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APS NEWS

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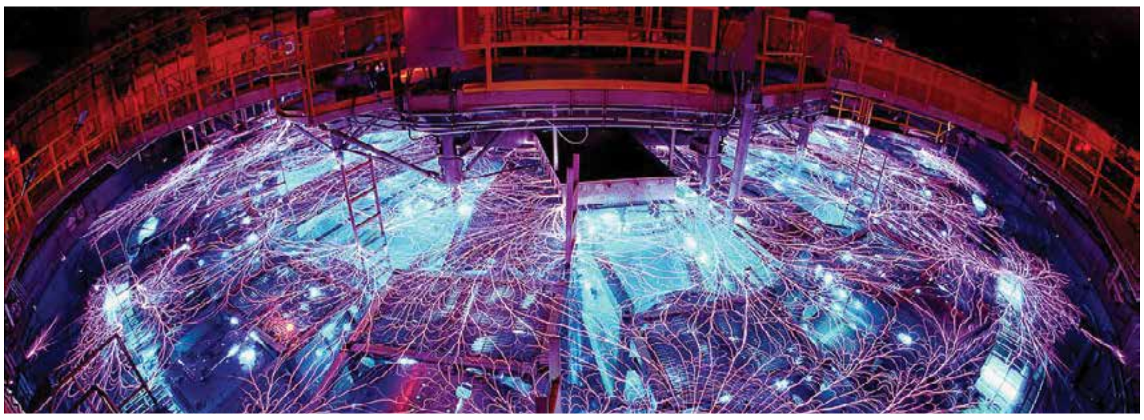
MEETINGS

How to Squeeze a Rock Like the Center of a Planet

Scientists shared research at SHOCK22, an APS conference about materials under pressure.

BY SOPHIA CHEN



The Z Machine at Sandia National Labs in Albuquerque, New Mexico, which scientists can use to study the intensely high-pressure environments of the inner Earth. CREDIT: SANDIA NATIONAL LABORATORIES

Extreme conditions lie just beneath our feet. The Earth's mantle—a rocky layer that begins about seventy kilometers underground—ranges from 1,000 to 3,700 degrees Celsius. The mantle gives way to our planet's iron-nickel core, where pressure rises above a million times that of sea level.

To study matter under these high temperatures and pressures, researchers turn to shock and compression physics, which combines experiments with theoretical thermodynamics, chemistry, and condensed matter. The work informs subjects ranging from planetary formation to the design of explosive weapons.

This July, scientists gathered in Anaheim, California, to discuss research on these extreme conditions at the 2022 Conference of the APS Topical Group on Shock Compression of Condensed Matter (SHOCK22). The conference featured sessions on experiments for studying the interior and exterior of Earth—and even bodies in outer space, like our very own Moon.

SHOCK CONTINUED ON PAGE 5

MEETINGS

The Newest Quantum Frontier: Building a Skilled Workforce

Education in quantum mechanics has lagged for years. Experts are trying to change this.

BY MEREDITH FORE

In the last few decades, quantum technology has moved from the theoretical to the tangible: Quantum computers can have hundreds of quantum bits (up from a few dozen just a few years ago), quantum information can be transmitted hundreds of miles and even to and from orbital satellites, and quantum sensors are becoming some of the most precise instruments in the world. But as this wave of innovation continues, a necessary element lags behind: a quantum-educated workforce.

"Investments in [quantum information science and technology] by new and existing

QUANTUM CONTINUED ON PAGE 7

The "Schrödinger's cat" thought experiment, conceived in 1935, is one of physics' most famous paradoxes—and an enduring example of the challenge of teaching quantum mechanics.

PEOPLE

Danielle Buggé Wants High Schoolers to "Fail Productively" in Physics

An interview with the 2022 PhysTEC Teacher of the Year.

BY TARYN MACKINNEY

Do you remember your high school physics teacher? Danielle Buggé's students certainly do. Dr. Buggé—a physics teacher at West Windsor-Plainsboro High School South in New Jersey—has taught for 13 years, and her teaching approach is rooted in research on how kids learn best.

"We want students to learn physics the way physicists do," she says.

Danielle Buggé

Dr. Buggé has been named the 2022 National PhysTEC Teacher of the Year, an award that recognizes outstanding physics educators. The Physics Teacher Education Coalition (PhysTEC)—an initiative of APS and the American Association of Physics Teachers—seeks to address a shortage of qualified physics teachers in the US. The Teacher of the Year receives funding to attend two conferences focused on physics education and a $1,000 grant for classroom materials.

APS News spoke with Dr. Buggé about her background, teaching approach, and advice for aspiring teachers. This interview has been edited for brevity and clarity.

Which came first, your interest in physics or your interest in teaching?

BUGGÉ CONTINUED ON PAGE 4

RESEARCH

Scientists Create New Way to Predict Rogue Waves in Crossing Sea Conditions

"Rogue" waves—unusual and enormous—pose a threat to ships.

BY MARGARET OSBORNE

A rogue wave more than 60 feet tall, striking a tanker in the Gulf of Alaska in 1992. CREDIT: CAPTAIN ROGER WILSON/NOAA

For hundreds of years, massive waves in the open ocean—called rogue waves or freak waves—were thought only to be maritime legend. Occasionally, sailors reported these rare waves creating enormous walls in the sea, smashing into ships and swallowing their crews. But many scientists were skeptical and dismissed these tales as exaggerations.

Then, on New Year's Day of 1995, scientists recorded an 85-foot wave hitting an oil platform off the coast of Norway. This was the first rogue wave ever reliably measured, confirming its legitimacy in the scientific community.

Subsequent research has found that rogue waves—waves twice the height of others around them—are rare, but not *that* rare: Some scientists estimate that 1 out of every 10,000 waves is rogue.

These waves pose a significant risk to ships and maritime structures because of their massive size and force, but they remain difficult to predict. Now, in a new paper published in *Physical Review Fluids*, a team of researchers has proposed a novel method to quickly forecast the occurrence and shape of rogue waves in specific conditions.

Over the years, scientists have created models to calculate and predict the properties of ocean waves. One such model, the linear wave model, is a quick and simple way of tracking waves. According to this theory, when two waves combine, they form a large wave twice the height of the smaller ones.

But not all waves in the ocean—including rogue waves—can be explained by linear models. Instead, when two waves meet, energy passes between them in complex and nonlinear ways. Indeed, rogue waves occur because of the "nonlinear interaction between two

WAVES CONTINUED ON PAGE 3

RESEARCH

Computer Simulations Uncover How Barnacles Slow Down Ships

The critters force boats to burn more fuel—and create more emissions

BY TESS JOOSSE

Every year, over a billion tons of stuff gets shipped around the world. Cars, clothes, electronics, food, and fuel glide across oceans on cargo ships, on their way to stores or front porches. This hefty load comes at a price: The global shipping industry, which relies heavily on fossil fuels, is responsible for an estimated 3% of global greenhouse gas emissions each year, more than is produced by the entire country of Germany.

Worse still, a tiny menace is forcing ships to burn even more fuel. Barnacles, mussels, and other marine organisms can gather in such numbers on the hulls of ships that they can mess with the vessels' efficiency and performance, a phenomenon known as "biofouling."

Now, new research, published July 16 in *Physical Review Fluids*, seeks to understand the specifics of barnacle biofouling using computer simulations, which could inform new tools to better beat back the pesky creatures.

"[Biofouling] is a wide and important problem, and one that has an emissions impact and an economic impact," says Angela Busse of the University of Glasgow and a co-author of the paper. When a ship moves through the sea, a layer of fluid forms at the ship's surface as water flows over it. This "turbulent boundary layer" creates drag, preventing the ship from cutting cleanly through the water.

With effort, ships can cope with this drag—but any roughness on the ship's hull can slow it even more, and a lot of small barnacles can have a huge impact. A 2007 study led by Michael Schultz of the United States Naval Academy estimated that a ship with heavy biofouling might have to overcome up to 80% more resistance than a clean ship.

