's alternative quantum mechanics, described in a series of papers in early 1926. Schrödinger treated electrons as waves — something people could picture. And physicists versed in optics were already comfortable with wave equations. In May 1926, Schrödinger proved that matrix mathematics and wave mechanics were equivalent, but he still pushed for his version, and Heisenberg for his.

Experimental results seem to suggest a strange world: Light, for instance, behaves like particles sometimes and a wave at other times. Physicists have had to accept this duality. "The present version of quantum mechanics is a mix of Heisenberg and Schrödinger," says Darrigol.

While Heisenberg shaped quantum mechanics and articulated the uncertainty principle soon after, his legacy is complex. In 1937, an SS publication called him a "white Jew," and he was investigated by the Gestapo for a year. After the war started, Heisenberg visited occupied countries as a representative of the German government. He told a Dutch colleague that democracy was not strong enough to prevail in Europe and warned that either his country or the Soviet Union would take over the continent — and he favored Nazi Germany.

He also worked on Nazi Germany's atomic bomb project. Historians disagree about why this project was unsuccessful, but it's possible that Heisenberg's limited skills as an experimentalist were a factor.

One hundred years later, physicists are celebrating Heisenberg's 1925 breakthrough as part of the International Year of Quantum Science and Technology. In June, a century after Heisenberg fled to the island, physicists gathered on Helgoland for a weeklong conference in his honor.

"The struggle continues today to understand the quantum mechanical behavior of events at the smallest levels," writes Cassidy in Beyond Uncertainty. Indeed, Heisenberg's work raised questions that remain unanswered — something he acknowledged in a lecture some 30 years after his breakthrough paper.

"The mathematical forms that represent the elementary particles will be solutions of some eternal law of motion for matter," he said in that lecture. "This is a problem which has not yet been solved."

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BACK PAGE

What happens when AI does the grading?

Physics education needs humans — but maybe not for everything.

BY ZHONGZHOU CHEN

If you're a physics educator who has tried generative AI, your mind has probably wandered through one, or all, of a few thoughts.

"Maybe this could save me time," you think, wincing at the stack of ungraded exams on your desk. So you ask ChatGPT a question, and it gives an unnervingly good answer. "Oh my," you think. "Will this replace me?" Then it makes a couple of ridiculous mistakes, and you think, "This is useless."

Each one might have some truth to it. But after spending months testing the abilities and limits of GPTs, I now worry less about whether or when AI will replace human educators, and I think more about other important questions: What is the unique value of humans in education, and how can we work with AI to amplify those values?

When I began studying generative AI grading, I too rode a roller coaster of predictions. I started with a simple goal: get ChatGPT to grade student written responses. My first few trials were so good that I thought graders would soon be out of a job. Then it screwed up spectacularly, and I wondered if AI grading was a disaster waiting to happen.

But I'm like a lot of physicists: If you say there's a skunk under my porch, I'll run toward it for a closer look.*

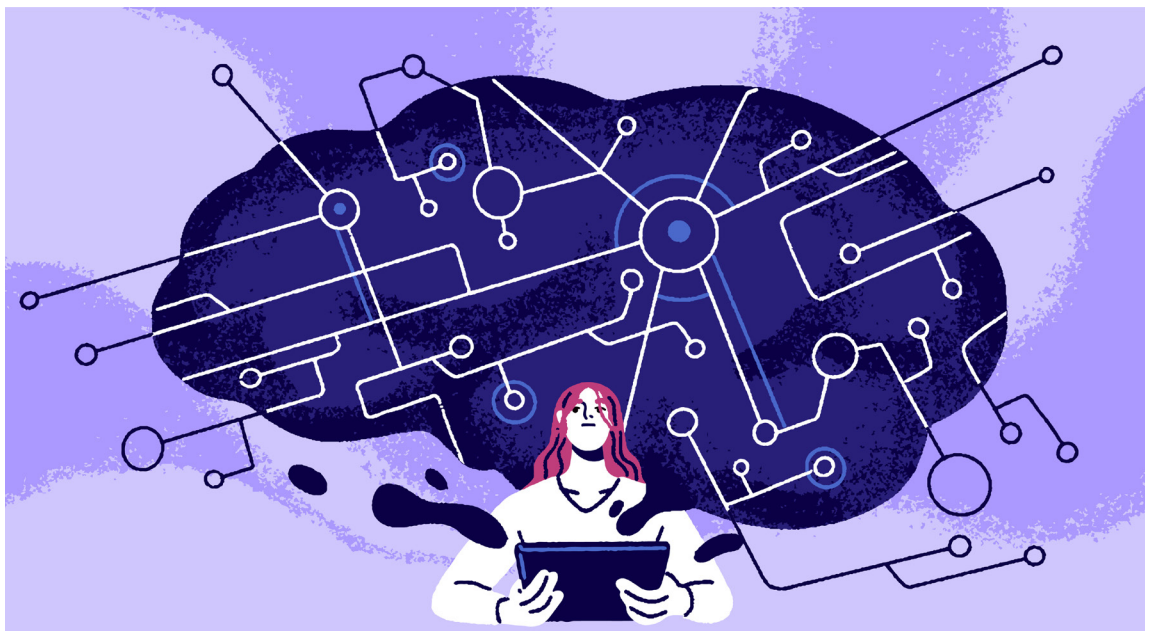
I decided to test AI's grading ability thoroughly, starting by replicating what others had done. Nearly a dozen studies have shown that models like GPT-4 could score students' written responses at accuracy levels comparable to human raters.

