APS News

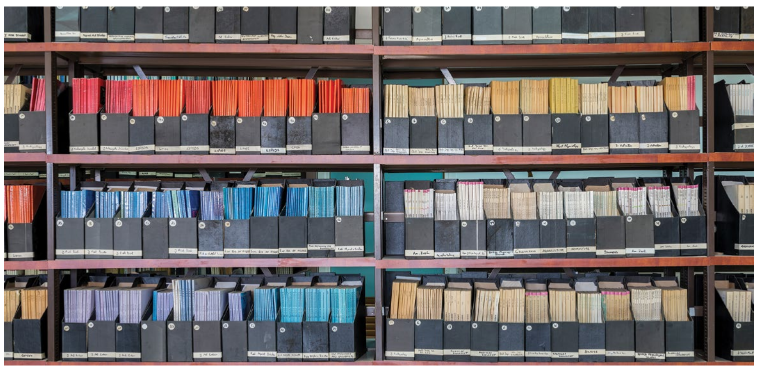
A Publication of the American Physical Society | aps.org/apsnews | March 2024 | Volume 33 | Number 3

As Academic Journals Move Toward Open Access, Some in the Industry Take Action to Reduce Inequity

Challenges remain in making sure that open access models are sustainable in the long run.

BY SHI EN KIM

The road to open science, in which research processes and products are accessible to all, is paved with good intentions. One of its principles is the concept of open access, in which the public can peruse published research for free. On the surface, open access seems like a noble idea. But while it makes the products of scientific inquiry freely available to all readers, implementing it has generated inequities among the authors in the scientific enterprise.



"It's very attractive if it works," says Franco Martin Cabrerizo, a member chemist of the National Scientific and Technical Research Council in Argentina, of the open access framework. "But if we don't take concerted actions, we can create more problems."

For example, on the path to open access, one of the many models that publishers have used is called the hybrid model, making papers pay-to-read unless authors cover an additional processing fee to publish their work under open access. Inequity arises when the additional costs prevent those who cannot afford them from sharing their scientific work with a broader audience beyond the circle of journal subscribers.

Cognizant of this issue, some players in the publishing industry have moved to course-correct. Recently, the American Physical Society (APS) announced that it will cover all article costs for publishing in its journals for scientists at nonprofit institutions in over 115 countries and territories, as well as refugee camps, this year onward. Under the new policy, eligible authors from lower- and middle-income countries will automatically qualify for a waiver of any article publishing fees when they publish in the APS journal collection. APS has also partnered with the organization Research4Life to give free subscriptions to its journal collection to researchers from these communities.

The open access movement in academic publishing draws its roots from the founding of arXiv.org in 1991, whereby physics researchers

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What Comes After Football? Astrophysics.

After an injury derailed his athletic career, Dakotah Tyler pivoted to exoplanets.

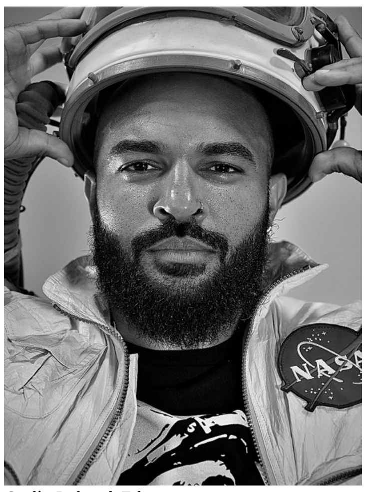
BY SOPHIA CHEN

Life can turn on a dime — or in the case of Dakotah Tyler, on a knee. During a home football game in September 2012 at the University of Kentucky, the 21-year-old Division I football player knocked into an opposing player, felt his knee twist the wrong way, and experienced a shock of pain.

The MRI revealed the injury: He had torn his ACL. "It was devastating to get that news," he says. As months passed in recovery and rehab, he realized that his childhood dream of playing for the NFL was over. "I couldn't really train anymore because I kept re-aggravating my knee injury," he says. He had to leave his position as a safety on Kentucky's team.

But Tyler didn't languish. "I just know myself," he says. "I can't go through life and be happy if I don't know what direction I'm going."

As he rehabbed the injury, he watched documentaries on the stars and planets. Drawn in by the voices of Carl Sagan and Neil De-



Credit: Dakotah Tyler

Grasse Tyson, "astronomy became this new, intense passion that I had that could take the place of football, which was so central to my life up to that point," he says.

His world began to open up. Prior to the injury, "a lot of my identity was built around being a football

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Headed to APS April Meeting 2024 in Sacramento? Here's What You Should Know.

The meeting convenes nuclear, high energy, and particle physicists in all career stages.

BY LIZ BOATMAN

An infrared image of actively forming stars, taken by the James Webb Space Telescope in 2023. Credit: NASA, ESA, CSA. Image Processing: Joseph DePasquale (STScI)

Themed around "New Challenges and Questions for the Micro and Macro Universe," April Meeting 2024 will bring physicists from around the world to learn about and discuss the latest research and news on gravitational waves, dark matter, neutrinos, and more.

In-person events for April Meeting — scheduled from April 3 to 6 — will be held in Sacramento's SAFE Credit Union Convention Center, in the heart of California's capital city.

Select sessions will be live-streamed from Sacramento each day, while virtual sessions will run over the same days as the in-person event, offering additional opportunities for attendees in Sacramento. All recorded sessions will remain available, on-demand, to every meeting registrant for 90 days after the meeting.

This year's Kavli Foundation Special Symposium is themed around

April Meeting continued on page 3

Jocelyn Bell Burnell, Whose 1967 Discovery of Pulsars Landed Her Supervisor a Nobel, Tells Young Physicists, "Don't Second-Guess Yourself"

CUWiP's 2024 keynote speaker addressed thousands of attendees across the U.S.

BY LIZ BOATMAN

On a physics exam in the early 1960s, a student read a simple question: What's the speed of light? She wrote the correct answer, 186,000 miles per second, but then paused. That seemed so fast. *Too* fast. Doubt crept in. She erased "second" and wrote "hour," which dropped her score — to 97%.

That student was Jocelyn Bell Burnell. Only a few years later, in 1967, she discovered pulsars — a feat that helped earn her doctoral advisor, Anthony Hewish, the 1974 Nobel Prize in Physics. While Bell Burnell didn't win a Nobel, she has since won other science honors, including the 2018 Breakthrough Prize (she gave the $3 million in prize money to a doctoral scholarship fund for women and people from other underrepresented groups in physics).

Bell Burnell, the keynote speaker for APS's 2024 Conferences for Undergraduate Women in Physics (CUWiP), recounted the story of her first exam error to thousands of young women and gender-diverse attendees. The talk was streamed live across 14 CUWiP host sites throughout the United States on Saturday, Jan. 20.

"You're often right the first time, so don't second-guess yourself," she said — a lesson that's especially important for women in a field still dominated by men.