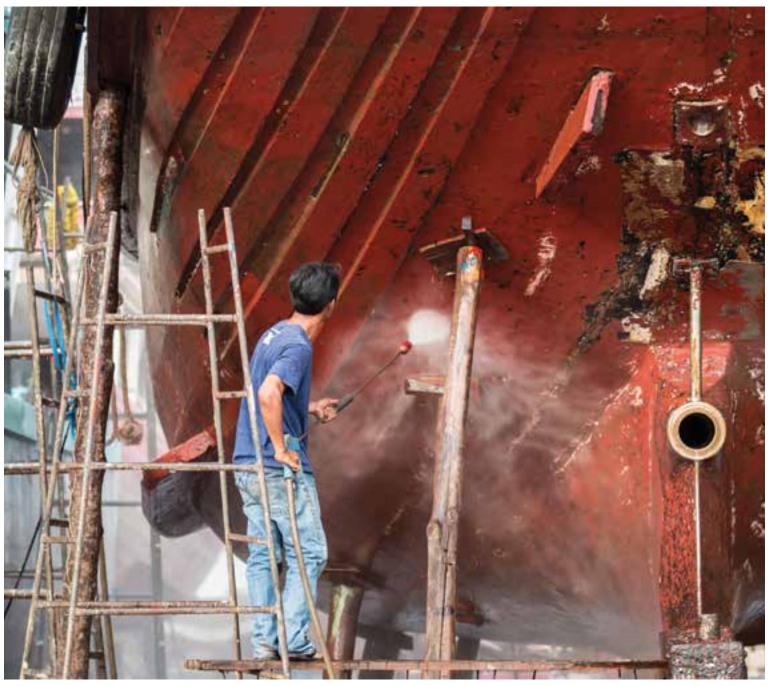
As a result, more fuel is required to propel a ship forward, Busse explains. A 2011 study, also by Schultz, estimated that a Navy destroyer with fouling might require 20.4% more fuel. And a preliminary report from November 2021 found that barnacle or tubeworm biofouling could increase emissions by up to 55%, depending on the ship.

"Not only is it bad for greenhouse gas emissions, but also the bottom line," Busse says.

Since the 1960s, toxic chemicals used to strip barnacles from ship hulls have been phased out or banned, and today, shipping companies and maritime institutions like the US Navy implement extensive cleaning and painting regimens to remove or prevent barnacle growth on their ships. It's an essential step to keep boats in ship-shape, but it's costly.

For the new paper, Busse and Sotirios Sarakinos, a co-author and fellow University of Glasgow

BARNACLE CONTINUED ON PAGE 6



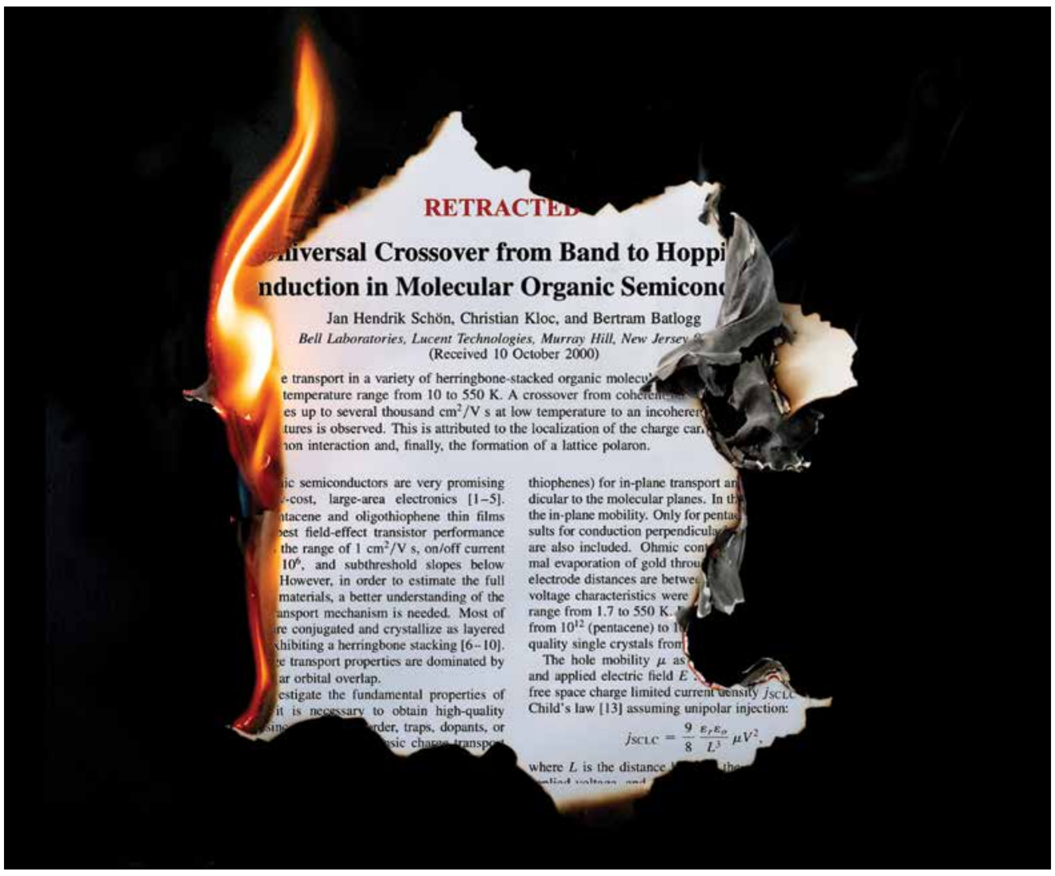
Barnacles are a problem for the shipping industry and maritime institutions. Here, a man pressure-washes a boat hull, where barnacles tend to gather.

THIS MONTH IN

Physics History

September 2002: Schön Scandal Report is Released

BY DANIEL GARISTO



CREDIT: TARYN MACKINNEY

In an age of p-hacking, paper mills, and predatory journals, it isn't hard to spot unsavory behavior in science. But prolonged scientific fraud masquerading as groundbreaking discovery is mercifully rarer. Twenty years ago, a condensed matter physicist at Bell Labs shook the scientific world when his years-long work was revealed as a forgery.

On September 26, 2002, an investigatory committee released a report concluding that Jan Hendrik Schön—and none of his coauthors—committed scientific misconduct in at least 16 cases.

"The works in question report accomplishments that, if valid, would represent a remarkable number of major breakthroughs in condensed-matter physics and solid-state devices," the committee stated. Led by Malcolm "Mac" Beasley, an eminent Stanford condensed matter physicist (and later, 2014 APS President), the Schön report came after months of community skepticism. It closed the book on Schön and his fraud, but fallout from the scandal lingers today.

"Even when compared to other cases of scientific misconduct, Schön's case was uniquely large in scale," Eugenie Reich writes in *Plastic Fantastic: How the Biggest Fraud in Physics Shook the Scientific World*. "It was unprecedented in terms of the number of discoveries he faked and the number of other scientists he misled or deceived."

In response, APS established guidelines for coauthor responsibility based on the report's recommendations. Debate still smolders about whether the scandal reflected the success of science's self-correction or the failure of its institutions.

Schön was born in 1970 in Verden an der Aller, a town in northwest Germany, and raised by his mother and stepfather near the Austrian Alps. He studied physics at the University of Konstanz, where, in Reich's reporting, the seed of Schön's misconduct was planted: He began to smooth data in order to align his results with the accepted values. Still, colleagues reflected that, at the time, he was an "honest and proper person" who was technically skilled and careful about data collection.

When Schön arrived at Bell Labs in the late 1990s, the storied research facility was experiencing a bit of a renaissance. Though the glory days of the transistor and laser were behind it, Bell was benefiting from the dot-com boom, and for three years in a row, its past or present researchers won part of the Nobel Prize in Physics. The desire to publish high-impact research was very much alive.

Schön's first experiments at Bell centered around transforming organic crystals of

SCANDAL CONTINUED ON PAGE 7

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RESEARCH

For Agile Flight, Just Add Feathers

Humble feathers called "coverts" could inspire new designs for aircraft wings.

BY JESSE KATHAN

Birds can dive, swerve, and perform complex aerial maneuvers unmatched by any aircraft. A new study suggests that subtle movements of specific feathers might be key to their agility.

In the study, published June 14 in *Physical Review Fluids*, researchers simulated the way air moves around a wing tilted sharply up, modeling a bird's position during takeoff and landing.

When wings have a slight tilt, as most airplanes do, air glides smoothly over them. But at steep enough angles, eddies, or vortices, of air swirl off the front and back edges of the wing. These vortices alternately wax and wane in intensity in a process called vortex shedding.

