APS News

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Despite Strong Interest in Physics, Some Universities Are Shuttering Departments

At least four physics bachelor's programs have been suspended in the last year. They have a warning for other programs.

BY LIZ BOATMAN

In the early 2000s, after decades of ebb and flow, the number of students pursuing physics in college took off, doubling to 9,000 in just over a decade. Even after COVID-19 battered U.S. higher education, the discipline awarded more than 9,400 bachelor's degrees in 2021.

But if interest in physics remains strong, why have four universities — Bradley University in Illinois, SUNY Potsdam in New York, the University of North Carolina at Greensboro, and St. Cloud State University in Minnesota — discontinued their undergraduate physics and physics teaching programs over the past year?

"The university said they needed to find a way to save $13 million dollars," says José Lozano, physics chair at Bradley. "They started cutting programs, and we were among the first to go."

"The department really brings in money because of the service courses," says Lozano, referring to physics courses taught as requisites for students in other fields. "But the administration was focused on the number of physics majors," which had fallen from an average of 12 to less than 6 in recent years, he says.

Lily Li, a physics professor at SUNY Potsdam, chats with students. SUNY Potsdam is one of several universities that have shuttered physics departments in the last year. Credit: Wayne Patton

"The last two students we have, as soon as they graduate next year, that's it," he says. "We'll just be a service department for premed students and the engineering college."

The other three programs have similar tales. In the early 2000s, enrollment was growing and the number of physics majors was strong. At St. Cloud State, the university even built a new 100,000-square-foot science and engineering facility.

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How ChatGPT Could Help Educators Teach Physics

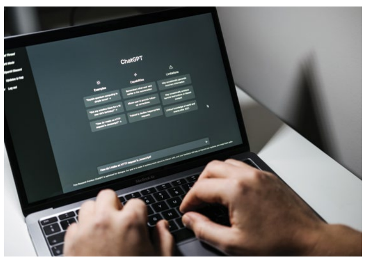
Education researchers are studying novel ways to use generative AI in classrooms.

BY SOPHIA CHEN

Since the release of OpenAI's chatbot ChatGPT in November 2022, Anthropic's chatbot Claude in March 2023, and Google's chatbot Gemini in February 2024, millions of people have used generative AI to write emails, plan travel, and create art. Proponents say the technology is poised to upend entire industries, from marketing to scientific research.

Generative AI has cropped up in education, too. While many early headlines were cautionary, highlighting students who used the technology to cheat, researchers are also studying how educators could embrace the technology in the classroom.

"Instead of viewing AI as an enemy, what we really should be doing is to help people develop skills to properly use AI, and understand its abilities and limitations," says Zhongzhou Chen of the University of Central Florida, who presented his physics education research on ChatGPT at this year's meeting of the APS Division of Atomic, Molecular and Optical Physics in Fort Worth, Texas.



Generative AI tools like ChatGPT are already widely used by college students. Credit: Irissca / stock.adobe.com

Yasemin Kalender, a physics education researcher at the University of Liverpool, suggests that educators view generative AI as another teaching tool. She also notes that banning large language models — the AI technology that powers chatbots — simply isn't realistic. "This tool is out there," she says. "Instead of

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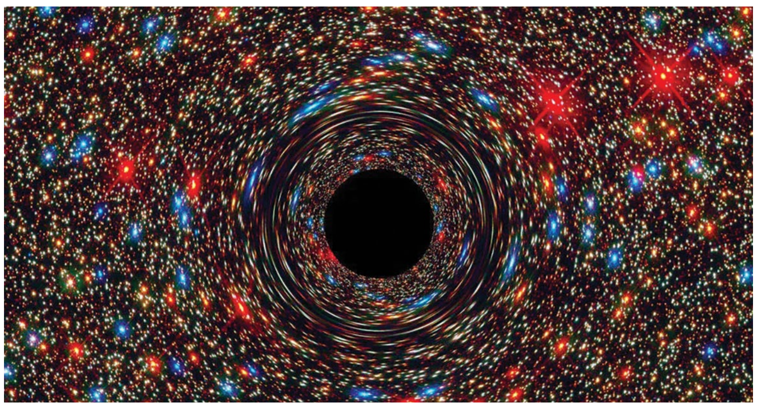
Black Holes Can't Be Created by Light, Study Finds

The formation of a black hole from light alone is permitted by general relativity, but a new study says quantum physics rules it out.

BY PHILIP BALL



This simulated image shows the distortion of starlight around a black hole at the center of a galaxy. Credit: D. Coe, J. Anderson, and R. van der Marel/NASA/ESA/STScI

Black holes are known to form from large concentrations of mass, such as burned-out stars. But according to general relativity, they can also form from ultra-intense light. Theorists have speculated about this idea for decades. However, calculations by a team of researchers now suggest that light-induced black holes are not possible after all because quantum-mechanical effects cause too much leakage of energy for the collapse to proceed. The team's study was published July 26 in *Physical Review Letters*.

The extreme density of mass produced by a collapsed star can curve spacetime so severely that no light entering the region can escape. The formation of a black hole from light is possible according to general relativity because mass and energy

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When Challenges Arise, the National Mentoring Community Helps Students Stay in Physics

This year, the APS program celebrates its 10th anniversary.

BY KENDRA REDMOND

Navigating a physics degree can be difficult for any student, but the challenges can be even greater for students from minoritized or marginalized groups. To support these students, APS launched the National Mentoring Community (NMC) in 2014. Ten years and hundreds of student–mentor matches later, participants say the program is still making a difference.

"Mentors have influenced my path greatly," says Italian Johnson, a physics major at Jackson State University. A first-generation college student, she credits a high school internship mentor for introducing her to physics and helping her transition to college. More recently, NMC mentors have helped her explore career options, attend conferences, and build a network. "Your network is your net worth," she says. "Gaining those connections is helping me to get farther in life."

The NMC is set up kind of like a dating app, says APS program manager Bri Hart. The mentors — physicists at any career level in any sector — complete a profile. Then, the mentees — undergraduate or graduate students in physics or related fields — browse the profiles and indicate who they'd like to connect with. If there's a match, the pair decides when and how often to meet. Along the way, the NMC augments the experience with prompts, resources, and community-building events.

Through the NMC, Johnson matched with Jami Valentine Miller, a Ph.D. physicist at the U.S. Patent and Trademark Office and founder and CEO of African American Women in Physics (AAWP), Inc. In addition to their shared physics interests, Johnson was drawn to Valentine Miller's experience as a Black woman in physics who also attended an HBCU.

Attendees at an APS National Mentoring Community event in 2020. Credit: APS

"To find someone that looks like you and that understands your struggle — not even just your struggle but understands your background, it definitely helps," Johnson says. About once a month, they meet virtually to discuss Johnson's goals, career pathways, professional development opportunities, and anything else on her mind.

Valentine Miller believes in the power of mentoring, in part because of how mentors impacted her own life. "It gave me a lot of confidence to know that so many professionals believed in me and were interested in seeing me succeed," she says. Valentine Miller participates in a variety of mentoring programs and especially appreciates the structure and guidance the NMC provides, along with a key benefit introduced in 2017 — emergency financial aid for mentees.

The NMC's Bringing Emergency Aid to Mentees (BEAM) Fund offers quick financial assistance, typically $1,000–2,500, to mentees in an emergency. Made possible by a donation by Kenton and Amy Brown, the fund has helped mentees get home during emergencies, buy food, pay for car repairs, and meet other financial challenges that may have otherwise derailed their education or limited professional opportunities.