When Bell Burnell graduated with her bachelor's from the University of Glasgow and headed to Cambridge for her doctorate in 1965,

Jocelyn Bell Burnell (center). Credit: Carl Bigmore / Institute of Physics

Cambridge "was full of young men who were very full of themselves," she said. She worked her "very, very hardest" to prove she deserved to be there, too.

Just two years earlier, astronomers had discovered the first quasar, an extremely bright galactic core with a supermassive black hole at its center. By 1965, only about 20 quasars had been identified. Bell Burnell spent the next two years helping build a gigantic radio telescope that could detect more of them. "And we did," she said. "We found a *lot* more."

Covering a four-acre patch of countryside, the radio telescope relied on 120 miles of wire and cable to receive incoming radio signals. A strip chart recorder captured those signals on long spools of paper, in printouts that looked similar to a lie detector's. Energetic, high-frequency pen lines could be indicators of a strong radio signal, like that from a quasar.

The telescope spat out 100 feet of chart paper per day. From miles of paper, Bell Burnell went on to discover more than 200 quasars in a few years.

But one day in November 1967, she noticed an unusual signal, dozens of lines scrunched into one-quarter of an inch on a 400-foot spool. The pattern looked like a blip of electrical interference, except at much higher frequency.

Near it, she scribbled a question mark.

As the days passed and the paper piled up, Bell Burnell kept wondering about that question mark. "I'm left puzzled by that signal … and then I see it again, from the same bit of sky," she recalled thinking. Her

Bell Burnell continued on page 5

APS Bridge Program Grad Takes on Plasma

From Alabama to Los Alamos, Dylan Funk has always been intrigued by the fourth state of matter.

BY NYLA HUSAIN

Dylan Funk

By Earthly standards, plasma is an extreme state of matter, most often generated by intensely high temperatures in space — much hotter than it usually gets on Earth. So while plasma makes up more than 99% of matter in the visible universe, it's less common here on terra firma.

That hasn't stopped Dylan Funk, a plasma physicist, from spotting it whenever he can. "You see plasmas all over the place," he says. "Lightbulbs are plasmas because they glow when you put electricity through them." Lightning and auroras also contain plasma. So do, well, plasma TVs.

When particles in a gas are heated, electrons break free from their atoms, creating the electrically charged matter known as plasma. "Think of [plasma] as a soup," he says. "The broth is the electrons running around, as well as the ions that they've separated from."

Funk, an APS Bridge Program graduate, and now a plasma physicist at Los Alamos National Laboratory in New Mexico, studied dusty plasma — the "chunks of food" suspended in the plasma soup — as part of his doctoral research at Auburn University. Dusty plasmas are commonly observed in space, he says, in places like Saturn's rings and planetary nebulae. "If you look at a nebula, you're looking at the glow from the plasma, but you're also seeing the dust that's sitting around the solar system," Funk says.

The APS Bridge Program, which supports underrepresented students of color as they pursue doctorates in physics, helped connect Funk to the faculty in charge of Auburn's Magnetized Plasma Research Laboratory (MPRL), Uwe Konopka and Edward Thomas. They later became his Ph.D. advisors and mentors. "From there, [APS] would check in to make sure I was properly mentored and see how school was going," he says.

The MPRL is equipped with a 4-Tesla superconducting magnet, which generates a magnetic field 80,000 times stronger than Earth's — allowing researchers to investigate how dusty plasmas move in nebulae, and how dust particles could be manipulated in fusion energy reactors.

When he saw glowing plasma in a chamber during his first visit to the MPRL, he was hooked. "All of a sudden, the whole thing's glowing pink, and then they shine a laser on it and it moves in a way where you can match it to an equation just by looking at it," Funk says. "You don't get to see Coulomb's force in action very often with your own eyes."

As a Ph.D. candidate, Funk developed a method to measure the charge that dusty plasma collects from surrounding plasma — research he defended for his dissertation and presented at the 2023 meeting of the APS Division of Plasma Physics.

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THIS MONTH IN PHYSICS HISTORY

March 27, 1800: William Herschel Proposes the Existence of Invisible Light

In clever experiments studying what he called "radiant heat" — what we now know as infrared light — Herschel realized there might be light we can't see.

BY KENDRA REDMOND

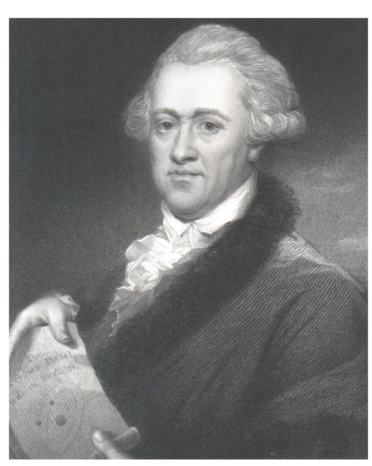
If something is transmitted like light, refracts like light, and disperses like light, could it be light?

Already a renowned astronomer and telescope builder, William Herschel was optimizing filters for viewing the sun when, fortunately, he was distracted by this chain of thought. Over a short time, he would experimentally investigate the question, rapidly produce three papers, and conclude — incorrectly — that the answer was probably no. Nevertheless, Herschel was the first to discover infrared radiation and propose the existence of light beyond the visible range.

Herschel's work in 1800 came after decades of respected work in astronomy — most famously, with telescopes.

Born in Hanover, Germany, in 1738 as Friedrich Wilhelm Herschel, the future astronomer had a musical upbringing. His father played oboe for the army there, and Herschel himself joined the military band. When he was 19, he moved to London, learned English, and established himself as a musician.

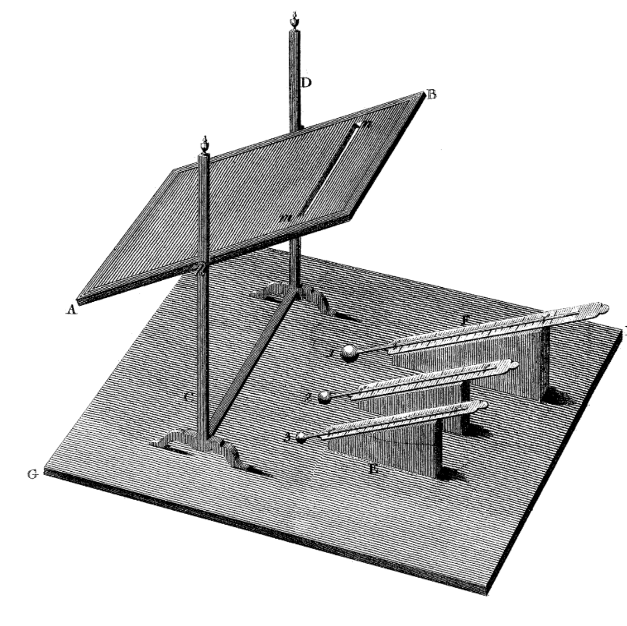
In the mid-1760s, Herschel moved to Bath, England, working as a musician and studying languages, math, optics, and astronomy in his spare time. In 1772, he brought his sister Caroline over from Germany and, not long after, began observing with a small reflecting telescope, reportedly even during breaks in his own performances.