The front vortex creates a zone of low pressure over the wing, lifting it up. But the rear vortex sends a stream of air in the wrong direction, back towards the front of the wing. This stream, called reverse flow, robs the wing of the lift needed to fly.

To address the reverse flow problem, the researchers looked to coverts, the outermost row of feathers on bird wings, which cover the bases of the long, finger-like flight feathers. During flight, covert feathers can slightly angle up from the wing's surface. To model how coverts might affect flight, researchers attached a flap to the top of a simulated wing. When extended, the flap stopped reverse flow from interfering with the wing's lift.

"The flap essentially acts as a dam," said Nirmal Nair, an aerospace engineering graduate student at the University of Illinois–Urbana-Champaign and author of the paper. "It does not allow the pressure on the front and rear side of the flap to mix together, and that helps in maintaining that low pressure region in front of the flap."

Previous studies have examined how these flaps can improve lift, but most have modeled the flap either as a rigidly attached bar or a freely moving hinge. Nair's paper is one of the first to simulate the flap attached at various levels of stiffness.

In the simulation, the flap worked best at a middle level of stiffness. Too flexible, and the flap would raise more than necessary; too stiff, and it wouldn't move at all. "There was a sweet spot in between," said Nair.

FLIGHT CONTINUED ON PAGE 6

CAREERS

How to Build a Crisis Management Plan for Your Career

Jobs can end abruptly, as COVID showed. To cope then, prepare now.

BY ALAINA G. LEVINE

At the beginning of 2020, I had an exciting year ahead for my career, with a full calendar of speaking engagements, including one at the University of Tokyo. When the pandemic hit and all my contracts (and most of my income) disappeared into a void of anger, fear, and cupcake crumbs, I knew I had to act. I did—and by the end of the year, I had booked more business than I had in any year before. How? By developing and using a career crisis management plan. You need one too—*before* crisis strikes.

Crises can happen anytime to anyone. They can derail our plans for career advancement, cost us precious resources, or lead to job loss. And as the pandemic has shown for so many people, crises also take a physical and emotional toll.

In short, crises suck.

But you have the power to overcome them—in this case, by building and executing a customized crisis management plan for your career. This strategy serves as insurance, letting you identify and mitigate points of risk that could hurt a career in a crisis.

A major component of this plan is networking, in which you craft and activate mutually beneficial relationships with the aim of supporting one another during challenging times—and enabling everyone to harness their hidden capacities for success in the face of loss. And by building the plan now, we foster resilience and increase the chances of professional sustainability, for us *and* our connections. Here's how you design and implement your career crisis management plan.

A crisis can happen anytime, to anyone—but a career crisis management plan can help.

Recognize your emotions and give yourself space and time to feel them. Our feelings, whether positive or negative, are valid and valuable. You may not be able to heal before you need to take action, but by acknowledging these emotions, you prevent them from festering.

View the situation as a logic problem. Physicists are excellent problem-solvers; one of your assets is your ability to think logically and see challenges as a series of questions for which you need answers. This is how I think too! My mathematics background helps me break problems down into nanosteps with a logical framework. This guide is a good place for you to start.

Check your record and inventory your skills (intrinsic data). Crises

CRISIS CONTINUED ON PAGE 5

WAVES CONTINUED FROM PAGE 1

wave systems," write the authors of the new paper. These interactions produce high crests and low troughs, the highest and lowest points on a wave.

As a result, rogue waves are trickier to predict. To calculate the probability of a rogue wave occurring, scientists use the Benjamin-Feir Index (BFI), which is essentially the "ratio of wave steepness to spectral bandwidth," the authors write.

But the BFI has a downfall: It only considers ocean conditions in which waves travel in one main direction. By contrast, many rogue waves happen in what are known as crossing sea conditions, when two wave systems travel at an acute or obtuse angle to each other, explains Xinshu Zhang, professor of naval architecture and ocean engineering at Shanghai Jiao Tong University in China and a coauthor of the paper.

"There have been several accidents reported, historically, that actually occurred in the crossing sea," Zhang says. "So that's one of our motivations to study this topic."

Cross swell visible from Ile de Ré, an island off the Atlantic coast of France.

CREDIT: MICHEL GRIFFON/CC BY 3.0

Suspected rogue wave accidents in crossing sea conditions include the *Suwa Maru*, a fishing boat carrying 20 crew members that sank off the coast of Japan in 2008; the *Louis Majesty*, a cruise ship off the coast of Spain that was hit with a massive wave in 2010, killing two passengers; and the *Prestige*, an oil tanker that sunk off the northwest coast of Spain in 2002, spilling nearly 18 million gallons of oil.

To overcome the BFI's limitation, the authors created a new coupled BFI (CBFI) that can be used in crossing sea conditions.

"It's a very simplified model to rapidly evaluate how dangerous the crossing sea is," Zhang says. Using parameters that scientists can obtain in advance from weather forecasting systems, the model can predict other wave parameters, and therefore evaluate the probability of a rogue wave happening.

The researchers then validated the model by running simulations and comparing them to past experiments.

"In our simulations, there are thousands of waves," coauthor Shuai Liu, also from Shanghai Jiao Tong University's State Key Laboratory of Ocean Engineering, says. "[Imagine] maybe 400 waves propagating in one direction and another 500 waves propagating in another direction. So, we consider lots of waves in these simulations."

While previous studies focused primarily on the probability of rogue wave occurrence, the authors also considered the shape of these waves.

"The freak wave shape is important to predict the loads on the ships and offshore platforms," Zhang says. Right now, engineers base their predictions of a wave's force on a ship or marine platform on the linear theory, he says, which don't take shape into account.

The study found that wave shape is influenced more by changes to the crossing angle rather than the properties of individual waves.

One constraint of the new CBFI is that it assumes that the two waves in the crossing sea states have the same wave period—the time it takes two successive wave crests to reach a fixed point—which is not always the case. Liu explains, though, that if the two wave periods are the same, it's most likely to generate a rogue wave.

"We considered the most dangerous conditions, but in the real ocean, it's not exactly what we assumed in this paper," Liu says. "That's our future plan, to study more on the effects of the difference of the wave periods."

Margaret Osborne is a freelance writer based in Utah.

BUGGÉ CONTINUED FROM PAGE 1

Physics. I studied physics and studio art in college, which were interests I had in high school.

I had a high school physics teacher that inspired me. I had fun in her class, and she made it accessible for us. It was challenging; I had to keep asking questions. I got to know my classmates well, too, because we had to work together to learn.

What got you into teaching from there?

My family and friends encouraged me. They'd say, "Listen, you've been doing this throughout your life—working with younger students, mentoring. You'd make a very good teacher." So I attended Rutgers University for my Master's in Education and physics teacher certification.

In your classroom, you use a teaching approach called the Investigative Science Learning Environment, right?

Yes—ISLE, for short.

What is ISLE?

ISLE is a philosophy of learning and teaching where the things students do in the classroom mirror what physicists do when they do physics. I learned about ISLE from Eugenia Etkina, my mentor at Rutgers, who pioneered the approach. We want students to learn physics the way physicists do, and feel good about themselves in the process. They're not just learning content—they're developing content.

We start out with observational experiments, and then the students, in teams, come up with explanations for what they saw. They ask themselves, "What's going on? What might explain this?"

But we don't stop there. The students then design and perform experiments to test their explanations. It's often tough for students when their predictions don't match the outcomes of the experiments. They think something's wrong. That's when we say, "No, no, no—it's okay that they don't match! That's part of the process." They're developing the ability to think like scientists, and to use the processes that scientists use every day in the real world. And they're doing it with their peers.

You're aiming for a collaborative environment?

Yes. It's not you against me—we're working on this together. That's what happens in science, right? And because we encourage our students to revise their ideas, they experience productive failure. Physicists don't have all the answers the first time, so we shouldn't expect that of students.

It sounds like having students learn to cope with frustration and failure is a part of the process.

Absolutely. We want them to ask, "How can I figure things out? Who am I as a learner?" We're giving them space to develop a growth mindset, which will benefit them in the future.

What have you learned from your own research on ISLE?

So, we surveyed alumni who had learned physics in ISLE classrooms about what they remembered and learned from the courses. We received more than 200 responses from students going back 10 years.

Many of them remembered physics content. But many also talked about being in a space where they could fail productively, without ramifications—about having a safe space to learn. And many alumni, whether in STEM or non-STEM fields, reported that they'd been able to transfer specific skills to their later studies and careers, like critical thinking, metacognition, and collaboration.