I then upped the ante. I collected around 75 student responses to several calculation-heavy physics problems for which students had typed answers using a mixture of words and their own creative math notation, from "½ k x^2" to "0.5k x2." Instead of asking the AI for a single numeric score, I gave it a multi-component rubric and tried to get AI to do three things: Evaluate each rubric component individually; produce some type of "confidence" score for its own grading; and, for each answer, write feedback for a student.

Some of the results were expected. After months of prompt engineering, GPT-4o's grading agreed with human graders as much as, or more than, human graders agreed among themselves. Such high-quality grading takes GPT-4o about 2 hours for every 100 responses — not very different from a human, but at $5 to $10 for the batch, far cheaper than a human.

But two results surprised me. The first was how transparent the entire grading process had become. To get accurate results, we instructed the AI to write down its reasoning for every point it assigned or deducted. This prevented the AI from just making up scores that looked right. As a byproduct, the AI meticulously explained every single grading decision, which I would never expect from a human grader.

The second was how easy it became to give students detailed, personalized feedback. After just one morning of light coding and prompt engineering, AI gained the ability to write a personalized explanation for each student of what they got right or wrong — something I'd never seen any colleague who teaches more than 20 students do regularly.



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Finding the human role

Since I started this project, I've wondered: Am I just finding a way to eliminate human graders? But the investigation actually helped me identify what humans can uniquely contribute.

There are at least three roles that still need a human, at least for now. First, a human has to explain the rubric to the AI. The biggest jump in accuracy came when I started telling the AI what an intro physics instructor would normally count as valid evidence for each rubric component. When a student writes a sloppy answer like "mv^2 - gh = 0," do I want to give them credit for thinking about energy? Without that context, the AI acted like either an overly strict or an overly generous teacher. In contrast, human graders who had taken the course themselves graded just fine without the explanation. This seems to come from the shared experience between instructors and students — something that apparently can't be learned from massive training data.

Second, humans need to be the supervisors. To achieve high grading accuracy, I always had to let the AI grade a small batch first, have a human review, tweak the prompts, and then let AI grade the rest. Human review is needed not only at the beginning, but also the end. There were always a handful of responses where the AI couldn't make up its mind — it would offer three or four different outcomes when asked to grade five times. Those needed human eyes, too.

Finally, all that added transparency creates a new challenge. When students can see detailed reasoning for every point they missed, many will disagree with the AI's decisions. These students will want to argue with a human instructor, in much the same way that I yell, "talk to a human representative!" when I sense a chatbot on the phone.

Should our next grader be an AI?

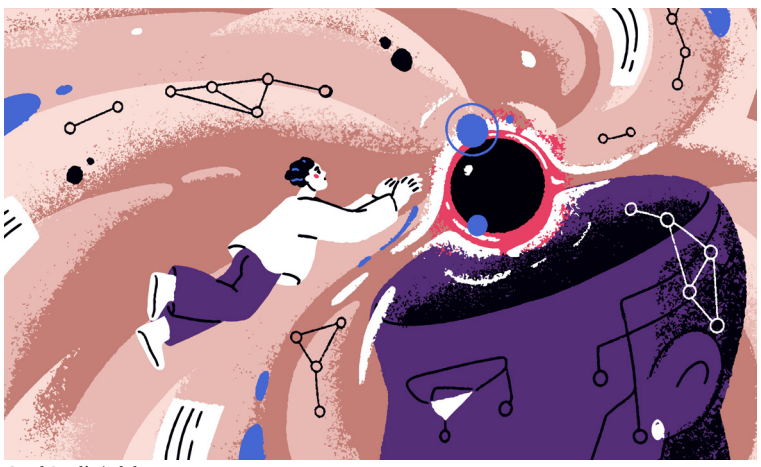
Yes, I think so, but not because it's cheaper. Rather, it's because an AI grader provides unparalleled transparency in its grading process, and it can be continuously and iteratively improved.