Unexpected school fees threatened to keep Jaylyn Umana, then

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It's Hard to Talk About Inclusion in Physics Classrooms. Meet the Physicists Making Inroads.

A workshop designed by the EDI Fellows Program, funded by APS, aims to equip physics educators for tough but important conversations.

BY KENDRA REDMOND

An in-person planning meeting of the EDI Fellows Program. Credit: Marty Baylor

Marty Baylor, a physics professor at Carleton College, chaired the APS Committee on Education during the turbulence of COVID-19 lockdowns and the 2020 murder of George Floyd, a Black man killed by a police officer in Minneapolis. In addition to discussing how best to support virtual teaching, committee members raised another concern: Issues related to equity, diversity, and inclusion (EDI) were cropping up in physics classrooms.

Many physics educators wanted to respond to these issues, but they didn't know how and feared causing more harm. Baylor calls them the "willing but hesitant." She gets it. Most physicists aren't trained to deal with challenging dynamics like these in the classroom.

"I care about [EDI] issues, and I've read about them, and I've tried to incorporate them in my teaching," says Teresa Herd, a physics professor at Assumption University. But when faced with a disparaging comment about women in physics or professors with accents, she, like many others, felt lost, she says. "There was this 'freeze' moment. What do I do? What should I do? What can I do?"

To address such questions, in 2021 Baylor created the APS EDI Fellows Program with co-PIs Jesús Pando, a physics professor at DePaul University, and Peggy O'Neill, a social scientist from Smith College. With a grant from the APS Innovation Fund, which sponsors collaborative projects that advance physics, the team set out to teach a cohort of fellows, all physics educators, how to engage with EDI issues, and then design a workshop with them and train the cohort to present it to other physics educators.

Over two years, six fellows participated in regular training sessions, digging deep into issues like cultural competence, identity, and power dynamics with social scientists before turning their attention to developing the workshop. The social scientists "were great at moving us outside of our physics perspective," says Herd, who became an APS EDI fellow. In turn, they learned about the physics culture and its nuances.

"We physicists like to pretend what happens outside of the classroom stays outside of the classroom — that issues of race and gender and whatever political climate is happening, if there's a war, if there's a mass shooting, or whatever, that has no effect on what's happening in our classrooms," says Beatriz Burrola Gabilondo, a physics lecturer at the Ohio State University. But from

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THIS MONTH IN PHYSICS HISTORY

Sept. 30, 1954: The World's First Nuclear-Powered Submarine, U.S.S. Nautilus, Enters Navy Service

Years earlier, a physicist named Ross Gunn had recognized the potential of nuclear energy to power submarines.

BY KENDRA REDMOND

The first nuclear-powered submarine, the U.S.S. Nautilus, was launched in Groton, CT, on Jan. 21, 1954, and entered Navy service in September that year. Credit: U.S. Navy/Naval History and Heritage Command

In the spring of 1939, Enrico Fermi met with representatives from the U.S. Navy and Army to share big news: The uranium atom had been split, opening the potential of nuclear energy for explosives and power generation.

The meeting didn't spark an immediate bomb effort, as Enrico Fermi and his colleague Leo Szilard had hoped. It would take several months for the gears of what would become the Manhattan Project to start turning, spurred by a letter President Franklin D. Roosevelt received from Szilard and Albert Einstein in October of that year. But the meeting did spark immediate action in another direction: nuclear-powered propulsion.

For years, the U.S. Navy had been pursuing alternative energy sources for ships, particularly its submarines. Limited by their power source, the vessels could stay underwater for just 12-48 hours. Even before the meeting with Fermi, Ross Gunn, the prolific and versatile physicist in charge of the Mechanics and Electricity Division at the Naval Research Lab (NRL), had realized that theoretically, nuclear energy could revolutionize their capacity.

Gunn "was not particularly interested in the development of an atomic bomb, but he was pointedly aware of the distinct advantages of controlled nuclear power to the U. S. Navy," wrote Carl Holmquist and Russell Greenbaum in a 1960 article for the U.S. Naval Institute's *Proceedings*.

To Gunn, Fermi's meeting signaled it was time to start experimenting.

At the time, submarines relied on electric batteries for underwater propulsion, but the batteries were charged by diesel-powered generators that required frequent resurfacing, fuel, and oxygen. The Navy had considered other propulsion sources, such as fuel cells, but oxygen remained the limiting factor. Gunn envisioned an entirely new power source — a uranium core that would heat water to run a steam power plant onboard.

Shortly after Fermi's meeting, Gunn's division secured funding to begin research. Step one was to enrich uranium, so the team explored ways to separate uranium isotopes. Work progressed slowly at first but picked up speed when Gunn began working with Philip Abelson, a physicist at the Carnegie Institution of Washington who had recently pioneered a method of liquid thermal diffusion to separate the isotopes.

Abelson had designed a tall, thin column from three concentric pipes. The innermost pipe held steam, the middle pipe dissolved uranium hexafluoride, and the outermost pipe cooling water. The temperature gradient experienced by the middle pipe caused the lighter uranium-235 isotopes to diffuse toward the hot inner pipe and travel upward, while the heavier uranium-238 isotopes traveled downward, said Abelson in an interview with the Atomic Heritage Foundation. "All one has to do is fill this thing and put steam in and cooling water and go away for three days, and one has some separation."

of the shipyard's enriched uranium went to the Manhattan Project. Submarine research stalled.

"The NRL's efforts to develop a nuclear-powered submarine were blocked by the Manhattan Project's monopoly on nuclear research," wrote University of Pennsylvania archivist Joseph-James Ahern in an paper. He reports Gunn as having recalled, "We had the hose turned on us!"

On seeing Abelson's favorable results, the Manhattan Project built a copycat liquid thermal diffusion plant with 2,142 columns, each 15 meters tall, at Oak Ridge National Laboratory (ORNL). The so-called

Ross Gunn "was not particularly interested in the development of an atomic bomb, but he was pointedly aware of the distinct advantages of controlled nuclear power to the U. S. Navy."

The Bureau of Standards and NRL helped Abelson test the method on successively bigger scales — the greater the temperature gradient and taller the column, the better the output. After supporting the work for several months, Gunn hired Abelson in 1941. "For a time, the facility at the Naval Research Laboratory was the world's most successful separator of uranium isotopes," Abelson wrote in the National Academies *Biographical Memoirs*. By 1944, they had a 300-column plant at the Philadelphia Naval Shipyard.

In the meantime, the U.S. Army's Manhattan Project worked feverishly on other types of uranium enrichment but did not share any information, even with the Navy. Still, most

S-50 plant played a critical role in history. A trio of plants enriched uranium in series for the first atomic bomb, which was dropped on Hiroshima, Japan, on Aug. 6, 1945; the first feeder plant was S-50.

After World War II, Gunn received an award from the Secretary of the Navy for his "outstanding contribution to the development of the atomic bomb." He and Abelson returned to promoting research on nuclear-powered submarines as countries became increasingly adept at detecting diesel submarines. In 1946, at Gunn's urging, the Navy sent personnel to learn about nuclear energy from Manhattan Project

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White House Issues New Security Rules for Federally Funded Research

Researchers are a "first line of defense against improper or illicit activity," said the OSTP director.