Can you think of students whose experiences in your classroom shaped what they did after high school?

Yes, several. One of my students is pursuing a PhD in physics. He says it's completely my fault. *(laughs)* He came into my class unsure of himself, and we figured out how he learns and what excites him. He ended up being a lab assistant in my course. Now he's doing research on quantum optics, and he comes back every year to speak to my current students about physics.

Have any of your students gone into education?

Yes. One of these students said, about halfway through his junior year, that he wanted to be a physics teacher. He just finished his sophomore year in college. One of his professors emailed me and said, "I've heard all about you." *(laughs)*

That's a big deal, particularly given that the US has an acute shortage of high school physics teachers. The need for teachers in physics is greater than for nearly any other subject. In your view, what will help teachers overcome these challenges?

Having a support network is invaluable. If we want to retain teachers, they need to feel supported in the profession. That was important throughout my teacher prep program and as a new teacher—we planned lessons, gave feedback, and grew together.

If you don't have a community—if there's nobody to talk to—it's difficult. If you're feeling isolated, you're not going to challenge yourself or your students.

If a high school or college student were reading this, and they were thinking about becoming a teacher, what would you say to them?

If you're a high school student, I'd suggest spending time in classrooms. Ask your teachers, "Can I shadow you during my study hall? Can I help with lessons?"

For college students, I'd suggest talking to people in the education department. There's still a stigma about STEM in education, and you need to find the mentors who will support you. And you need to find like-minded students who want to major in education, even if it's not STEM. That way, you'll be able to form a community where you're able to grow together.

So, short and sweet—I'd say go for it.

To learn more about PhysTEC, visit phystec.org.

Taryn MacKinney is the Editor of APS News*.*

The views expressed in interviews and in opinion pieces, like the Back Page, are not necessarily those of APS. APS News *welcomes letters responding to these and other issues.*

APS COMMUNITY

The APS Topical Group on Hadronic Physics

Studying the strong force? You need a strong community.

BY ABIGAIL DOVE

It's a physics 101 principle: The strong force binds quarks and gluons together into the protons, neutrons, and nuclei that form most visible matter in the universe. But the laws governing these interactions—known as quantum chromodynamics or "QCD"—are far from fully understood: How are protons and neutrons bound together? How do quarks and gluons give a proton its mass and spin? How densely can they be packed in atomic nuclei?

With more than 600 members, the Topical Group on Hadronic Physics (GHP) is a hub for physicists seeking answers to these questions.

To unravel the mysteries of hadrons, physicists use some of the world's largest and most sophisticated particle accelerators to conduct two types of experiments: hot and cold. Key to the study of "hot" hadronic matter is Brookhaven National Lab's Relativistic Heavy Ion Collider, which smashes together two beams of gold ions traveling at nearly the speed of light, melting the protons and neutrons and momentarily freeing quarks and gluons. To study "cold" hadronic matter, many physicists rely on the particle accelerator at Thomas Jefferson National Accelerator Facility, which fires a stream of electrons at proton and neutron targets, causing their particles to scatter into an array of detectors. Other projects are going on at Fermilab and CERN's Large Hadron Collider, and physicists are excited about the Electron-Ion Collider, which will be sited at Brookhaven National Laboratory.

The Large Hadron Collider in Geneva, Switzerland, smashes subatomic particles called hadrons—mostly protons, a type of hadron—together at extraordinarily high speeds. CREDIT: MAXIMILIEN BRICE/CERN

"At the most basic level, we're trying to understand how quarks and gluons interact," explained David Gaskell, chair of GHP and a staff scientist at the Thomas Jefferson National Accelerator Facility.

Despite the breadth and depth of the field, hadronic physicists lacked a home within APS until GHP's establishment in 2001. "Hadronic physics used to fall into the realm of high energy particle physics, but that got left behind as the focus in

GHP CONTINUED ON PAGE 6

FYI: SCIENCE POLICY NEWS FROM AIP

What Projects Should Nuclear Physics Prioritize in the Next 10 Years?

A federal committee gets to work on an answer.

BY MITCH AMBROSE

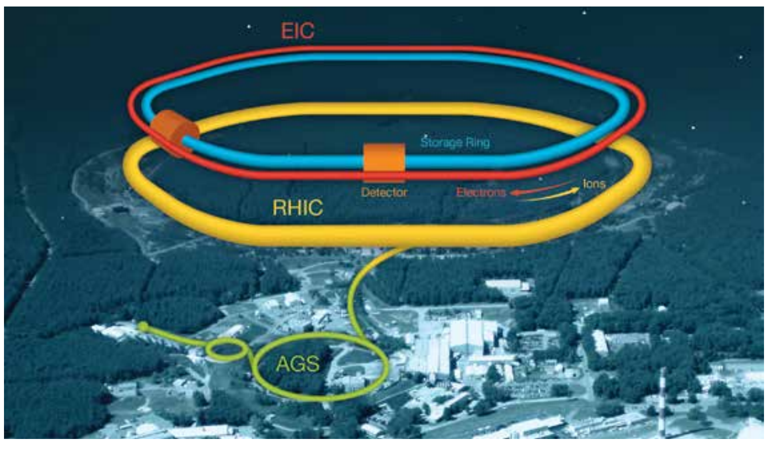
The US nuclear physics community has launched an 18-month effort to identify new research questions to pursue over the coming decade, and to prioritize the tools—like particle colliders—needed to answer them. The plan will shape investments by the Department of Energy and National Science Foundation, which provide the lion's share of federal funding for nuclear physics.

The plan will be written by the agencies' Nuclear Science Advisory Committee (NSAC), which has carried out the process seven times since its inception in 1979. The committee will recommend funding levels and projects required for the US to "maintain a world-leadership position" in nuclear physics.

NSAC's process has proven so effective at forging consensus priorities that other fields, including high energy physics and fusion research, have adapted it.

The committee will hold a kickoff event at the APS Division of Nuclear Physics meeting in Louisiana this October, and the division is holding a series of workshops leading up to it to collect community input.

Two high-priority goals in the previous NSAC plan, published in 2015, were to complete the Facility for Rare Isotope Beams (FRIB) at Michigan State University and to begin construction of an Electron Ion Collider (EIC). Those goals have come to fruition: FRIB began operating earlier this year, and the DOE has laid the groundwork for building the EIC at Brookhaven National Laboratory.



The not-yet-built Electron-Ion Collider (EIC, in red and blue), which will fit in the tunnel that houses an existing heavy-ion collider (in yellow) at the Brookhaven National Lab in New York. CREDIT: BROOKHAVEN NATIONAL LABORATORY/FLICKR

The FRIB and EIC facilities are essentially locked in as priorities for the next plan, so NSAC's task now is twofold: keep these facilities' operation and construction on track, and figure out what additional major projects to pursue in the coming decade.

FRIB can synthesize and sort more than 1,000 isotopes of heavy elements, many of which never before existed on Earth. The facility will yield insights into nucleus stability, help scientists understand how heavy elements form through astrophysical processes, and even shape applications in fields like medicine and materials science.

The EIC will share a tunnel with Brookhaven's existing Relativistic Heavy Ion Collider (RHIC), which has been operating since 2000. When complete, the EIC will let scientists probe atomic nuclei with unprecedented precision.

The DOE estimates that the collider—slated to be completed in the early 2030s—will cost around $2 billion. However, EIC Project Director Jim Yeck testified in July that Congress has funded

FYI CONTINUED ON PAGE 6

APS COMMUNITY

Physicists Coalition for Nuclear Threat Reduction Touts Achievements

BY TAWANDA W. JOHNSON

PHYSICISTS COALITION FOR NUCLEAR THREAT REDUCTION

When the Physicists Coalition for Nuclear Threat Reduction formed two years ago, Stewart C. Prager, co-founder of the organization, was cautiously optimistic about its future.

Fast forward to today, and the coalition has achieved more than Prager thought possible. Among its accomplishments: The organization has held more than 100 colloquia on nuclear weapons, reaching more than 4,000 attendees. Membership has grown to about 850 people, and members have participated in three advocacy campaigns aimed at ensuring that explosive nuclear testing does not resume, extending the New START treaty, and enacting a no-first-use policy.

"My expectations have been exceeded," said Prager, professor of astrophysical sciences at Princeton University and member of the Program on Science and Global Security, about the coalition's success.