William Herschel. Credit: Portrait from the Smithsonian Libraries

While fascinated, he wasn't satisfied. "When, in the course of time, I took up astronomy, I determined to accept nothing on faith, but to see with my own eyes everything which others had seen before me," Hershel later wrote in a letter to the editor of the *Göttingen Magazine of Science and Literacy*. His telescope wasn't big enough.

After learning to grind and polish mirrors, Herschel built his first large telescope in 1774, a reflecting telescope with a 7-foot focal length. Next came 10-foot, 20-foot, and 40-foot telescopes, often built with the help of his siblings Caroline and Alexander. The instruments were the best of their time, as were the observations Herschel made with them. After discovering Uranus in 1781, Herschel was invited by King George III to become the king's personal astronomer.



The experimental setup from Herschel's March 1800 paper. Credit: W. Herschel, *Philosophical Transactions of the Royal Society of London*, Vol. 90 (1800), pp. 255-283.

By the turn of the century, Herschel was a renowned and prolific astronomer. But his work on the sun set the stage for his foray into a new, interesting domain: The nature of light.

At that time, visible light was simply known as light. Infrared light, ultraviolet light, and the rest of the electromagnetic spectrum had yet to be discovered. James Clerk Maxwell wouldn't develop his theory of electromagnetic radiation for decades, and Albert Einstein wouldn't introduce the photon for another century. The prevailing scientific question on light pitted Isaac Newton against Christiaan Huygens: Is light a stream of tiny corpuscles (particles) or a wave?

Simultaneously, scientists were delving into the nature of heat. The prevailing theory, proposed by Antoine Lavoisier, was that heat was an invisible fluid that flowed from warm objects to cold ones and filled the spaces between an object's particles. Light and heat were seen as distinct entities, both flowing from the sun to Earth.

That is, until Herschel took up the subject. During years of solar observations, he had used pieces of colored glass to reduce the amount of light and heat coming through the telescope. While experimenting with different color combinations, he had made a surprising discovery: Certain color combinations blocked most heat but little light, while other combinations blocked most light but little heat. Furthermore, different color combinations produced different-colored images of the sun.

In a March 1800 paper he presented to the Royal Society of London, Herschel explained that these observations made him wonder whether the heating power of light varied by color. "It occurred to me, that the prismatic rays might have the power of heating bodies very unequally distributed among them," he wrote.

Herschel tested the distribution of heat with a careful experiment. He placed a prism in the window so that sunlight passing through created a rainbow on a nearby table. Then he positioned an adjustable card with a narrow slit between the prism and table. The card blocked all but a narrow band of color from reaching the table. The bulb of one thermometer sat in the light, and another sat nearby in the card's shade. Herschel meticulously recorded the temperature in the light and shade for bands of red, green, and violet light.

In each case, the temperature inside the light was higher than that in the shadow. Red rose highest, then green, then violet. Herschel concluded that the "radiant heat" in sunlight was being refracted by the prism according to the laws of dispersion — just like the light.

If radiant heat is unequally distributed among the colors, Herschel

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APSNews

Series II, Vol. 33, No. 3
March 2024

APS News is published 10 times per year by the American Physical Society, One Physics Ellipse, College Park, MD 20740-3844, (301) 209-3200. It contains news of the Society's units, events, initiatives, and people; opinions; and related information.

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player," he says. "Football is hailed in the United States. It's one of the biggest spectacles." The state of Kentucky didn't have a professional football team, so the university team had an outsized cultural importance in the state. Being on the team was almost like being a celebrity. But he realized that being a football player didn't tell him much about who he really was.

"I started to think, what else was out there?" he says.

He eventually Googled, "How do you become an astrophysicist?" Graduate school, the search results said. He called the University of Cincinnati to ask how to apply, and a professor said he needed to take multiple calculus and physics courses. So after he graduated from UK in 2013 with a degree in community and leadership development, he signed up for math and science classes at Ivy Tech Community College in his hometown of Indianapolis.

At the same time, he worked for FedEx unloading boxes from planes. "I worked nights, and then I would grab a nap, and then head to class, and then come home, do homework, and then go to sleep, and wake up and go back to work," he says.

That period was tough. In community college, he was retaking math that he never properly learned in high school, and the coursework felt far removed from his goal of being an astrophysicist. "It was a test of perseverance, of how badly I wanted it," he says.

Lessons from the field propelled him. "In football, basically every play, you win or lose," he says. "But when you lose, you don't throw your helmet off and go home and quit. It doesn't serve you to sulk. You line back up, and you try to win the next play."

In 2014, Tyler moved to Cincinnati, where he took calculus, physics, and chemistry at Cincinnati State Community College while working at a pizza place. A year later, he transferred to the University of Cincinnati for a second undergraduate degree in physics and astrophysics.

During that time, he joined APS's National Mentoring Community, where he was paired with L.C.R. Wijewardhana at the University of Cincinnati. The NMC helped him in multiple ways, he says: He gained experience presenting research at a 2018 Bridge Program and NMC conference at Stanford, and a recommendation letter from Wijewardhana helped Tyler get an undergraduate research role at the Harvard-Smithsonian Center for Astrophysics. He graduated from UC in 2019.

> "Astronomy became this new, intense passion that I had that could take the place of football, which was so central to my life up to that point," Tyler says.

Tyler is now a fourth-year astrophysics graduate student at the University of California, Los Angeles, studying how planets in our galaxy evolve over time. Among the more than 5,000 exoplanets discovered, many are slightly larger than Earth ("super-Earths"), and many are slightly smaller than Neptune ("sub-Neptunes"). Few planets have sizes that fall in between. Researchers hypothesize that the planets form at more sizes, but they lose material to end up at super-Earth and sub-Neptune sizes.

Tyler researches the processes by which exoplanets lose mass. Recently, he and his collaborators published in *The Astrophysical Journal* their study of WASP-69b, an exoplanet about 160 light-years away. WASP-69b is slightly larger than Jupiter but only a quarter of its mass, meaning its atmosphere is "puffy," says Tyler. Tyler's team confirmed that the exoplanet — which is about 22 times closer to its star than Earth is to the Sun — releases gas in a 580,000 kilometer-long tail. "Its atmosphere is just getting baked away by its star," he says.

Tyler also posts videos about science for the public on TikTok and Instagram. In many of them, he enthusiastically explains scientific concepts such as relativity and quantum mechanics. But he also shares his experiences with ADHD and produces motivational videos that draw from his perspective as a Black astrophysicist. Of the physics Ph.D.s in the US in 2018 and 2019, 1% were Black. This underrepresentation can manifest as "people being uncomfortable with me being here," he says.

While he sees his colleagues' discomfort as a problem for the field, he's personally undaunted. "I'm pushing the boundary," he says. "I'm reaching my potential."

In one video, he presents a parable about the Andromeda Galaxy. While the galaxy is visible to the naked eye, humans long assumed it was a cloud of gas and dust, until Edwin Hubble's observations in the 1920s. "Did Andromeda stop being a galaxy because the humans didn't think it was one? Did it stop doing its job as a galaxy of producing a trillion stars?" he says in the video. "It didn't stop doing its thing just because we underrated it. Just like the Andromeda Galaxy, your value is not based on the opinion on an external observer. [...] You can't let that stop you from being who you are, from doing your job in this universe."