BY LINDSAY MCKENZIE

In July, the White House published long-awaited guidelines aimed at ensuring research institutions take adequate measures to protect federally funded research from theft or misappropriation. The guidelines will require institutions receiving $50 million or more per year in federal R&D funding to operate suitable research security programs. The programs must cover four main areas:

Research: Institutions must implement a security training program for researchers, with individuals taking either the training modules developed by the National Science Foundation, future training programs developed by federal agencies, or training developed internally. The training must include examples of "known improper or illegal transfer" of R&D, while also conveying the value of international collaboration in research.

Foreign travel: Institutions must implement periodic training for researchers who travel internationally, as well as report where researchers travel, in cases where funding agencies deem this reporting necessary. The government has not yet created a training resource for international travel but plans to do so.

Export control: Researchers who participate in projects involving export-controlled technologies, like those with potential military applications, must complete training developed by the Commerce Department or developed internally that covers specific topics.

Cybersecurity: Higher education institutions must implement a cybersecurity program consistent with a forthcoming resource from the National Institute of Standards and Technology.

Credit: Bill Chizek / Adobe

The guidelines are meant to help researchers navigate a world characterized by "fierce military and economic competition," wrote Arati Prabhakar, the director of the White House Office of Science and Technology, in a preface to the guidelines. Prabhakar said the guidelines aim to ensure research institutions "recognize the altered global landscape and fulfill their responsibilities as the first line of defense against improper or illicit activity."

"We know that members of the R&D community are still acclimating to the changes in geopolitics," Prabhakar added. "Many of the actions that researchers were encouraged to undertake only a decade ago, including collaborations with the People's Republic of China, are now being recognized for the risks they may present."

Federal agencies now have six months to submit their implementation plans to OSTP and the Office of Management and Budget, with their final policies taking effect no more than six months later. Institutions will have up to 18 months to comply.

OSTP produced the guidelines in response to a presidential memorandum on research security issued at the end of the Trump administration and carried forward by the Biden administration.

OSTP has received criticism from Congress for how long it has taken to produce the final guidance, given that it published the draft version in February 2023 — a delay, Prabhakar told Congress, that stemmed from the time it took to address public feedback about undue administrative burden. The final guidance drops several requirements included in the draft version.

Tobin Smith, the senior vice president for government relations and public policy at the Association of American Universities, said the final guidelines are an improvement over the draft, but he worries that agencies will vary in how they implement the guidelines.

"This is much better than what we saw in February 2023 — we have much fewer concerns. It provides a great deal of flexibility to our institutions, which we appreciate," Smith said in an interview. "My only worry is that, instead, agencies will now use that flexibility to add their own additional requirements on, and that will make it hard for our institutions to comply and more costly and burdensome if we end up in a situation where there isn't harmonization."

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

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a physics undergraduate, from registering for classes one semester, but the BEAM fund enabled him to continue his education uninterrupted. Later, when faced with the choice of buying groceries over winter break or paying graduate school application fees, the BEAM fund came through again.

Now a graduate student at the CUNY Graduate Center in New York, Umana says that mentoring — especially by Jack Simonson, a physics professor at Farmingdale State College — profoundly impacted his life. "He was one of the few people that I think really, truly believed in me and my ambitions," Umana says.

About a year after Simonson began mentoring Umana, they joined the NMC. "Because we are affiliated through the National Mentoring Community, we now have all the perks that come with it," Umana says. That includes access to the BEAM fund, APS resources, and an official way to stay in touch, which they still use.

Umana came across a great mentor early in his physics pursuit, but many students aren't so lucky. Unapproachable and busy professors may discourage students from seeking support, says Mario Borunda, a physics professor and dean at Oklahoma State University. "This is where the NMC plays a key role," he says. Students can access a pool of dedicated mentors already committed to supporting students and diversity, equity, and inclusion.

Attendees at an NMC event in 2020. The program is celebrating its 10th anniversary this year. Credit: APS

As a Hispanic physicist, Borunda knows how it feels to be in the minority. He's been a long-time NMC mentor, working to ensure that students from marginalized identities and first-generation college students get the practical guidance and support they need. And if they're interested in a path he hasn't traveled — a career in industry, say — the NMC offers resources on those topics for him to share.

Borunda and Valentine Miller say that mentoring conversations often go deeper than which classes to take or how many graduate school applications to submit. Students want to know if it's possible to have a family in graduate school, how to handle microaggressions, and whether they're "good enough" to continue in the field.

That topic resonates with Johnson. "I always thought I was in a room because [the organizers] needed to meet a diversity quota," she says. But Valentine Miller helped her change that view. "She definitely helped me understand that if I'm in the room, I'm meant to be there," Johnson says.

The NMC is open to all undergraduates and graduate students in physics and related fields, although students who identify as Black or African American, Latino, or Indigenous receive priority. Mentor-mentee matches typically last for at least one academic year, although many last much longer, and participants can join anytime.

"The NMC plays a vital role in helping students to stay in physics," says Valentine Miller. "It's a very valuable program not just for APS, but for all of physics."

Kendra Redmond is a writer based in Minnesota.

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trying to police students, we can actually have an honest conversation."

Large language models come with caveats, including their energy consumption, says Kalender. Over the last five years, Google's emissions rose 48 percent, much of which is attributed to AI. The rise comes despite the company's goal in 2021 to achieve net zero emissions by 2030.

The models' propensity to "hallucinate" — generate false or irrelevant information — is also well-known. In June 2023, a U.S. federal judge fined two lawyers for citing fictional legal cases that ChatGPT invented. This February, Google apologized when Gemini generated images depicting Nazi-era German soldiers as people of color.

Chen and his colleagues have turned ChatGPT's fallibility on its head to teach students about misinformation. In a recent project, they first prompted the tool to generate misinformation about climate change that "sounded" valid — for example, that cool summers proved climate change was a hoax. A colleague then used that text to teach students about logical fallacies in a course on the physics of climate science. Chen plans to analyze how those generated texts affected the students' comprehension.

Chen is investigating generative AI's ability to write exams, too. He has used GPT-3.5, a large language model that ChatGPT used, to generate variations of problems that test the same concepts. He started by writing the "seed," which describes the problem (like a block sliding down a ramp), the known variables (like the ramp's angle), and what the student was to solve for. Then, he would brainstorm variations, like swapping the block for a cart. Using the seeds as input, ChatGPT fleshed out the problems in full sentences and chose numbers for variables. In this way, he created "banks" of 30 to 50 problems that tested the same concepts.

For an exam in a physics class in spring 2023, Chen assigned a problem from the bank, as well as another that was not in the bank but tested the same concept. The students' performance on both questions were correlated, implying that most students did not merely memorize the problem in the bank.

ChatGPT-generated problem banks could help instructors offer different versions of the same exam, potentially giving students more flexibility. Many nontraditional students, such as parents and working students, run into logistical challenges during final exams, says Chen. That flexibility could also help students whose coursework is disrupted by natural disasters, such as hurricanes in Chen's home state of Florida.

> "This tool is out there," Kalender says. "Instead of trying to police students, we can actually have an honest conversation."

Meanwhile, Kalender has explored how to incorporate ChatGPT in introductory physics labs. For example, she and a colleague had ChatGPT simulate a common lab experiment using a mass on a spring and then analyze the data to measure the spring constant. A plug-in to ChatGPT called CodeInterpreter generated "perfect" Python code for the analysis, she says. This may help students focus on learning concepts during the lab, instead of spending time debugging code. "It was taking them a little bit away from the physics," says Kalender.