The organization is wrapping up its partnership with APS, per guidelines outlined by the APS Innovation Fund, which supported the organization. The Carnegie Corporation also funded the coalition, and its support will continue beyond October 2022.

The coalition was launched to inform, engage, and mobilize the US physics community around the dangers of the world's nuclear weapons, and to build a network of scientist-advocates for nuclear arms control and disarmament policies. More than half the coalition's members are early-career scientists, including students, postdocs, and junior faculty members.

"[Early-career physicists] have latched onto this issue, despite an overload of major issues confronting them, as well as their lack of exposure to the Cold War," said Prager. "They fully appreciate the threat and opportunity as physicists to make a difference."

One of the coalition's first advocacy activities was to push, along with many other arms control organizations, for a five-year extension of the New Strategic Arms Reduction Treaty (New START) between the US and Russia. Advocates sent more than 175 letters to Congress. In early 2021, the Biden Administration extended New START through 2026, maintaining the current arms control regime and providing both governments time to negotiate a future agreement.

"[APS Government Affairs staff] provided guidance and execution in both advocacy and communication with coalition members," said Prager.

The coalition's Next Generation Fellowship saw major achievements, too. The fellowship sought to diversify and strengthen participation of graduate students, postdocs, and early-career scientists and engineers, especially women and members from underrepresented groups—and so far in 2022, the coalition has more than doubled its number of fellows.

"During the fellowship, I met other scientists who were interested in policy and who actually worked on it, so my interest in policy became more attainable as a career option," said Barbara Cruvinel Santiago, a PhD candidate at Columbia University and previous Next-Generation fellow. She has analyzed how Brazilian nuclear policy has evolved since the 1950s and why the country's nuclear policy changed dramatically in the last few years.

Angela DiFulvio, assistant professor at the University of Illinois–Urbana-Champaign, who serves as chair of the Next-Generation Fellowship, said she was pleased to see a three-fold increase in applications since last year.

"The enthusiasm of physics students and early-career scientists for the work of the coalition is a tangible sign of the success of the colloquia," she said. "For me, it is inspiring to work with the fellows and their mentors and see the growth of a vibrant and diverse community of informed advocates on the nuclear weapon threat and its reduction."

As for the coalition's future, the organization has formed a new partnership with the Arms Control Association to help further its goals. Prager explained the coalition will try to reach more physicists and other physical scientists, such as nuclear engineers, astronomers, and geophysicists. The organization also seeks to expand its advocacy initiatives and partner with physicists from other nations on the global nuclear issue.

"APS is proud of the work the coalition has accomplished, especially establishing scientist-advocates who can better navigate nuclear issues within a science policy context," said Francis Slakey, APS Chief External Affairs Officer.

Tawanda W. Johnson is APS Senior Public Relations Manager.

CRISIS CONTINUED FROM PAGE 3

can mess with your mind. A little voice in your brain can convince you that you'll never get out of this crisis, that a character flaw got you here in the first place, etc. To squelch this voice, review the truths of what you have accomplished. Your leadership, publications, awards, promotions, and other contributions—any indicators of the problems you've solved—are facts, not opinions, and they can cushion you when your sense of confidence wavers. Then, inventory your skills. List out the skills you gained from each CV item—for example, technical skills in science, engineering, and computing, as well as "business" skills in communication, leadership, and project management.

Understand your career ecosystem (extrinsic data). Gather data on the market or community you're seeking to work in. What are the gaps—e.g., for a type of employer or job—your inventoried skills enable you to fill? What employer pain points can you alleviate?

Refine your marketing materials. Marketing materials are anything you use to advertise your skills and availability. Review your CV, online research profiles, cover letters, LinkedIn profile, and more. These ought to clearly and concisely communicate your value, including the facts of your resume, the skills from your skill inventory, and the gaps you can fill in your career ecosystem.

Activate your network. At its core, networking is about generosity. When you network well, you don't ask, "What can I *get* from you?" Instead, you ask, "What can I do *for* you and *with* you?" When you invest in win-win alliances, everyone benefits (including you!). So, in a crisis, reach out to people. Request a short call or coffee break. Ask, "How can I help you during this challenging time?"

Diversify your network and skills. When you connect with people inside *and* outside your field, sector, region, and culture, you uncover opportunities to contribute value in new ways. New perspectives always lead to innovation—especially in career development. The same goes for skills. Ask yourself, "What novel skills can I learn that will enable my success in a crisis and protect me in the future?

Think entrepreneurially. Become what I call a Career Entrepreneur—someone who continually looks for opportunities to serve their community and add value by solving problems. Just like a startup aims to add value for its customers by solving a technical or business problem, we must connect the needs of the community (extrinsic data) with what we can do to meet those needs (our intrinsic data). Physicists naturally do this. And when you turn your physics talents toward career problem-solving and crisis prevention and mitigation, you can weather any storm.

Alaina G. Levine is a professional speaker, writer, and STEM career coach. This article builds on content that has appeared in her other works, including her columns, speeches, and book, Networking for Nerds (Wiley, 2015).

SHOCK CONTINUED FROM PAGE 1

Bethany Chidester of Los Alamos National Laboratory presented experiments that probe how the Moon formed. Scientists' current hypothesis is that 4.5 billion years ago, a Mars-sized planet collided with the proto-Earth, scattering debris into Earth's orbit. Over time, this disk of debris coalesced to form the Moon.

However, this "giant-impact hypothesis" fails to explain several observations. Samples indicate that the Moon is mostly made of the same material as Earth—but simulations of the giant-impact hypothesis suggest that the Moon formed largely out of debris from the Mars-sized planet, rather than from Earth. In addition, the Mars-sized planet's impact and any later collisions would not have produced enough debris to form the Moon.

"[The model] actually doesn't work to make a moon that we have," says Chidester.

In 2019, researchers in Japan tried to resolve these discrepancies by proposing that the collision occurred when Earth's surface was covered in a liquid magma "ocean." However, their model also used imprecise equations to describe the behavior of proto-Earth material.

> "[The giant-impact hypothesis] actually doesn't work to make a moon that we have."

To improve the accuracy of the equations, Chidester's group conducted high-pressure experiments on materials similar to those that may have been in that magma ocean. To replicate the crushing pressures of the inner Earth, the group relied on Sandia National Laboratory's Z Machine, which uses magnetic fields to move an aluminum plate into a sample, and the high-powered laser OMEGA EP based at the University of Rochester.

The group used samples made of enstatite and bronzite, iron-containing minerals found in Earth's mantle, and pyrolite, a synthetic glass with the same chemical composition as Earth's mantle. The group squeezed these materials with pressures as high as 1.6 terapascals—more than ten million times the pressure at sea level—and then measured the materials' temperature and reflectivity.

Even when her group updated the magma-ocean model with their new measurements, simulations still indicated that the Moon would be mostly made of the colliding planet. In other words, a magma ocean is not enough to explain why the Moon is mostly made of Earth materials.

"That model, in the way that they published it, is not a viable way to make the Moon that we see," says Chidester. The mystery of the Moon's makeup continues.

These experiments could reach beyond the systems they were designed to study. For example, Chidester studied how much the materials reflected light at various pressures. At higher pressures, the materials appeared to turn more reflective, indicating that they were becoming metallic. These results could inform our understanding of how planets generate magnetic fields, says Chidester.

In another talk, Hannah Bausch of Northwestern University presented work in preparation for a high-pressure experiment to study the boundary between Earth's mantle and core, about 3,000 kilometers underground. Using earthquake data, researchers have discovered that swaths of rock at this depth, some as big as continents, move about 30 percent slower than the rest of the mantle. These so-called ultra-low velocity zones have raised many questions—how did they form, for example, and why do they move so slowly?

One hypothesis is that the zones contain more iron than their surroundings do, which might slow them down. Bausch presented theoretical calculations of the properties of ferropericlase, an iron-containing mineral thought to be one of the main constituents of Earth's lower mantle. Bausch is using these calculations to design high-pressure experiments with these materials using—like Chidester—the Z Machine.

Experimental facilities like the Z Machine and the OMEGA EP are unique in their ability to apply high pressures to materials quickly without letting heat escape. As scientists are unable to actually study the proto-Earth of the past, or to retrieve samples from deep within Earth's mantle, the extreme conditions that these facilities create give scientists a glimpse of otherwise inaccessible environments.