I know many will disagree, and for good reason. We haven't yet mentioned the environmental cost of running the large language models. Also, AI graders can make mistakes, show bias against certain language patterns, and miss unconventional or creative answers. Students may try to fool AI graders, too.

But are human graders immune to these problems? Probably not. And we usually have no idea how often our human graders make mistakes or show bias. How can you ask a grader to justify every point they assign when you've just handed them 100 responses?

With AI, we can spot most problems, measure them, and fix them. If we work on improving the prompts and process, the next batch of students gets more accurate and fairer grading than the previous batch. Will my next human grader be better than my last one? Who knows?

The real advantage isn't efficiency. It's transparency and the ability to continuously improve.



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Will humans become obsolete?

If AI graders are so good, shall we stop hiring human graders altogether? I think it depends on what we mean by "graders."

If a grader's only job is to assign scores to student responses, then yes, that person will probably become obsolete. But grading can be so much more than that. As I found, the AI grading process relies on humans to serve in three roles: explainers, supervisors, and final arbitrators.

Will those roles disappear as more powerful models become available? I don't see it happening anytime soon. This is because I see grading not as simply comparing student answers to a standard solution, but as a way to communicate our expectations to students — what we want from them at each stage in their learning. Humans must also monitor whether AI is giving us what we want, and make corrections when AI deviates from what we want. These are likely to remain human tasks.

There's another, bigger reason I don't think humans will become obsolete in education. Yes, research shows that AI can be more efficient, transparent, and even accurate than many human instructors in daily tasks. But those results assume we keep doing the same regular, repetitive tasks in education — assigning the same textbook questions, giving the same lectures, administering the same exams. We've become so used to these routine parts of education that we forget they were designed to accommodate resource constraints, not to optimize learning.

Now that generative AI can help us overcome many of these constraints, there's no better time to rethink the basic building blocks of education itself.

If we can evaluate any answer without worrying about grading time, what types of questions will we choose to ask students? If students can access any resource they need, in any format they prefer, do we still want them to spend time in a classroom designed for centralized dissemination of knowledge? If they still need to be in one room, what should they be doing? If we can create and grade new exams at any time, do we still need midterm and final exams? Do we even need "terms"?

These questions, and the tasks they could spur, are uniquely human because they require innovation — testing new ideas that haven't been documented yet. As OpenAI co-founder Andrej Kaparthy puts it, LLMs are essentially high-resolution compressions of the internet. But innovation, by definition, means trying things that haven't been tested or documented. And deciding what's worth trying? That's entirely about "what we want."

This opportunity comes with urgency. Today's students will live in a world deeply integrated with AI, but our educational system isn't preparing them for that reality. If we keep lecturing and grading multiple-choice questions, we'll become irrelevant soon enough.

Being uniquely human

As I wrote this article about whether AI will replace humans in education, I found limited use for AI. The experience is uniquely mine, and the ideas are relatively new, so they're still scarce in the training data. Sure, I asked ChatGPT to find the right word or check a reference now and then, but that's about it.

Meanwhile, my daughters are in kindergarten, happily learning from a teacher who somehow gets a room full of six-year-olds to sit still and learn to read and count. If there's one type of teacher that won't be replaced by AI anytime soon, my bet is on them, not us college professors. It's hard to imagine a machine doing a job like that.

Most discussions about AI in education focus on skill mastery and knowledge delivery. But there's a uniquely human component that is arguably more important: I learned to think like a scientist by watching my mentors think, then mimicking and internalizing their approaches. Can future scientists develop that kind of thinking just by talking to an AI? I doubt it.

The real promise isn't that AI will replace educators. It's that AI might free us from routine tasks, so we can focus on what's more important. Perhaps when we no longer spend hours grading the same types of answers, we can think, discuss, and innovate more with our students — and, in the process, discover the parts of education that are uniquely human.

**Dave Pritchard, my mentor at MIT, gave me the "where's the skunk?" story and mentality.*

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