Kalender has also used ChatGPT to brainstorm lab activities. After prompting ChatGPT to come up with a two-week lab exercise on projectile motion, the chatbot suggested a timeline for a catapult-building lab. Upon further prompting to make the lab "equitable," the chatbot recommended a format for dividing the labor in which students rotated roles between weeks. These pedagogical cues could be helpful to instructors, says Kalender.

However, ChatGPT made mistakes in the lab, including on error propagation, a skill that students typically struggle at. While ChatGPT could correct its mistakes after prompting, it may pose problems for students.

"The traditional mode of everybody marching at the same pace is facing increasing difficulty because of the diversity of the student population, and even also climate change," he says.

However, Kalender is wary that students will rely on ChatGPT too readily. "In learning theories, there is this concept of 'productive struggle,' where in order to learn new information, you have to struggle — not too much, but a little bit," says Kalender. She is concerned that ChatGPT "will take away from that productive struggle."

Chen envisions a future in which students are allowed to use any tools, including AI, to learn physics. Come exam time, students solve problems in a proctored room with no access to AI. This way, students have less motivation to use AI without actually learning the material, says Chen, "because they know that their end goal is to perform without using AI." He also thinks that educators should design tests to assess students' ability to use AI.

But it's not only students facing the trials of new technologies, notes Kalender. "It's forcing us as educators to come out of our comfort zone."

Sophia Chen is a writer based in Columbus, Ohio.

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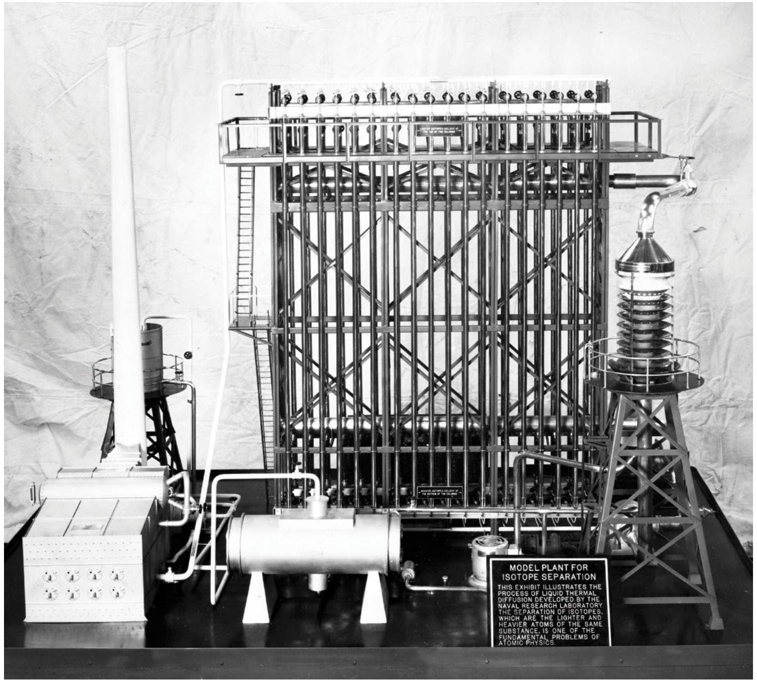


Apparatus for the liquid thermal diffusion method pioneered by Philip Abelson, which enabled the separation of uranium isotopes key to the nuclear submarine program. Credit: U.S. Navy

scientists, now under the Atomic Energy Commission.

That same year, Abelson returned to the Carnegie Institution and transitioned to biophysics. Soon after, Gunn left NRL for the United States Weather Bureau. In their wake, a new champion for nuclear-powered submarines emerged: Captain Hyman Rickover.

Rickover, an electrical engineer, was one of five people the Navy assigned to learn about nuclear energy. He quickly grasped the benefits of nuclear power and went on to head the new Nuclear Power Branch of the Navy's Bureau of Ships and, simultaneously, the Division of Reactor Development for the Atomic Energy Commission. With the uranium quest resolved, he led the effort to design a safe and compact power plant for a submarine.

Under Rickover, a group of engineering duty officers worked with experts such as physicist Alvin Weinberg, administrator of ORNL, and Harold Etherington, director of the Naval Reactors Division at Argonne National Laboratory, and their civilian teams to experiment with reactor designs.

"There were several reactor concepts; the real challenge was to develop this technology and transform the theoretical into the practical," says a commemorative article released by the Naval Nuclear Propulsion Program in 2023. "New materials had to be developed, components designed, and fabrication techniques worked out."

The team designed a pressurized water reactor, a model for the most common types of nuclear reactors, even today. Water in a coolant loop is kept under high pressure and pumped near a core of slightly enriched uranium. The water heats up, but the high pressure keeps it from boiling. The heated water then travels into a steam generator where it vaporizes water in a secondary loop. The resulting steam turns a turbine generator and creates electricity.

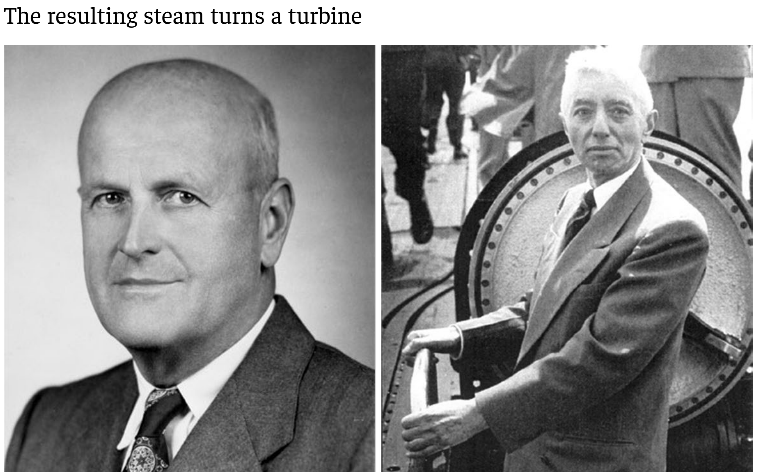
In the early 1950s, Rickover contracted with the manufacturing company Westinghouse to build the reactor and the Electric Boat Division of General Dynamics to build SSN-571, the submarine it would power. The submarine underwent extensive safety testing before and after the Navy installed the reactor. In addition, Rickover personally interviewed and approved every Navy member of the nuclear reactors program — not just initially, but for decades.

U.S.S. Nautilus was launched on Jan. 21, 1954, and on Sept. 30, more than 1,200 people gathered for the submarine's commissioning. The world's first nuclear-powered submarine raised its U.S. flag, and the vessel officially entered Navy service. After a few months of additional testing and construction, Commander Eugene P. Wilkinson ordered the lines cast off Nautilus in January 1955, and it took to sea, signaling back, "Underway on nuclear power."

Nautilus and its crew "dominated virtually every NATO exercise they participated in," wrote Tom Clancy in his book *Submarine: A Guided Tour Inside a Nuclear Warship.* It crushed speed and distance records, submerged for more than two weeks at a time, and avoided the best submarine detection systems. In 1958, it became the first vessel to cross under the North Pole. Nautilus was a prototype for the Navy's revolutionary submarine fleet, and the reactor a prototype of the commercial reactors to come.

Nautilus remained in service for 25 years and traveled half a million miles before being decommissioned in 1980. It's now a national historic landmark open to the public at the Submarine Force Museum in Groton, Connecticut.

Kendra Redmond is a writer based in Minnesota.



After Ross Gunn (left) left the Naval Research Lab, Hyman Rickover — shown here on the U.S.S. Nautilus — led the nuclear-powered submarine program. Credit: Naval Research Laboratory/public domain

PRX Life's Chief Editor on What's Next for the Journal That Unites Physics With Biology

As the journal celebrates its first anniversary, Serena Bradde aims to connect with new research communities.