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FLIGHT CONTINUED FROM PAGE 3

At the sweet spot, the flap lies flat when the lift-boosting front eddy dominates, and raises when the lift-inhibiting back eddy is more powerful. "You get this kind of beautiful synchronization between the way that the flap starts moving and the way that vortex shedding is occurring," said Andres Goza, an aerospace engineer at the University of Illinois–Urbana-Champaign who also authored the study. When the flap and the vortices are in sync, the wing reaps the full benefits of the front vortex while mitigating the burden of the rear vortex.

A lesser whistling duck preparing to land, with covert feathers visibly raised from the surface of its wings.

"I think this paper was really nice. It provided a nice simplified representation of the problem to really get at the fundamental mechanisms, so that we can understand what it is that these covert feathers are doing for these birds," said Daniel Floryan, a mechanical engineer at the University of Houston who was not involved with the research. "By focusing on this simplified problem and trying to get at general mechanisms, it provides a great path forward to try to adopt these strategies that birds use in future man-made vehicles."

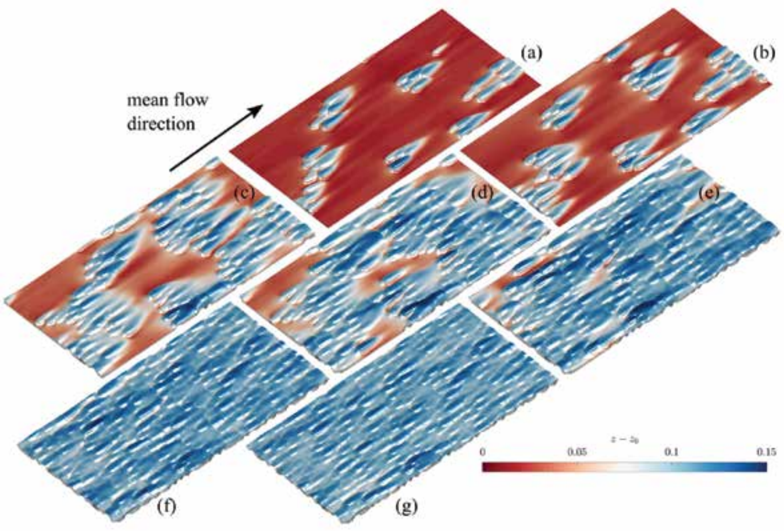
Next, Nair and Goza aim to bring their simulation to life. To do that, they're collaborating with Princeton engineer Aimy Wissa, whose lab uses inspiration from nature to create new kinds of robotic and aerospace vehicles. Wissa is using a wind tunnel to test physical models of wings with covert-inspired flaps.

"One thing that Amy and I are hoping is in the works is that we're going to be able to work with some zoologists to actually get some bird feathers and see what types of dynamics those can undergo," Goza said.

By better understanding the flight dynamics of birds, the collaboration could be the first step toward creating drones or other aircraft that match their abilities.

Jesse Kathan is a science journalist based in Berkeley, California.

BARNACLE CONTINUED FROM PAGE 2



Researchers created a simulation that models how different numbers of barnacles affect how water flows over a surface. Here, small cones represent barnacles as they gather in increasing numbers. CREDIT: SOTIRIOS SARAKINOS AND ANGELA BUSSE/PHYS. REV. FLUIDS 7 (2022)

researcher, developed a simulation that models how different levels of barnacle fouling affect how water moves over a surface. Past studies relied on simulations that didn't realistically replicate barnacle colonization, or required scientists to observe real barnacles—a time-consuming task.

In their new study, Busse and Sarakinos created an algorithm that mimics barnacles' natural behavior, including their tendency to settle near one another—what's known as "gregarious" behavior.

"The idea was to place 'barnacles' on a surface, and then try to create small groups that would eventually grow and meet other groups," Sarakinos explains. Using this algorithm, they created seven different virtual surfaces dotted with an ascending quantity of barnacles, from 10% to 85% coverage. The researchers then used a computational approach called a direct numerical simulation (DNS) to create virtual turbulence flows and passed them over each surface type.

The duo found that, with low barnacle coverage, the "water" moving over the surface retained some behavior seen over smooth walls, a result not typically seen in previous studies. And when they characterized the topographical properties of the layer of fluid blanketing the surfaces in the same way they'd characterize the surfaces themselves, they found a simple, linear relationship between the roughness's effect on the flow and the barnacles' "effective slope"—a measure based on the height and density of the rough layer.

In other words, the greater this particular measure of barnacle roughness, the greater the effect of that roughness on the water's flow—"an unexpected result," Busse says.

"The thing that is exciting about this work to me is that it opens up the door" to develop real-life tools, says Schultz, who was not involved with the study. For example, the Navy performs periodic underwater inspections to document how much fouling has built up on ship hulls. "But they don't have a great way at present of taking that knowledge and saying, 'What is the hydrodynamic penalty of that?'" Schultz says.

If this were possible, inspectors for the Navy or commercial shipping operations could make informed decisions on whether cleaning the hull at a given time would be economically "worth it" to save fuel, he explains. Studies like Sotirios's and Busse's will help researchers develop the models needed to make those decisions, Schultz says. "We're getting better at doing that, given data like these."

Tess Joosse is a science journalist based in Madison, Wisconsin.

GHP CONTINUED FROM PAGE 4

particle physics shifted to searching for the Higgs Boson," Gaskell explained. "Hadronic physics can also be considered a part of nuclear physics, but this is quite a broad field—lots of topics fall under that umbrella." Accordingly, many hadronic physicists are dispersed between the Divisions of Particles and Fields or Nuclear Physics, huge fields in which hadronic physics can slip through the cracks. GHP provides a community where hadronic physics is front and center.

GHP's activity is centered on APS's April Meeting and GHP's Biennial Meeting. At the 2022 April Meeting, GHP's sessions—which included talks from invited experts and mini-symposia—covered topics ranging from heavy-ion collisions from a QCD perspective, the multi-dimensional structure of hadrons, and briefings on experimental programs at the Brookhaven and CERN colliders.

GHP's Biennial Meeting is cozier, drawing between 100 and 130 participants. The meeting is held in odd-numbered years and at the same venue as the April Meeting, so attendees can attend both conferences in one trip.

At GHP Biennial Meetings, longer time slots enable more comprehensive discussions. "At the April Meeting, contributed talks are only 10 minutes long," Gaskell explained. "It's difficult to address a topic in any real depth in this length of time." In contrast, talks at the Biennial Meeting clock in at 20-25 minutes. "It's fun as a speaker to be able to go into more detail about a topic you're interested in, and as an audience member, you can get a much deeper understanding of others' work," he said.

The 2023 GHP Biennial Meeting—which will take place in Minneapolis, Minnesota, in the days leading up to the April Meeting on April 15-18—marks the first time the hadronic physics community will gather in-person since the Covid-19 pandemic began.

Still, the pandemic did expand meeting accessibility: The fully remote 2021 Biennial Meeting drew nearly 300 participants. "It opened my eyes to the fact that there's a huge community of people who want to participate in our meetings, give talks, and get information about the latest findings in hadronic physics, but for whatever reason can't make the trip. We haven't been serving them appropriately," Gaskell explained.

In addition to expanding access to meetings with hybrid options, another goal of the GHP executive committee is to elevate students and early career scientists in hadronic physics, who comprise 36% of the group's ranks. To this end, GHP offers young researchers travel grants to attend meetings, as well as prizes and awards, including for best dissertation, to recognize excellent work in the field.

Prospective members have plenty to gain from joining GHP. "The main reason to join is the physics, to join a community that is trying to understand QCD and the strong force," Gaskell said.

Visit engage.aps.org/ghp/home to learn more.

Abigail Dove is a writer based in Stockholm, Sweden.

FYI CONTINUED FROM PAGE 4

the collider at levels "well below" those needed to keep the project progressing smoothly. He warned that Brookhaven might lose personnel critical to EIC construction after the planned shutdown of RHIC in 2025.

The budget demands of the EIC and other existing projects will affect how quickly DOE can pursue new projects, absent sufficient increases to the agency's topline budget. For example, an outstanding priority is the search for neutrinoless double beta decay, a theorized phenomenon that, if detected, promises to reveal new physics beyond the Standard Model.

Less progress has been made on the search than hoped: In 2015, the committee expected that the DOE would commit "in a few years" to building a "ton-scale" experiment capable of finding the phenomenon, but—seven years later—it has not selected a design to pursue. However, DOE Nuclear Physics head Tim Hallman is a strong proponent of the idea.