Sophia Chen is a writer based in Columbus, Ohio.

Proposed Changes to H-1B Visa Rule Would Hurt STEM in the United States, APS Argues

A new plan would limit foreign-born physicists' job opportunities.

BY TAWANDA W. JOHNSON

Caption: Walter Cicchetti - stock.adobe.com

Physicists routinely build careers in many diverse fields, such as climate science, computer engineering, and quantum technology. But a proposed rule by the U.S. Citizenship and Immigration Services (USCIS) could make it more difficult for physicists to secure those jobs through an H-1B visa, which allows U.S. employers to hire foreign workers with specialized skills to work in the U.S. for a specific period of time.

The proposed rule would require that STEM workers' degrees be "directly related" to the job they are seeking. However, physicists often get jobs with titles that don't directly match their degrees. Plenty of students with degrees in physics go on to succeed as quantum engineers, systems analysts, or physical chemists, for example.

The change would upend the agency's longstanding practice of entrusting the employer to ensure an H-1B worker's education — bachelor's degree or higher — is appropriate for a job position.

APS recently submitted a public comment to the USCIS, urging the agency to change the language in its proposed rule. In its letter, APS asks the USCIS to consider the full body of work that goes into obtaining a doctorate in physics. After all, a newly minted Ph.D. physicist will have succeeded at learning technical tools, designing experiments, managing research programs from inception to completion, and communicating results to fellow scientists. This experience is crucial and applicable for many STEM careers.

The proposed rule would make it harder for foreign-born scientists and engineers, who are integral to the U.S. economy and national security, to build careers here, APS's letter notes. Quantum science is a stark example. "Quantum workforce needs will only continue to grow," the letter reads. "We need all hands on deck to leverage this new technology domain, including both domestic and foreign-born physicists."

It's not clear when the USCIS might finalize the proposed rule, but some parts may be approved next month.

Tawanda W. Johnson is the Senior Public Relations Manager at APS.

Leaders of Eight Physics Societies Convene in Washington

At the APS Annual Leadership Meeting, the heads of physics societies throughout the Americas discussed their visions for the future.

BY BAILEY BEDFORD

Now more than ever, physics is a global effort. Researchers work with colleagues in distant countries, building on decades of scientific progress made around the world. In recognition of this trend, the theme of APS's 2024 Annual Leadership Meeting — hosted in Washington, D.C., from Jan. 23 to 26 — was "creating global community connections."

One panel, "Challenges Facing International Physics Societies," sat down six leaders of prominent physics societies from across North, Central, and South America, as well as the president designate of the International Union of Pure and Applied Physics (IUPAP). Young-Kee Kim, the 2024 APS president, moderated the panel. Though separated by borders and thousands of miles, these societies have much in common.

"Membership-based organizations like APS — our physics societies — are facing many shared challenges," said Kim. "And many challenges cannot be solved or resolved by one country." To make progress, she suggested, physics leaders have to "roll up our sleeves" and sit down together to brainstorm.

And they did. The previous day, the group had participated in a regional summit for leaders of physics societies in the Americas. During the panel, they shared insights from the summit.

Rodrigo Barbosa Capaz, president of the Brazilian Physical Society, speaks during an APS panel. Credit: American Physical Society

"Despite the fact that we are obviously in different stages of development in physics, we share a very large number of challenges — for instance, increasing public awareness in science, improving high school physics curricula, and enhancing gender and racial equity in physics," said Rodrigo Capaz, president of the Brazilian Physical Society.

Inequitable representation in physics, including by gender and race, was a recurring theme. In the U.S., for example, only about 25% of physics bachelor's degrees were awarded to women in 2021, and less than 4% were awarded to Black students. Capaz noted that Brazil and the U.S. — both home to many people with African ancestry, as a result of similar historic experiences with the African diaspora — now face similar challenges with racial inequity in physics. And Leopoldo Soto, president of the Chilean Physical Society, added that efforts to promote equity in physics must also include members of the neurodivergent community, such as those who have autism, obsessive-compulsive disorder, or bipolar disorder.

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"Big Questions and Challenges for the Next Decade."' Panelists include Gail Dodge from Old Dominion University; Hitoshi Murayama from the University of California, Berkeley, who chaired the P5 panel that recently released its report on the future of particle physics; and Andrei Seryi, the associate director of accelerator operations at Jefferson Lab in Virginia. Their discussion will explore nuclear, high energy, and accelerator physics, as they share the collective vision for the future of these disciplines and hurdles to overcome to get there.

Plenary sessions will take a deep look at the scientific impact of major facilities, with a spotlight on the Relativistic Heavy Ion Collider, the Large Hadron Collider, and the Laser Interferometer Gravitational-Wave Observatory, as well as physics and multi-messenger astronomy. Barbara Jacak from UC-Berkeley, Michelangelo Mangano from CERN, and David Reitze from Caltech will dive into the impact of these facilities' experimental results on modern conceptions of physics.

The meeting will also offer an array of events tailored for undergraduate students, such as the 'Meet Your Future: Industry Panel and Networking' event, featuring physicists from a range of career paths.

So, whether you're interested in physics at the smallest or largest scales in the universe, APS hopes to see you at April Meeting this year.

APS has compiled resources to help international attendees for April Meeting, and attendees from less-resourced countries may qualify for discounted registration through the Society's equitable registration pricing structure. All April Meeting attendees are encouraged to review APS's code of conduct. Visit april.aps.org to learn more.

Liz Boatman is a science writer based in Minnesota.

Science Policy Highlights

BY THE FYI TEAM

Fermilab in winter 2023. *Credit: Ryan Postel/Fermilab*

New DOE fusion head sketches out vision

Jean Paul Allain, who took the helm of the Department of Energy's fusion program last summer, recently detailed his priorities in a major presentation to the Fusion Energy Sciences Advisory Committee (FESAC). Allain said he will push to expand collaborations between academia and industry, including through new Fusion Innovation Research Engine (FIRE) Centers focused on "use-inspired, use-defined" research that addresses key gaps in fusion materials and technology development relevant to building a pilot fusion power plant. Allain also said he intends to launch a program to explore potential alternatives to tokamak-based fusion reactors, and to establish research centers focused on advancing plasma science and exploring ways to apply plasmas "in every part of life."

Stressing the increasing global interest in fusion energy, Allain estimated that China is spending roughly $1.5 billion a year in the field and is taking actions along the lines of those proposed in the U.S.' own long-range plan for fusion, which FESAC published in 2020. Allain noted DOE has asked FESAC to report back by fall 2024 on what elements of the fusion program should be prioritized to support both the long-range plan and the White House's "bold decadal vision" for the development of fusion power plants.