BY NYLA HUSAIN

Living systems obey the same laws of physics as any other matter. As quantitative and computational capabilities grow, scientists across disciplines are developing new tools to investigate how these systems behave, from individual molecules to large ecosystems.

Since its launch last year, the APS journal *PRX Life* has published cutting-edge research at the intersection of physics and biology. *APS News* spoke with its chief editor, Serena Bradde, about *PRX Life*'s first year and what's next.

Serena Bradde

You've been a statistical physicist for more than a decade. What's interesting to you about that field, and how did it draw you into biology?

As a student in Italy, I learned statistical physics, a subfield that studies in great detail how systems made up of many microscopic elements behave at a macroscopic scale — like how billions of molecules in a room can be described as a gas at a given temperature and pressure. This is what I like about physics generally: being able to connect microscopic processes to macroscopic phenomena.

As a researcher, I realized I could apply the same methods to understand biological systems. In an early project, my colleagues and I developed a statistical physics formalism to explore how populations of antibiotic-resistant and antibiotic-sensitive gut bacteria change in response to antibiotics. Since then, I've been fascinated by how bacteria and other living systems sense and adapt to changing environments.

What makes multidisciplinary fields like biological physics and quantitative biology so important? What kinds of phenomena have *PRX Life* authors investigated?

Tools from physics can describe biological behavior quantitatively, but biological systems can also teach us new physics. And if we learn how living systems work and predict their behavior, it could fuel new discoveries in fields from molecular and cell biology to neuroscience, epidemiology, and ecology.

PRX Life publishes research that intersects with all of these disciplines. In one of our more recent articles, scientists identified a mechanism by which drug-resistant cancer cells interacting with their normal cells may persist longer than expected, leading to treatment failure. This new finding will allow us to be able to predict pre-existing drug resistance in cancer patients before treatment.

Another *PRX Life* study addressed long-standing questions about chromosome replications in bacteria — results that not only advance our understanding of how bacteria divide and grow, but can have practical implications for designing synthetic cells.

How was the inaugural year of *PRX Life*?

I'm really proud of all the work our team did to launch the journal in July 2023. With the help of our editorial board, we interviewed and surveyed a variety of research communities to inform our strong, multidisciplinary scope. I'm also excited by the high interest we received from the community, which allowed us to publish a few months after opening for submissions.

Some of our studies have been well-covered in the news too, like the study on swimmers in viscous fluid, namely, single-celled algae and human sperm, that "break the law" — Newton's third law of motion — with the help of their elastic flagella.

What's next for the journal?

We're always looking for new ways to connect with broader research communities. In a future Editorial, we'll share guidance to help authors navigate the journal's review process more smoothly, especially early career scientists. Also, in addition to being fully open access — meaning the journal's content will always be freely available to read — author publication charges are being waived, so authors can publish in *PRX Life* for free through 2024.

Along with the latest research, we'll be publishing special content to showcase the fast-evolving, multidisciplinary research landscape at the interface of physics and biology. We're launching mini-reviews, reviews, and tutorials to equip new and existing readers, from college students to experts across disciplines, with background and insight into the complexities of this dynamic field.

My team and I will continue our outreach at conferences around the world to spread the word about the journal. Part of that effort includes a *PRX Life* invited session at the American Physical Society's joint March Meeting and April Meeting — now the APS Global Physics Summit. This session of invited talks will give some of our authors the opportunity to participate in an annual forum highlighting the latest research in front of an audience of international experts in biological physics — so stay tuned!

Nyla Husain is the science communications manager at APS.

EDI Fellows continued from page 2

personal experience, she says, that's not true.

Once, she says, a usually friendly and engaged student came to class withdrawn and upset. Afterward, he told Burrola Gabilondo that he had just lost his best friend to suicide. She felt helpless. "There is this opportunity for me as a teacher, as a person in a position of authority, as a person in a position that can help, and I don't have the tools," she remembers thinking. She decided to find those tools, starting on a path that would lead her to become an APS EDI fellow.

Personal tragedies, pandemics, and nationwide protests aren't the only outside forces that impact physics students. "There are identity-based issues in the classroom happening all the time," Pando says. Sometimes they're recognizable, like comments that reinforce stereotypes, but not always. After Pando took a class through the ballistic pendulum problem, in which a bullet is fired into a suspended wooden block, a student told him that it had been difficult to concentrate on the physics given the recent violence in their neighborhood.

Pando acknowledges that instructors can't "understand and adapt to the entire classroom of lived experiences," but says it's important to be aware of identity-based issues in the classroom and have practical tools to handle them.

Those are key aspects of the team's new interactive workshop on engaging with EDI in the physics classroom. It's the first of its kind in physics, a field that some argue has struggled to embrace EDI as wholeheartedly as many in the humanities and social sciences.

"We tend to look at our humanities colleagues and say, 'That's where you talk about it,'" says Kelley Sullivan, a professor at Ithaca College and APS EDI fellow. She disagrees. "Students in our department need to know that we care about them as whole people," she says.

Pando concurs. "If your goal is to be a great lecturer and then walk out of that class, then maybe it doesn't matter," he says. "But if your goal is to help students thrive and succeed, it's probably important to pay attention to these kinds of issues."

The team has piloted the workshop for select groups of physicists and integrated their feedback. This summer, Baylor submitted an NSF IUSE (Improving Undergraduate STEM Education) proposal to expand the workshop, bring it to the wider physics community, and train additional cohorts of leaders. The team hopes their workshop for physicists and by physicists will draw many of the willing but hesitant.

"We are applying for funding, but we have the fellows. We have the workshop," says Baylor. If you want to get involved now, reach out, she adds. "We're ready to go."

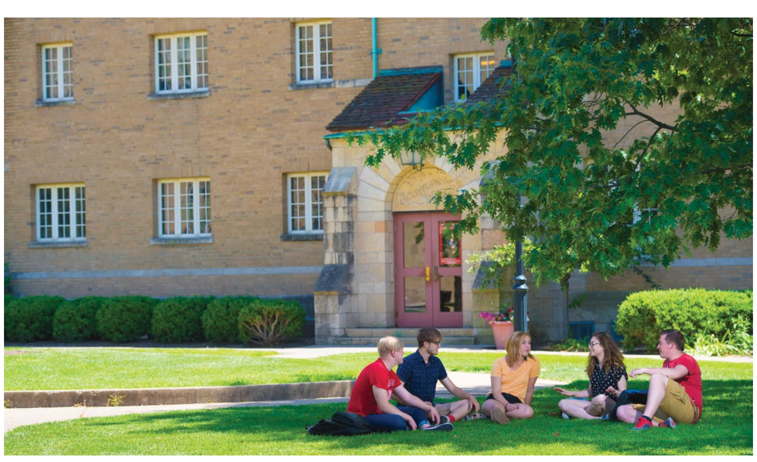
Kendra Redmond is a writer based in Minnesota.

Closures continued from page 1

But now, with campus enrollment nearly half what it was just two decades ago, the university is struggling to manage the building, says physics Chair Kevin Haglin. This May, St. Cloud State proposed suspending one in three academic programs — 47 in total, including physics — in an effort to save itself from financial collapse.