"The potential discovery of a neutrinoless double beta decay would be every bit as much of a game-changer as the discovery of supersymmetry at CERN, and as compelling as any accelerator-based research currently underway," he told NSAC last year.

Hallman reiterated this view to NSAC this July, though he stressed it will be up to NSAC to decide whether to keep the search for double beta decay as a top priority.

Mitch Ambrose is Director of FYI. Published by the American Institute of Physics since 1989, FYI is a trusted source of science policy news. Sign up for free FYI emails at aip.org/fyi.

QUANTUM CONTINUED FROM PAGE1

companies have accelerated over the last decade, and the supply of talent is not keeping up with demand," reads a strategic plan published by the National Science and Technology Council. The answer? Train and prepare more people for quantum careers.

In June, experts in quantum education gathered at the 53rd Annual Meeting of the APS Division of Atomic, Molecular and Optical Physics (DAMOP) to discuss how the field can meet the growing need for quantum-educated workers. It may require changes to the quantum mechanics curriculum that's been taught for almost a century, as well as new degrees, courses, and programs.

Some online initiatives teach quantum principles through interactive games for students. "Quantum chess," created by researchers at Caltech, Google, Quantum Realm Games, and others, is free to the public. CREDIT: QUANTUM REALM GAMES HTTPS://IQIM.CALTECH.EDU/QUANTIME

Part of the challenge is quantum mechanics itself: The field is notoriously unintuitive. Fundamental quantum concepts such as superposition and entanglement have no direct analogy to a person's everyday experience, and so are often taught using their mathematical foundations—with mixed success.

"Teaching quantum mechanics using standard differential equations doesn't work very well with the students," said James Freericks, professor of physics at Georgetown University. "We teach it three times, almost identically every time: sophomore, upper-level undergraduate, and graduate. And often even after seeing it three times, students struggle with it."

> Part of the challenge of quantum education is quantum mechanics itself: The field is notoriously unintuitive.

Gina Passante, physics education researcher at California State University–Fullerton, heard similar sentiments from faculty she interviewed who taught courses in quantum information: Quantum mechanics was an obstacle for almost all students. One faculty member said that "how much quantum mechanics the students had previously been exposed to was not a very good indicator [of]…how well they did in the course."

Already, initiatives to fill these gaps have sprouted up across the country. The National Q-12 Education Partnership is compiling resources and learning tools for grades K-12 to "inspire the next generation of quantum leaders." The QuSTEAM initiative is developing undergraduate curricula for quantum information science and engineering, some of which are being rolled out in institutions this fall. Federal quantum research centers have started workforce development efforts of their own, and schools like the University of Chicago have launched professional certificate programs to help workers transition their STEM careers into the field of quantum technology.

"This is a great time to talk about quantum education," said Theresa Lynn, professor of physics at Harvey Mudd College. "It's certainly a time where there are many players and many ideas out there about how to teach quantum to a growing workforce, how to prepare a workforce, and also how to make quantum-aware graduates in many different fields."

Freericks noted that a lot of the standard quantum pedagogy comes from lectures by the physicists Oppenheimer and Dirac, given nearly 70 years ago while quantum mechanics was in its infancy. He suggested it's time for a change, by focusing more on building intuition about conceptional ideas such as entanglement and emphasizing experiments rather than mathematics. An emphasis on experiment, Freericks said, can help keep quantum mysticism at bay by "teaching quantum science, not quantum science fiction."

There are currently no bachelor's degree programs in quantum engineering in the United States, and only a handful of PhD programs. Many institutions are adding tracks within majors, or one-off courses in quantum technology. But almost all these initiatives fall under the umbrella of physics, even though the quantum workforce will require interdisciplinary talent.

"Primarily, the burden of quantum education in the US has been shouldered by physics departments," said Thomas Searles, associate professor in electrical and computer engineering at the University of Illinois Chicago (UIC). "Engineering departments can and should do more with respect to educating our students in quantum information."

Searles highlighted a workshop, hosted by the National Science Foundation, on building a framework for an undergraduate quantum engineering program. The framework outlined four education levels for jobs in the quantum workforce: quantum aware, quantum proficient, specialists, and non-quantum engineers. To put this framework into practice, UIC is creating a general education course called "Survey of Quantum Industry Careers" and devoting funding for an Undergraduate Quantum Engineering Research and Education Laboratory.

Searles also emphasized the need for inclusive quantum engineering programs. "You're taking traditional disciplines like physics, ECE, CS, that have not done very well numbers-wise with respect to gender or racial diversity," he said. According to the Pew Research Center, for example, Hispanic workers make up 17% of all employees in the US, but only 8% of employees in computer science—and women earned only 22% of engineering degrees and 19% of computer science degrees. "But because [quantum engineering] programs are new, you're able to design them in such a way that you don't compound the problem by merging these fields," Searles said.

At Harvey Mudd College, Lynn has been teaching a stand-alone course in quantum information theory intended for the general STEM major. She says physicists are a minority in the class, which mostly consists of computer science and engineering majors. This is relevant to research that shows that jobs in the quantum industry for physicists more often require PhDs, while quantum jobs for engineers tend to require bachelor's degrees.

"I think there's a real call to think about how we can teach quantum in a way that doesn't always focus on the physics student and is much more broadly accessible," she said.

Large-scale efforts to develop a quantum workforce are still nascent. There are no widely accepted educational standards for a career path in quantum information technology, and formal degrees and programs are few and far between. But there is a growing surge of enthusiasm, funding, and research to cultivate quantum-educated talent across a range of fields, and this could change the way quantum mechanics is taught to its traditional recipients: physics students.

Meredith Fore is a science writer for the Chicago Quantum Exchange.

SCANDAL CONTINUED FROM PAGE 2

alpha-sexithiophene into transistors. He diligently measured the current of circuits attached to the crystal, but recorded them on scraps of paper, which he later threw away—a shoddy record-keeping practice that would aid Schön in his deception. Faced with underwhelming results, Schön began to manipulate data, tugging the curve of a plot to give the impression of much higher current. With the new data, Schön attracted the attention of journal editors much more easily.

The mobility of organic crystals—essentially a measure of how freely electrons move around—is comparatively low because electrons get caught in molecular nooks and crannies. But as Reich reports, Schön began to measure astonishingly high mobilities. At the end of 1999, Schön parlayed these advances, spending a full night "discovering" the fractional quantum Hall effect in an organic crystal. From there, the fabricated breakthroughs continued. Schön developed organic single-molecule transistors, lasers from organic crystals, and superconductivity in plastics like polythiophene.

The research enthralled scientists and industry alike. If organic crystals could exhibit properties like superconductivity, they could replace traditional inorganic silicon chips and revolutionize electronics.

By 2001, Schön was publishing a paper every eight days—but skepticism was growing. "Our devices just didn't act like their devices," says Doug Natelson, a condensed matter physicist at Rice University. "You do this for a few months, and you start thinking, 'I'm a neophyte at this, but, boy, it's really hard to see how you get there.'" Natelson, like others, tried and failed to replicate Schön's purported observation of superconductivity in polythiophene.

By the time the 2002 APS March Meeting rolled around, allegations about issues with Schön's data had reached a fevered pitch. In May of 2002, Bell Labs management formed a committee to investigate "the possibility of scientific misconduct, the validity of the data and whether or not proper scientific methodology was used in papers by Hendrik Schön, et al., that are being challenged in the scientific community." The committee investigated 25 papers and three allegations: data substitution, unrealistically precise data, and data that violated the laws of nature.

Some of the data substitution was egregious. In a paper on polythiophene superconductivity, Schön's measurements of resistivity were identical down to the smallest bumps from random noise—impossible if the data were real. When questioned by the committee, Schön had no excuse.

"He acknowledged that, yes, he had done those things," Beasley says. "But he was firm to the end in a straightforward and unflinching way. He said, 'What I presented represents the truth … and I made those changes to make it more beautiful.'" There is no small irony here, Beasley notes: in German, *schön* means nice, or beautiful.

Following the committee's report, Schön was fired, his papers were retracted, and eventually, he lost his PhD.

Despite the potential consequences, large-scale scientific fraud occasionally rears its head. In July, an investigation by *Science* magazine alleged that a landmark 2006 study on Alzheimer's disease, led by Sylvain Lesné, used doctored images. If the allegations prove true, Lesné's fraud could have helped misdirect some Alzheimer's research for years.