Fermilab operations contract up for grabs

In January, the Department of Energy began accepting proposals for the contract to operate Fermilab, the foremost U.S. laboratory for high-energy particle physics research. Fermilab's managers have come under scrutiny in recent years in part due to large cost increases on the lab's flagship neutrino project, which contributed to the lab receiving a low performance grade from DOE in 2021. The lab has been managed since 1967 by the Universities Research Association, a consortium of research universities. The last time the contract was put up for competition, in 2007, URA partnered with the University of Chicago to form the lab's current contracting entity, Fermi Research Alliance LLC. URA and the University of Chicago are seeking to continue operating the lab. Another bidder is Associated Universities, Inc., which operates astronomical observatories on behalf of the National Science Foundation.

Former science committee chair, Eddie Bernice Johnson, dead at 89

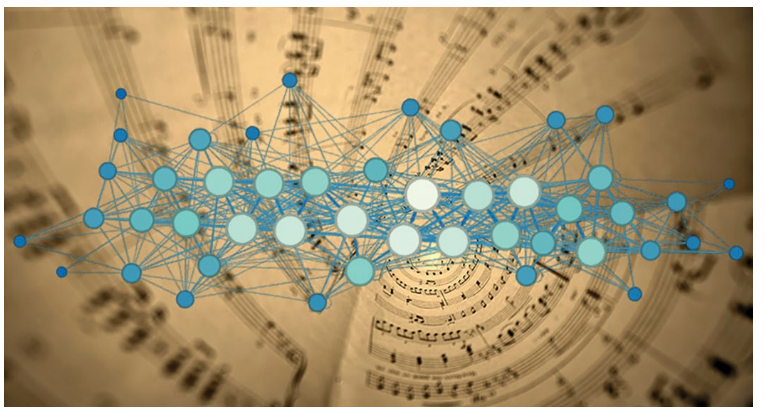
Former Rep. Eddie Bernice Johnson (D-TX), who chaired the House Science Committee from 2019 to 2022, died on Dec. 31 at the age of 89. Johnson began her career as a nurse before turning to Texas state politics in 1972. She was first elected to represent her Dallas-area district in 1992 and served as a member of the House Science Committee throughout her time in Congress. She rose to lead the committee's Democratic membership in December 2010, continuing in that role until her retirement. Johnson was the first woman and first African American to chair the science committee since its establishment in 1958. She worked to maintain the committee as a haven for bipartisan cooperation, including while developing provisions for the CHIPS and Science Act of 2022, the committee's signature achievement during her time as chair. The act includes measures that aim to increase the diversity of the STEM workforce, a cause she championed.

FYI is a trusted source of science policy news, published by the American Institute of Physics since 1989.

Measuring the Information Delivered by Music

A network-theory model, tested on the work of Bach, offers tools for quantifying the amount of information delivered to a listener by a musical piece.

BY MATTEO RINI



Credit: APS/Carin Cain

Great pieces of music transport the audience on emotional journeys and tell stories through their melodies, harmonies, and rhythms. But can the information contained in a piece, as well as the piece's effectiveness at communicating it, be quantified? Researchers at the University of Pennsylvania have developed a framework, based on network theory, for carrying out these quantitative assessments. Analyzing a large body of work by Johan Sebastian Bach, they show that the framework could be used to categorize different kinds of compositions on the basis of their information content. The analysis also allowed them to pinpoint certain features in music compositions that facilitate the communication of information to listeners. The researchers, who published the work in February in *Physical Review Research*, say that the framework could lead to new tools for the quantitative analysis of music and other forms of art.

To tackle complex systems such as musical pieces, the team turned to network theory — which offers powerful tools to understand the behavior of discrete, interconnected units, such as individuals during a pandemic or nodes in an electrical power grid. Researchers have previously attempted to analyze the connections between musical notes using network-theory tools. Most of these studies, however, ignore an important aspect of communication: the flawed nature of perception. "Humans are imperfect learners," says Suman Kulkarni, who led the study. The model developed by the team incorporated this aspect through the description of a fuzzy process through which a listener derives an "inferred" network of notes from the "true" network of the original piece.

The researchers focused on Bach's work, analyzing hundreds of preludes, fugues, chorales, toccatas, concertos, suites, and cantatas. Bach seemed an ideal starting point for this analysis, as his work has a highly mathematical structure, says Kulkarni. What's more, Bach's prolific production allowed comparisons between widely different compositional forms, she says.

To build a simplified network representation for each of Bach's pieces, the researchers assigned a node to each note and connected it to other nodes through directed edges representing transitions from each note to the notes played thereafter. They then assigned different "weights," or thicknesses, to the edges depending on the frequency with which the corresponding note transitions occurred in the piece. For each of the networks derived from the pieces, they quantified the amount of information in the network by computing the "Shannon entropy," a metric from information theory.

The procedure allowed the researchers to compare different compositional forms, showing that they could be distinguished on the basis of entropy, or information content. For instance, chorales had the lowest entropy, while toccatas and preludes had the highest entropy. Kulkarni says that these differences likely reflect the functions of each form. Chorales — meditative hymns designed to be sung by groups in churches — are simple pieces whose predictability implies low information content, while toccatas and preludes — aimed to entertain and surprise — communicate a wealth of information through their complexity. Examining the entropy of the pieces, the team found that those belonging to the same compositional forms are clearly grouped in clusters with similar entropy.

After building true networks for the analyzed pieces, the researchers computed the inferred networks using a model that describes an average process of human perception. In this process, humans seek a tradeoff between accuracy — achieving a sufficiently precise representation of the perceived network — and cost — skipping or simplifying details to reduce the computational complexity of information processing. The team found that, for Bach's pieces, the differences between true and inferred networks were much smaller than for randomly generated networks—suggesting that music compositions possess features that reduce perception discrepancies. The model allowed the authors to pinpoint some of those features, including certain forms of clustering in the network and the presence of "thick" edges representing note transitions that are frequently repeated.

Kulkarni says that the framework needs to be expanded to incorporate a more realistic description of a musical piece, including elements such as rhythm, timbre (the unique sound quality of a given instrument), counterpoint (the relationship between different melodic lines), and the presence of chords. Such multifaceted aspects of music could be mathematically captured through so-called multilayered networks that are often used in the

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Funk spent the first few years of his Ph.D. designing laboratory experiments at the MPRL. However, once COVID-19 hit, he switched to computer models that simulate the same physics from the lab — a challenging pivot, he says, but much more interesting.

Funk has lived all over the place, from California and the Philippines in his childhood, to Philadelphia and then Pittsburgh for his undergraduate studies at the University of Pittsburgh, where he majored in physics and first learned about the APS Bridge Program. He found out he'd been accepted into graduate school only a couple weeks before packing up and driving from Pittsburgh to Auburn, Alabama.

"Alabama's an interesting place to be. You're close to a lot of history," he says, noting how close Auburn was to Tuskegee, Montgomery, and Birmingham, where many key events of the civil rights movement took place. "I found a lot of people who were kind to me there, and people who were doing some amazing things."

Traveling has inspired him, too. He recalls a trip he took to Denver during grad school. During a hike, the crisp mountain air made him wonder what equation describes oxygen differences at high versus low altitudes — an equation he later used to improve his physics simulations. "It was really cool to be able to see something in real life, and then make an equation, and make that equation fit to the code."