Small ripples in otherwise calm seas were easy to overlook a decade ago. Physics departments were restricted from trying to fill vacated tenure lines, for example, even as administration extended new tenure lines to other departments. Then came cuts to internal research funds, fewer teaching releases (when faculty can forego teaching responsibilities for certain periods), and increased teaching loads. Soon, programs were told to streamline curricula and boost the number of students in each class, and faculty who taught service courses with atypically high drop, fail, withdrawal (DFW) rates were enrolled in workshops aimed at modifying their teaching methods.

By the time COVID-19 struck, Haglin says, St. Cloud State's physics department had been battling stormy seas for years. In 1998, they had 12 faculty, including four astronomers, and a thriving undergraduate physics program with 58 students. Today, the department has four faculty — no astronomers — and 20 students.



Bradley University in Peoria, Illinois, announced late last year that it would be cutting more than a dozen programs. Physics courses will be available, but physics will no longer be a major. Credit: Bradley University

It's not that the department was blind to its problems, Haglin says. They tried various initiatives to boost student numbers, but "enrollment continued to drop." In the thick of the pandemic, Haglin says the university's administration "gently suggested … that if you don't change your curriculum, it will be changed for you."

"We finally got [the new curriculum] approved on a Monday in May [earlier this year], and on Thursday of the same week we learned the program was on the list for being suspended," says Haglin.

UNC Greensboro's (UNCG) physics program — cut this February, along with 19 others — was issued a similar directive several years ago, says Ian Beatty, director of undergraduate physics. The new curriculum streamlined the major and reduced the program's teaching needs, but it also left the program "more brittle," he says. If a student failed just one upper-level course, it could delay their graduation by up to a year.

The program took steps to boost student numbers, too. The physics faculty spent years building the foundations for a new nanoscience concentration, designed to funnel students into the Joint School of Nanoscience and Nanoengineering, a collaboration between North Carolina A&T State University and UNCG. It was a "win-win," says Beatty. Physics could recruit more students, and the joint graduate school would have a new "feeder."

> "If we had known what we learned from DALI" a decade ago, says Lozano, "I think we could have saved ourselves."

"I thought that would buy us at least two years," says Beatty. "I was wrong."

At SUNY Potsdam, the physics faculty spent more than four years developing a new 3+2 physics bachelor's and engineering master's program, joint with SUNY Binghamton, says Wayne Patton, a visiting scholar in physics at the Potsdam campus. "But then there was no administrative support," he says. "It just died." Last November, SUNY system administrators approved plans to phase out nine degrees, including physics and chemistry, following a decline in enrollment and the announcement of a $9 million deficit.

Several leaders from these physics programs noted another challenge: resistance from some 'old-guard' faculty to modernizing their pedagogy and curriculum, including by creating pathways for students with less robust math skills.

"We have to teach the students we get," says Beatty. "The students coming into UNCG over the last four or five years have become gradually less able to do physics," because of weaker math foundations and what Beatty's colleagues have sensed is a growing struggle among students to persevere through challenging problems, he says. In 2022, just 31% of graduating high school seniors were ready for college-level math (as measured by ACT scores), a decline from 40% in 2018. This makes calculus a barrier, with many intended physics majors struggling to pass UNCG's traditionally taught, theory-intensive mathematics courses. "So, we've been whittled down," Beatty adds.

As trouble mounted, faculty from these physics programs often found university administration to be less than transparent. "There was always a strong request from faculty to know how they were judging the departments," says Patton. "But they're still being opaque." Even SUNY's faculty union "can't get a single detail," he adds. And at Bradley, Lozano says physics was "well above the mark" in terms of the university's financial analysis of its programs, but it was still cut.

As a result, rumors abound on these four campuses around what triggered the cuts, and how programs were selected for elimination. Some faculty point to university mishandling of funds, high DFW rates in service courses, or even retaliation against faculty as contributing factors.

Were the closures inevitable, or is there something these departments could have done?

Haglin, at St. Cloud State, says that, since 2017, his university has been bracing for the 2025 enrollment cliff, when shifting demographics are forecast to cause a multi-year nosedive in college-bound high school grads. But what they failed to appreciate back then was the extent to which the demographics of the university's student pool were already changing.

At Bradley, Lozano says, the physics department worked hard to develop a new recruitment approach, first implemented this past school year — one of several tactics in the department's comprehensive "plan of attack" to boost enrollment. All the department's interventions were borne out of engagement with the Effective Practices for Physics (EP3) guide and the associated Departmental Action Leadership Institute (DALI), says Lozano.

In fact, all four of these departments knew about EP3 and had attempted to implement at least some of the guide's suggestions. But mostly, engagement with EP3 was limited — the result of several factors, including faculty turnover and sometimes resistance.

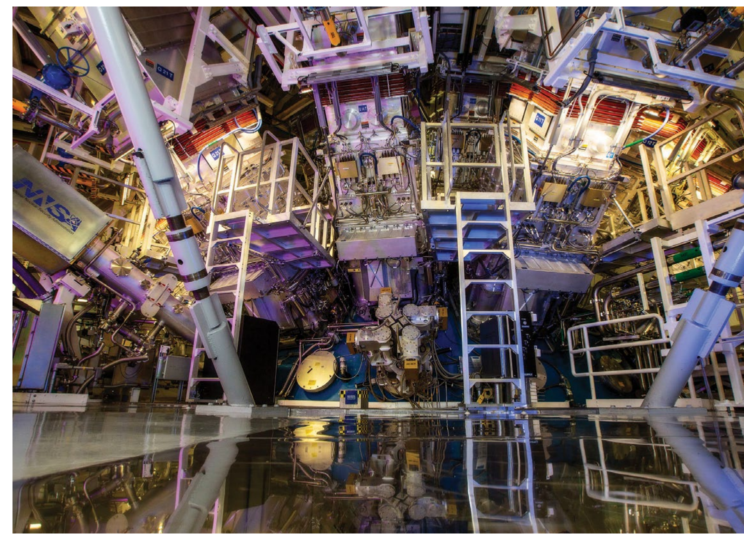
"If we had known what we learned from DALI" a decade ago, says Lozano, "I think we could have saved ourselves."

At UNCG, Beatty says the physics department was in an unwinnable battle. Their foe wasn't just shifting enrollment, declining math preparedness, or resistance to modernization, but the university's mentality of "cutting to the bone." There comes a tipping point when a department simply can't do more with less.

To future-proof your department's physics program before it faces rough seas, visit EP3Guide.org.

Liz Boatman is a science writer based in Minnesota.

Black Holes continued from page 1



The outside of the target chamber (blue sphere) at the National Ignition Facility at the Lawrence Livermore National Laboratory in California, where some of the brightest lasers in the world are used to briefly ignite nuclear fusion. Future lasers that are even more intense would be expected to stimulate the spontaneous creation and emission of electrons and positrons — the process that would ultimately prevent very strong electromagnetic fields from forming a black hole. Credit: Jason Laurea/LLNL

are equivalent, so the energy in an electromagnetic field can also curve spacetime. Putative electromagnetic black holes have become popularly known as *kugelblitze*, German for "ball lightning," following the terminology used by Princeton University physicist John Wheeler in early studies of electromagnetically generated gravitational fields in the 1950s.

Kugelblitze have been previously enlisted for speculative theories describing exotic physical phenomena ranging from dark matter to cosmic censorship — the hypothesis that the singularity within a black hole is never visible. Light-induced black holes have even been proposed as a means of propulsion for starships. But the question has remained: Are they truly possible?