The latest news is a reminder for scientists to be vigilant against misconduct—especially when it aligns with their publication desires and scientific dreams.

Daniel Garisto is a writer based in New York.

THE BACK PAGE

Teachers Have Great Careers. People Think Otherwise Because of Bad Data.

It's time to correct the record.

BY WENDY K. ADAMS

Right now, middle and high school physics classrooms across the nation face a challenge. *I know the problem,* you might think—*We don't have enough physics teachers!* And you're right: Not enough people are entering the profession, so the US has too few physics teachers.

But this isn't the challenge I'm talking about—at least, not all of it. Instead, I'm talking about the challenge *causing* this teacher shortage: inaccurate information about teaching. The data is clear: Teachers rate their lives more highly than nearly all other occupation groups. Half of students are interested in becoming teachers. Nearly all faculty would support that choice.

These facts indicate that teaching is a great career option—but negativity and misinformation about teaching is pervasive. That's why, since 2016, my dedicated colleagues and I have dug into the facts about the teaching profession, conducting research and mining data from a range of external sources. Our initiative, called Get the Facts Out (GFO), aims to counter misinformation about the teaching profession and solve the teacher shortage—and you can help solve it, too.

Since 2016, here's what we've found.

The physics teacher shortage is caused by too few people entering the profession.

The US has well-documented shortages of teachers in physics, chemistry, and mathematics. Only a third of certified physics teachers have a major or minor in physics—a problem, because when science teachers don't have degrees in their field, their students are less likely to go to college and major in STEM. And the situation is getting worse.

But this shortage is *not* caused by teachers leaving the profession. In fact, data shows that teacher retention is one of the best in the nation. A large-scale study by the Department of Education found that, at five years, 79% of secondary teachers are still in the classroom—higher than for all other careers except health professions. And according to the Bureau of Labor Statistics, the separations and quit rates for the State and Local Education (Public) Sector is around 10% annually, compared to 30% for all sectors.

The real issue is that too few people are *entering* the teaching profession. The number of people entering teaching has dropped by about a quarter in the last 10 years. This decline is particularly acute for math teachers, with a 30–50% decrease. And given that negative stories about teaching travel quickly and widely, perceptions of the teaching profession are worsening.

So why are existing teachers staying in the profession but new people not entering? Because, as the data shows, students who could become teachers—and the faculty and mentors who guide them—have an inaccurate picture of the profession.

So what does the data actually say about teaching?

The data paints a clear picture of teaching as a great career.

#1: Teachers in the US rate their lives better than all other occupation groups, trailing only physicians.

We've identified three major reasons why teachers rate their lives so highly: work-life balance, student and colleague relationships, and financial stability. Let's look at each of these (the last reason is so important that I've separated it into its own point—see #2).

Work-life balance. From focus groups of teachers and other STEM private-sector professionals, we've learned that there are three features of work-life balance where teaching excels:

1. Flexible summers to rest, spend time with friends and family, and pursue other interests.
2. Scheduled three- and four-day weekends and holiday breaks. Teachers work hard, and these regular extended breaks give them a chance to recharge.
3. Time to take care of "life things" during business hours from about 3:30–5:00pm, which isn't possible for most other jobs.

And in any discussion of work-life balance, it's worth noting another fact: Teachers in the US retire at age 59 compared to age 63 for all occupations.

Colleague and student relationships. We asked a room full of science and math teachers to write down answers to the question, "What provides you with day-to-day satisfaction?" Then we had tables swap responses and asked each table to only keep those answers that resonated with everyone at the table. When we looked at the 60 approved responses, six sources of satisfaction emerged.

1. Students—building relationships with them, watching them learn and grow over time, and, in particular, witnessing students' "lightbulb moments."
2. Teachers' day-to-day work schedule (the time for "life things" mentioned above).
3. The challenge and science of teaching ("Teaching is a science; teachers constantly use their STEM skills as teachers").
4. Colleagues ("Other committed teachers make amazing coworkers and friends").
5. Learning content ("Teaching provides the drive/reason to explore new and challenging areas of physics").
6. Autonomy in the classroom ("There's a lot of responsibility, but it's nice to be able to make all of the decisions, within basic guidelines, in my room").

#2: At year 15, the middle 50% of teachers earn \$64,000–\$102,000 per school year (25th–75th percentile).

This compensation is very competitive with national data for physics majors' average compensation; while teachers should be paid more, they are squarely middle class in every community we've evaluated.

Our surveys, as well as the APS POPA report, have found that both student and faculty perceptions of salaries are anchored by examples from the bottom quartile for teaching, but the top quartile for physics careers in private industry. This creates a perceived wage gap that doesn't exist, and it may deter students.

#3: Teachers feel they're respected in their communities. In a survey of 5,000 teachers, 95% of teachers said their co-workers treated them with respect; almost 90% said that their students' parents and their students did.

Only about 40% of teachers felt respected by local and national media, and that makes sense: After all, many media portrayals of the teaching profession are negative and unrepresentative. In contrast to these portrayals, teaching is a great career, and teachers feel valued in their communities.

So, how can we get more students to enter the profession?

If you mentor or teach, you can help solve the physics teacher shortage.

Did you know that half of physics majors have an interest in becoming middle or high school physics teachers, as do nearly 75% of students of color? Students indicate that they often do not mention this to faculty for fear of disapproval. Most university faculty believe that only 1 in 20 students are interested in teaching—an underestimate.

Additionally, 88% of faculty surveyed (n=2200) agree or strongly agree with the statement, "I would be comfortable with my strongest student becoming a grade 7-12 math or science teacher." This is the case even though more than 40% of students surveyed (n=2300) indicate that they've never heard a faculty member mention teaching as a career option. Faculty also indicate that they perceive their colleagues as not supportive of the career—a misperception.

In short, many students are interested in teaching, and nearly all faculty support that choice. So, to start to fix the teacher shortage, let's talk about teaching! If you are a college faculty member or mentor to students of any age, you are in a position of influence. Here's what you can do:

- Learn accurate information about teaching, especially in your area. As our data shows, grade 7-12 teaching is a great career by many measures.
- Always mention teaching as a career option when discussing careers with physics majors—or, for that matter, anyone who studied, is currently studying, or wants to study a STEM field.
- Create an environment of knowledgeable, supportive peers and faculty by sharing teaching facts with everyone. Students often report that they don't like having to defend their career choice; teaching is an excellent career, and once the physics majors in your department know this, students interested in pursuing teaching can do so with pride.
- Ask students if they have considered being high school teachers. We often hear stories from teachers about how their path to teaching began when a college professor asked, "Have you ever considered teaching high school?"
- Resist sharing negative anecdotes. Instead, only share facts you've verified through a reliable source (e.g., a school district website or Get the Facts Out). For example, it's critical to share actual teacher salaries in your area and the range of salaries students can earn with a physics major. GFO has spent years studying the financial compensation packages for teachers by state, and we've created resources to easily share this data with students. Take advantage of these resources.

As a teacher or mentor, you'll reap the benefits of guiding students toward a meaningful career like teaching. It's important to understand career paths and support students while they explore options; for me, that's what's so fulfilling about working with students, and I've personally come to see teaching as one of the best careers a physics major can pursue. In fact, my son just changed careers to become a high school teacher!

Encouraging physics students to pursue their interests in teaching will also reap rewards for your department. What better way to recruit students for your department than having one of your graduates teaching physics in a nearby high school? Since so many STEM students have an interest in teaching, students may choose another field of study if they don't know upfront that teaching is a great path.

On a final note, there's reason to be optimistic. The last two years have brought new challenges to people in all careers, but I'm hopeful that many of these challenges are temporary, including for teachers. Based on our work with teachers across the US and federal data, teacher employment is stable, even while quits in other careers have increased.[5] We believe that teacher well-being, and their desire to support students, have bolstered them through these challenges.

And we believe that, if we work together to get the facts out about the teaching profession, we can solve the teacher shortage, get more physics majors into meaningful teaching careers, and—along the way—educate the next generation of great scientists *and* great teachers.

For sources used in this article, visit https://go.aps.org/teacherdata. For GFO's research, visit getthefactsout.org.

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The Back Page is a forum for member commentary and opinion. The views expressed are not necessarily those of APS.

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