> "If you look at a nebula, you're looking at the glow from the plasma, but you're also seeing the dust that's sitting around the solar system," Funk says.

Funk, who's always been geared towards math and science, draws inspiration from his Ph.D. advisors, who he says helped him navigate the plasma physics community and guide his transition from experimental to computational analyses.

His advice to undergraduate physicists thinking about grad school? "Have an idea of what you want to do with your research earlier on." But, he adds, "It's always helpful to be adaptable."

Although he spent three years working on a laboratory experiment that he never got to build, it wasn't wasted time, he says. "It's in my dissertation, and now someone else has built it and they're doing that research. That's exciting to me."

Since July 2023, Funk has been developing simulations for plasma physics research at Los Alamos. "I didn't expect to like coding as much as I do," he says. "There's a certain kind of thought process that goes into connecting the real world with lines on a screen, and I feel myself using [my Ph.D.] every day to connect those dots."

He's awed by the history of Los Alamos, the stomping grounds of many scientists who have famous equations named after them — like J. Robert Oppenheimer, whose house he drives by. And he loves New Mexico's natural beauty. "I do not mind [the commute]," he says. "It is absolutely beautiful. Every single day, I consider stopping to take pictures of the sky."

Nyla Husain is a science writer based in Washington, D.C.

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wondered, could illuminating power be also? That is, are objects easier to see in some colors than others? To test this, he placed small objects under a microscope. He illuminated them with only one color of light at a time (orange, yellow, green, blue, indigo, and violet), produced as in the first experiment.

By carefully rating the visibility of different objects in different colors, Herschel concluded, "The maximum of illumination lies in the brightest yellow, or palest green." As we now know, the sensitivity of the eye peaks in exactly this range.

Reflecting on both experiments, Herschel came to a deep physical insight. Consider the spectrum from violet to red light, he told the Royal Society. Illuminating power starts low, peaks, and then decreases. But the intensity of radiant heat starts low, increases, and continues increasing. Could the peak be outside the visible range of light?

In experiments referred to in his March 1800 paper (and described in a follow-up paper presented shortly after), Herschel found the answer. "The full red still falls short of the maximum of heat," he wrote. He had discovered infrared radiation.

Herschel went on to suggest that if radiant heat peaked beyond the red, "radiant heat will at least partly, if not chiefly, consist, if I may be permitted the expression, of invisible light; that is to say, of rays coming from the sun, that have such a momentum as to be unfit for vision." It was a novel and seemingly contradictory idea — to think of something invisible as light.

The paper was received favorably, though not without criticism. However, in his third and final paper on the subject, published in two parts (one in May and one in November of the same year), Herschel backed away from his conclusion. He outlined his experimental findings on the similarities and differences between light and radiant heat and concluded that they were likely distinct entities, in part because his results were difficult to correctly interpret given the knowledge of the time. Herschel returned to observational work, making new discoveries for another 20 years before his death in 1822. But it would take generations for the scientific community to realize the full value of his brief trek into the nature of light.

Herschel's final comments on the matter go against what we now know to be true. Even still, his insightful work laid the foundation on which scientists like Johann Wilhelm Ritter and Wilhelm Conrad Röntgen would uncover the full light spectrum, and others like James Clerk Maxwell and Max Planck would build the framework for electromagnetic radiation.

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Open Access continued from page 1

could choose to make their preprints freely available by uploading it to a public online repository. The movement gained momentum in the next few decades when countries around the world, including the United States, India, China, and various European nations, announced their commitments to support or mandate that government-funded research be made publicly available without a paywall. From 2000 to 2020, the fraction of open access research articles rose from roughly 20% to about half of all the scholarly literature.

"It's very attractive if it works," says Franco Martin Cabrerizo, a member chemist of the National Scientific and Technical Research Council in Argentina, of the open access framework. "But if we don't take concerted actions, we can create more problems."

However, in the rush to meet the readership side of the open access equation, addressing the supply end has lagged. The fees to enable open access have shifted the inequity from readers to authors. High article processing charges — nearing or even exceeding $10,000 a paper in some journals — can be prohibitive for researchers in many countries. In some cases, the cost to publish in top-tier journals can be as much as, or more than, the yearly salary or entire research budget of a professor in a developing country, Cabrerizo says.

The fees could compound inequality in the scientific discourse, as they risk giving the work of research groups who can afford the extra costs a greater reach over others who can't pay for open access. "We'll be excluded as writers," says Márton Demeter, a professor of communication and media studies at the National University of Public Service in Hungary, of this model. "From the perspective of knowledge production, it is very bad, I think, because though we will be able to read for free, we cannot raise our voices."

While fee waivers are a laudable start, researchers say more needs to be done to hasten the inexorable rise of open access and make sure its rollout is equitable.

Some countries are exploring open access options beyond the hybrid model. The Scientific Electronic Library Online (SciELO) network is a coalition that includes over a dozen countries, such as South Africa and several Spanish- and Portuguese-speaking nations across Latin America and Europe, that publishes research from member countries under the diamond open access model, in which both publishing and reader access come at no cost. The goal is to publish research by local researchers for local researchers and on locally relevant topics. As another example, one of APS's own journals, *Physical Review Accelerators and Beams* (PRAB), operates under the diamond open access model, with no charges for authors and no subscription fees for readers.

However, logistical challenges threaten these models from being adopted more broadly. The most glaring issue is sustainable financing, given the lack of a funding stream from the authors themselves under the diamond open access model. Usually, journals like these, including PRAB, rely on industrial or institutional sponsors — a funding model that is likely not feasible for many journals. "There are still really huge questions about how to get the money to flow, how to fund these kinds of models in a sustainable way," says Tony Ross-Hellauer, an open science researcher at the Graz University of Technology in Austria.

Additionally, a scholarly-consortium-led publication model such as SciELO might result in much of the administrative burden falling onto the researchers themselves. "It does seem an extra hidden amount of work is assumed that scholars would have to take on, not only contributing as reviewers or editors for journals, but also in helping run the infrastructure," Ross-Hellauer says. "It may become some administrative Leviathan." With the inevitable rise of open access publishing across all fields of scholarship, he says that we'll have to wait and see which publishing model the academic world converges on eventually, be it the hybrid model or the diamond version or something in between.

Extravagant article publishing fees can also incentivize unscrupulous publishers to churn out as many papers as they can in their journals, which may compromise the quality of the research literature. On the extreme end, "predatory" publishers charge high fees but provide little or no quality review. APS, for its part, recently co-founded Purpose-Led Publishing, a coalition of nonprofit physics publishers committed to prioritizing high-quality research over profit. These nonprofits pledge to invest all their funds back into science.

At the heart of the inequity issue in academic publishing is the performance evaluation system of young researchers, which inadvertently makes them willing participants and victims of the problem. As criteria for career advancement and eventual tenure, institutions often require early-career scholars to land their work in international journals with high-enough impact factors, regardless of the processing fees incurred. Oftentimes, research grants may come with the stipulation that researchers publish open access, forcing young investigators to bear the costs of doing so.