The problem is that the electromagnetic-field strengths thought to be necessary would generate many quantum particles, as highly concentrated photons may disintegrate spontaneously into electron–positron pairs in a process called the Schwinger effect. These particles, accelerated by the intense electromagnetic field, would then stream out from the region, carrying away energy.

The question is then whether gravitational collapse would still be possible or whether energy loss resulting from the Schwinger effect would undermine it. Mathematical physicist José Polo-Gómez of the University of Waterloo in Canada and his colleagues have carried out calculations to see which way the balance tips.

The amount of electromagnetic energy that must be concentrated within a given spherical volume to form a *kugelblitz* is easily calculated from general relativity, and it depends on the radius, the speed of light, and the gravitational constant. The hard part of the problem is to estimate the energy dissipation from the Schwinger effect — in particular, how the timescale for particle escape compares to the collapse time of the black hole.

One of the main challenges is accounting for the way that this particle production feeds back on itself, because such particles generate electric fields that influence the creation of more particles. And because the Schwinger effect is more than just a minor correction to the calculations for black hole formation, "many of the usual tools for quantum field theory aren't helpful here," say Polo-Gómez and colleagues in a joint statement. As a result, the researchers had to make some simplifying assumptions and approximations and then had to demonstrate that these choices did not affect their conclusions.

Polo-Gómez and colleagues find that the Schwinger effect does indeed dissipate the energy of the electromagnetic field before a *kugelblitz* can form for all sizes between 10^{-29} and 10^{8} m. Smaller length scales approach the Planck length, the scale at which quantum field theory breaks down, while at larger scales no known processes in the universe would be energetic enough to make black holes from light. "We believe that our results settle the debate," say Polo-Gómez and colleagues. "While it would be scientifically wonderful if we could create microscopic black holes using very intense lasers, our research shows that this is not possible."

"The results look convincing to me," says Silvia Pla García, an expert in quantum field theory and gravitation at King's College London. She adds that the researchers' approximations all seem reasonable. "The work is exciting from the theoretical point of view because it's an example of how different things can be when quantum effects are considered," she says. She notes that this question has long been debated for conventional black holes, which are predicted to slowly evaporate because of pair production near their surfaces. Theoretical physicist Reinhard Alkofer of the University of Graz in Austria agrees that the results are persuasive, although he adds that other experts have long suspected that quantum effects would undermine *kugelblitze*.

> "While it would be scientifically wonderful if we could create microscopic black holes using very intense lasers, our research shows that this is not possible." — Polo-Gómez and colleagues

Polo-Gómez and colleagues say that even if their calculations can't be experimentally verified, the predicted creation of particle pairs by the Schwinger effect could potentially be observed. The highest intensity lasers generate electric-field strengths only 1000 times weaker than the threshold for such particle creation, they say, so future lasers may be capable of generating the effect.

Philip Ball is a freelance science writer in London. His latest book is How Life Works *(Picador, 2024). This article is reprinted from APS's Physics Magazine.*

BACK PAGE

Feeling the Force: How Physics Helps Us 'See' the Beauty of Running

In the biomechanics of running, science and art converge.

BY RICHARD TAYLOR

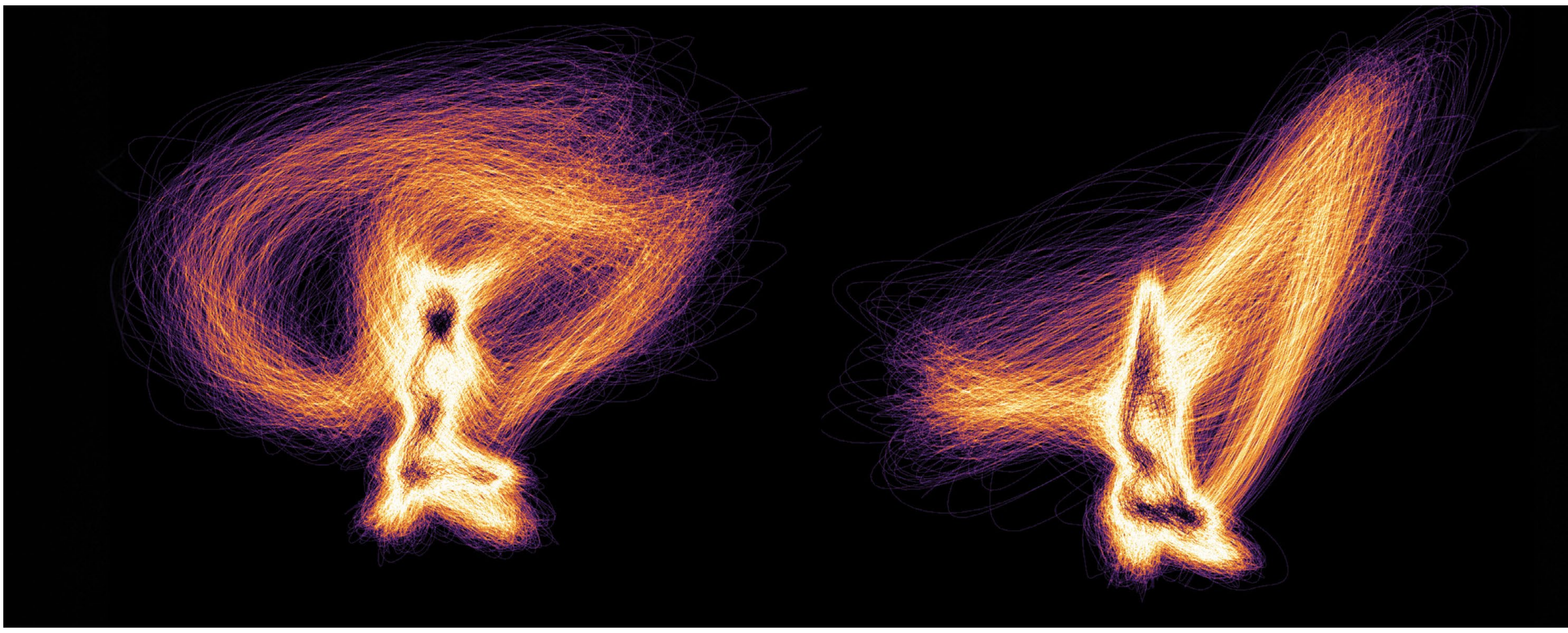


Figure 1: Plots of a runner's acceleration at the start (left) and end of a 14-mile race. This plot is of a runner's rear view, plotting acceleration in the vertical (y axis) and sideways (x axis) directions.
Credit: Project Dasein (projectdasein.com)

Growing up in England in the mid-1970s, cross-country races involved battling wild and icy Arctic winds, wading through deep and icy rivers, and clambering up steep and icy mudbanks. Pretty much everything was icy during those mid-winter challenges.

Sunshine arrived in the form of my running coach, Wilf Richards, who bore a striking resemblance to the coach in *Chariots of Fire*, the 1981 film drama about two British athletes in the 1924 Olympic Games. My teammates joked he looked old enough to have joined his doppelganger in those Olympics.

I sometimes reminisce about him clutching his stopwatch as I passed in the rain, shouting lap times or his old battle cry — "Einstein was wrong!" — as though it might boost our running speed faster than, well, the speed of light.

Along with all other physics professors, I don't like these running puzzles. I like to cram my General Physics classes with well-explained sports demonstrations. ... What, then, can physics tell runners?

Wilf didn't have much in the way of equipment to measure our progress. His stopwatch would jam half the time, and he'd calculate the distances of our runs using a strange implement donated by our geography teacher. A little wheel at one end was run along the surface of a map while a dial at the other end showed the distance. The method was so precarious that a bad crease could easily add 500 meters. Despite the challenges, he'd pour over the data scribbled down in his long tables and periodically issue profound declarations such as, "If you want to run fast, you're going to have to run *fast*."

Wilf's only piece of reliable equipment was his eye. Even though running is the simplest of sports — you just put one foot in front of the other — he could tell when it was performed with beauty. Yet like many great art scholars, he struggled to capture this beauty in precise words and numbers. I don't blame him: Strange things can emerge from this beauty.

As an example from the mid-1970s, Bill Rodgers won the Boston and New York Marathons four times each. Those races added up to about 450,000 strides for Bill — all performed beautifully, despite one leg being a half-inch shorter than the other. From more recent times, consider Femke Bol, the Dutch track and field athlete. Speeding down the final stretch, she was just a few meters away from winning a gold medal at the 2023 World Championships. As the holder of the 400-meter indoors world record, she'd practiced putting one foot in front of the other millions of times. And yet, with the world watching, she fell. She couldn't explain why. (She showed her talent most recently at the 2024 Olympics in Paris, where she won a gold medal.)

Along with all other physics professors, I don't like these running puzzles. I like to cram my General Physics classes with well-explained sports demonstrations. If you want your golf ball to fly far, try launching it at 45 degrees. If you want to spin fast, tuck your arms close to your body. Skeptics walk away convinced that the power of physics can solve any sports riddle.

What, then, can physics tell runners? About 10 years ago, this question went beyond academic interest when I learned an interesting statistic the hard way: At any one time, a quarter of runners are injured. I should have listened to Wilf's prediction: "Your Achilles heel will be *your* Achilles heel."

As is typical of people who spend a lot of time running, I also spend a lot of time with my physiotherapist. In fact, I've spent so much time with Sean Roach that he has become my close friend. We talk a lot about the beauty of running during my sessions. Recently, we've recruited two of my previous physics students, Cooper Boydston and Conor Rowland, to help turn this talk into action by utilizing the latest running technology.

These days, when I set out for a run, satellites follow my progress with precision and beam my progress to the 'watch' on my wrist. Perhaps sadly, virtual training partners have now replaced my teammates, although I like to imagine that my old friends' runs are being tracked by those same satellites.

No doubt, Wilf would have embraced these advances, as long as they helped in his search for beautiful running. Thinking back to his tables of scribbled numbers, I suspect he would have worried that the sheer amount of data could overwhelm any hope of making sense of it all. Of course, this dilemma goes well beyond running. It lies at the heart of all of today's "big data" projects.

My approach to handling complex running data came from another search for beauty. Around the time that I was running in (track) circles around Wilf, I found an art book at a yard sale that featured the abstract paintings of Jackson Pollock. I've been mesmerized by his work ever since. During the 1950s, Pollock rolled out huge canvases across the floor of his barn and poured paint from a can. A remarkable demonstration of Action Art, his motions through the air were captured by paint trajectories on the canvas — patterns I have since studied.

During my physiotherapy visits with Sean, I reminisced about using computers to analyze Pollock's paint trajectories in the hope of understanding the beauty of his art. Once we started to brainstorm, it was a short journey to the idea of using computers to assess the beauty of running. Pollock's work contained fractal patterns, originating from the multi-scaled swaying motion of his body when maintaining balance. Given that running is often described as a 'controlled fall,' would fractal balance turn out to play a key role in running too?

Wilf once declared "all runners think they can win the race, but only one *knows* they can win" — knowledge, he speculated, that came from a runner's ability to *feel* a good running form.

Sean and I began to wonder if we could visualize the forces behind this form. Exploring an analogy from car mechanics, there's only so much you can learn from watching the wheels spin — at some point you'll have to look under the hood. This interest in visualizing forces and motion lies at the heart of all physics lessons on mechanics. To look under the hood, Sean and I asked our physics team to develop an accelerometer-based sensor with the aim of combining physics with physiotherapy.

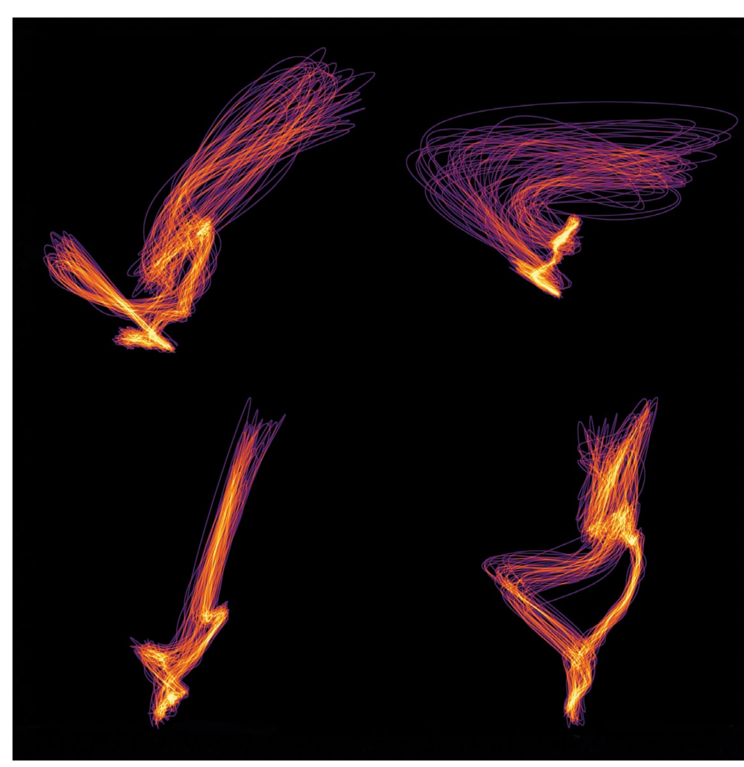


Figure 2: Force portraits for four different runners reveal the variety of patterns. In each, 25 gait cycles are superimposed and colored according to the fidelity of their repetition. White indicates when trajectories from different cycles coincide in acceleration space, while purple indicates deviations. *Credit: Project Dasein*

Figure 1 shows results when our sensor is placed on the runner's sacrum, at the base of the spine, where many of the forces experienced by the body intersect. We refer to the results as 'portraits' because their features vary significantly between runners — shown clearly across the four runners in Figure 2.

How, though, does beauty reveal itself in one portrait more than another? Some running activities demand the body to be highly efficient while others require sheer power. If both qualities can be captured simultaneously in a sustainable, injury-free fashion, then that basic running task — putting one foot in front of the other — has been mastered. This is reflected in the size and shape (including the symmetry) of the portrait. The fractal texture generated by the subtle balance variations between the different gait cycles might also play a vital role. In Figure 1, all these features vary as the runner becomes fatigued and so prone to injury. The runner has lost their beauty.

Ultimately, machine learning will categorize and determine the significance of changes in the portraits. This capacity will then be used to provide real-time feedback to the runner. In addition to learning about the body, the sensor will also be able to investigate the role of the only piece of equipment essential to running: the shoe. Should you run barefoot, as previous fads proposed? What about the latest shoes with carbon-fiber plates? What about those with two plates? You can see why we call our sensor the "guardian of the run."

Wilf once noted wryly, "If you want to observe things, use your eyes." If he were here today, I think he might add, "use science technology too."

Richard Taylor is a professor of physics at the University of Oregon. This article was adapted from a contribution by the author in the APS Forum on Physics and Society newsletter.