"These journals are the currency of your life when you are an academic," Demeter says. He adds that he recognizes his privilege in having the freedom to publish in any journal he prefers, having crossed the tenure hurdle a few years ago. Nevertheless, he suggests that institutions adopt alternative metrics, such as the societal impact of a researcher's work and its influence on local policy, for evaluating research performance. A more holistic assessment of individuals scaling the ivory tower should ease many of the structural problems of academia, including paving the way toward greater publishing equity.

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advisor, Hewish, suggested she feed the paper faster, to stretch the signal out and make it more visible.

Bell Burnell measured the period of the object's signal at about 1.3 seconds. Again, not just fast — *too* fast. Hewish worried that Bell Burnell had set up the equipment wrong. He called a colleague with access to a second radio telescope.

When that telescope picked up the same rapid pulses, Bell Burnell and Hewish knew for certain: The signal was real, and it was coming from "something up there amongst the stars."

"But we'd come to recognize quite a serious problem," she said. Their analysis revealed the object was 200 light-years away, and tiny. Stranger still, the signal's intensity never wavered. For its signal to travel so far and remain so strong, the source would have to be producing an incredibly high-intensity radio signal.

Jocelyn Bell in June 1967, a few months before her pulsar discovery. Credit: Roger W. Haworth (Flickr, CC BY-SA 2.0 DEED)

Then Bell Burnell found another cluster of rapid pulses elsewhere in the sky — a second object with a similar signal. By early 1968, the duo had enough data to publish a paper in *Nature*, which attracted a media frenzy. Unhappy with the wordy label "pulsating radio star," the press landed on "pulsar" instead. Scientists now know that pulsars are dense, rotating neutron stars that shoot radiation from their magnetic poles.

A composite image showing the Vela Pulsar, one of the brightest pulsars. Credit: NASA/CXC/SAO (Chandra); NASA/MSFC/F. Xie et al. (IXPE); Optical: NASA/ESA/STScI; Image processing: NASA/CXC/SAO/J. Schmidt, K. Arcand

In the years since, Bell Burnell says many have approached her at conferences or written to her to recount moments when they "nearly discovered pulsars" but second-guessed themselves, or weren't believed. "These stories are interesting," she said, "because they say a lot about how science works."

For example, about a decade before Bell Burnell's discovery, in 1957, one young woman was viewing the crab nebula through a research telescope that was open to the public one night per month. She told the observatory assistant that one of the stars was flashing.

The assistant couldn't see it, and he dismissed her comment. We now know there's a pulsar in the crab nebula that flashes at 30 Hz, said Bell Burnell, a flicker rate that's too fast for most people — but not all people — to see. "I think she saw it," Bell Burnell said.

Bell Burnell finished her talk by listing the circumstances that she believes led to her discovery of pulsars in 1967. Chief among them was having the time and space as a graduate student to dig into anomalies with painstaking thoroughness — a thoroughness borne partially, she noted, from "imposter syndrome," from so many years of being the only woman in the room. To combat self-doubt, she tackled her work with intense attention to detail.

So, what about that moment in 1967 when Hewish suggested Bell Burnell had set up her equipment wrong? She told the audience that, as a grad student, she knew her instrument and data inside and out. The young Bell Burnell knew, without a doubt, that the curious cluster of signals in her miles of spooled paper were real.

Liz Boatman is a science writer based in Minnesota.

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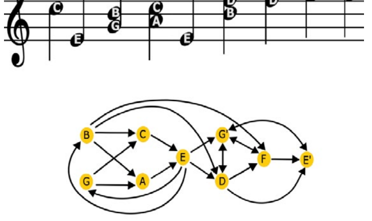
modeling of multidimensional, real-world networks. She says that an important direction for further work involves a refined description of the perception process, for instance, exploring variability among individuals or considering factors such as musical training and cultural influences.

A more complete representation of the information content in music could allow quantitative comparisons between different pieces. Such an approach could reveal how the music of a specific composer has changed over the course of their lifetime or how compositions have evolved across music traditions, Kulkarni says. She also suggests that the quantitative metrics delivered by the framework could provide feedback to aid composers in their writing process. For example, a music composition software could display measures of entropy and direct the composer toward edits that could either amplify entropy — generating surprise by contradicting musical expectations — or diminish it — through harmonious, easy-to-anticipate resolutions. Kulkarni notes that similar approaches could be applied to other art forms, such as literature, to analyze their information content and learnability. Progress in these fields will depend on exchanges between artists, sociologists, musicologists, and neuroscientists, she says. "There are tall walls between disciplines that complexity science can help tear down."



In the network representation of music used by Kulkarni and coworkers, notes are represented by nodes, and transitions between notes are represented by directed edges connecting the nodes. Credit: S. Kulkarni et al., *Phys. Rev. Res.* 6, 013136 (2024)

This article is reprinted from Physics Magazine, *of which Matteo Rini is the Editor.*

THE BACK PAGE

Physics Needs Community Colleges

Two-year colleges help millions and boost the U.S. workforce. We neglect them at our peril.

BY KRIS LUI AND SHERRY SAVDRA

For decades, parents across the United States have offered their kids the same advice: Work hard and get a good education — in college, if you can.

Community, or two-year, colleges have long been a major lane on this tried-and-true road.* Since their rise to prominence in the mid-20th century, they've provided a sensible alternative to four-year schools, for less money (a third of the cost per year of public four-year institutions, on average). Their reach and affordability have opened the door to education and vocational training for millions of people.

But community colleges, which receive less than half the funding per student that four-year colleges receive, stand on shaky ground.

We, the authors, are former faculty in physics at community colleges, and we believe that our field suffers when the role of community colleges is ignored. One reason is obvious: Physics classes at community colleges are a crucial door into STEM for many students. But the second reason is often overlooked: While the physics community has long sought and struggled to diversify its ranks, it has too frequently looked right past an indispensable tool — community colleges.

The reach of community colleges

Science, it turns out, owes a lot to community colleges. Data from 2019 shows that 45% of all employed science and engineering graduates had attended one. In fact, in spring 2023, about 30% of *all* U.S. undergraduates were enrolled in them (and, depending on the dataset, some estimates are much higher).

What about physics specifically? While the number of physics majors in community college physics classrooms is small, the impact of these classes on STEM education is not. According to the AIP Statistical Research Center, among U.S. citizens, 16% of physics Ph.D.s from the classes of 2017 and 2018 started their education at a community college; so did 15% of those receiving bachelor's degrees in physics.

And it's not just science: Community colleges reach deep into the U.S. economy. An astonishing 48% of working adults have utilized community college at some point in their lives — as have 49% of workers with bachelor's degrees.

Consider, too, these schools' impact on sectors facing worker shortages, like healthcare. In health and clinical sciences, more than 1 in 5 people with doctorates started at a community college. We, the authors, have seen this impact ourselves, having taught countless students who were taking prerequisites for advanced medical, veterinary, dental, and physical therapy degrees. Kris just spotted a former student at a local pharmacy, working as the head pharmacist. Sherry recently accompanied her father to a podiatry appointment — only to realize the podiatrist was a former student.

No typical student

It's been said that there is no "typical" community college student, because these schools boast an extraordinarily diverse student body. Nearly 60% of attendees are women; 64% are first-generation college students, compared with 47% at four-year public institutions. Community colleges serve more veterans, parents, and students with disabilities than their four-year peers. A much higher percentage attend college part-time — often while working. And at community colleges in 2023, 42% of students were Black or Hispanic, compared with 32% at four-year colleges.

These students' goals are equally diverse. Some seek professional certifications or associate degrees; some aim to fulfill prerequisites before transferring to four-year schools. Meanwhile, dual enrollment programs for high school students are growing.

Regardless of the aim, physics is a stepping stone for many STEM-minded students. Beyond the students preparing for health-related degrees, we've both taught scientists and aspiring high school teachers, as well as many students fullfilling prerequisites for degrees in engineering, computer science, and — of course — physics. One of Sherry's students was a mother who took physics part-time, while working full-time; she's about to graduate with her bachelor's in physics and is applying to graduate school.

Perils, new and old

Unfortunately, the reach of community colleges has done little to shield them from storms.

These schools serve a higher proportion of students who need more support, academically and beyond, than students at four-year colleges. Yet public community colleges receive less than half of the annual funding, per student, that public four-year universities get — $8,695 per student compared to $17,540, according to the Center for American Progress. And funding has been falling.

Starved for resources, community colleges face real challenges. Students often struggle to transfer credits to four-year colleges, and employers "systematically underinvest" in partnerships with community colleges, according to a 2022 Harvard Business School report. About half of former community college students who enrolled with work-related goals said they fell short of their aspirations, a 2023 survey found. Enrollment, meanwhile, fell between 2010 and 2023 (although there are signs of a modest comeback).

For us, the explanation seems painfully clear: Supporting students — especially those already more likely to face additional obstacles — takes more resources than these colleges are getting.

Physics faculty at community colleges face difficulties, too. These faculty lack graduate assistants to help with grading, and very few have teaching lab support. And while some community colleges provide funds for professional development, most do not, so traveling for a conference or workshop is often too costly. Even when a professor can pay to attend, finding a substitute to cover for them is no small feat: About 60% of community colleges offering a physics class have just one full-time faculty member teaching physics — or none at all.

> We can think of few college-goers more deserving of support than these individuals, whose aspirations have carried them, often through hardship, toward the hope of a good education and career. As educators, it's our privilege to help them get there. As physicists, it's our responsibility to invite them into our field with gusto.

These trials have left many physics faculty struggling to connect with peers and mentors, grow professionally, and get good data on their students.

The path ahead

Many of these challenges won't be easy to fix. We doubt, for example, that solving a $78 billion state funding shortfall for community colleges will be a walk in the park.

But we have faith in the physics community. For our part, we and collaborators have created the Organization for Physics at Two-Year Colleges (OPTYCs), a community for faculty and their allies across the field. OPTYCs offers programs for professional development, facilitates mentoring and networking, supports physics education research in community colleges, and more.

But partnerships among community colleges must be complemented by partnerships beyond them. So, if you're a faculty member or researcher at a four-year college, reach out to your local community college and meet the physics faculty. Be open to learning from them, as they are experts on the needs of local college students. Also, find out how easily community college students can transfer to your university; there might be opportunities to create major-specific transfer pathways that you can help with.

But no matter your role, you can help with another monumental task: a shift in attitude. Community colleges have long been dismissed as a "lesser" option for higher education — and for employment. Like so many community college faculty, we the authors chose our careers because we discovered passions for teaching. Most community college faculty are innovative educators who are deeply committed to their students.

Worse, though, is when judgment is directed at the students themselves. In fact, we can think of few college-goers more deserving of support than these individuals, whose aspirations have carried them, often through hardship, toward the hope of a good education and career. As educators, it's our privilege to help them get there. As physicists, it's our responsibility to invite them into our field with gusto.

If physics is to live up to its potential, it must welcome more people from diverse backgrounds, and it must prepare a broader swath of the public for good careers and lives. The field can accomplish neither without community colleges, which need champions now more than ever.

**Most community colleges two-year degrees, like associate degrees, although some offer four-year bachelor's degrees.*

Kris Lui is the project director for The Organization for Physics at Two-Year Colleges (OPTYCs). Previously, she spent 13 years as a physics professor at Montgomery College, a community college in Maryland. Sherry Savdra is a co-PI for OPTYCs and retired as a physics professor at Seminole State College of Florida, a community college, after more than 30 years. Learn more about OPTYCs, which is supported by the American Association of Physics Teachers, at optycs.aapt.org. For sources, visit go.aps.org/TYC.

OPTYCs is federally funded (National Science Foundation Grant No. 2212807). Any opinions, findings, and conclusions or recommendations expressed in this article are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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The panel also talked at length about international collaborative efforts, some in progress already. Nathan Berkovits, the director of the ICTP South American Institute for Fundamental Research (ICTP-SAIFR), discussed a project in which his organization translated, into Portuguese and Spanish, high school physics lessons produced by the Perimeter Institute in Canada — an effort supported in part by the APS Innovation Fund.

Julio Mendoza Alvarez, president of the Mexican Physical Society, described future opportunities for international collaboration, like creating a shared catalog of physics programs throughout the Americas and expanding Mexico's annual science outreach event, The Night of the Stars, to additional countries.

To be successful, partnerships should be mutually advantageous, Capaz noted: "One thing that is very important, especially again when you realize that and understand that perhaps in the Americas we are talking about very asymmetric partnerships between countries at different stages of development, is we need to find a balance in which partnership is beneficial to both sides."

Some mutually beneficial types of partnership enable the movement of people — for example, ensuring that students can study internationally and researchers can travel abroad for their work. Omar Osenda, president of the Argentina Physical Association, emphasized that Argentina's physicists and students are a valuable resource in and of themselves.

But managing physical resources can benefit from collaboration, too. For example, Chile, Argentina, and Bolivia have natural sources of lithium, explained Leopoldo Soto, president of the Chilean Physical Society; coordinating the use of lithium is important not only for building batteries but also for its future applications in nuclear energy.

These ambitions rely on the field's ability to train and retain the next generation of physicists, as well as empower them to solve emerging problems — needs that physics societies could help meet. William Whelan, president of the Canadian Association of Physicists, suggested that expanding the definition of physics to include related fields might attract middle and high school students, by presenting physics as an interdisciplinary approach to addressing global challenges that concern them. Silvina Ponce Dawson, president designate of IUPAP, noted that Societies could offer more support for researchers studying physics with applications for sustainability, as well as create programs that train doctoral physicists to apply their expertise to modeling climate change.

The panelists seemed eager to move forward.

"There are real opportunities here for us to share information, share ideas, exchange ideas," Whelan said. "We were told yesterday this is the start of the conversation, so I'm excited about that."

Bailey Bedford is a science journalist based in the Washington, D.C. area.