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ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ NOVEMBER 5, 2022

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COVER Long COVID can include a troubling mix of fatigue, brain fog, heart palpitations, gut troubles and more. *T. Tibbitts, NIAID, Getty Images Plus*

FROM TOP: PAINTING/ALAMY STOCK PHOTO; PICTURE BY TAMBAKO THE JAGUAR/MOMENT/GETTY IMAGES PLUS; TERENCE DICKINSON, ESA

Long COVID brings another huge challenge to science

In the fall of 2020, the world was staggering under the attack of the SARS-CoV-2 virus. In the United States, more than 4 million cases were reported in November, more than double the number in October. Hospitals were overwhelmed. On the Thursday before Thanksgiving, 1,962 people died.

Now, despite more than 1 million deaths in the United States and more than 6 million worldwide, it's almost easy to forget that the pandemic's assault continues. That is, until you hear Belinda Hankins' story.

Hankins has been diagnosed with long COVID, a collection of symptoms that can include crushing fatigue, brain fog, pain and dizziness and that may affect 1 in 5 people infected with SARS-CoV-2, according to one conservative estimate. She talked with *Science News* staff writer Meghan Rosen during her appointment at the long COVID clinic at the Johns Hopkins Bayview Medical Center (Page 22).

"For months we've heard estimates about how many people have long COVID," Rosen told me. "I was interested in going beyond the stats to find out what it's like for the patients and doctors living with this."

That effort involved talking with doctors who are trying to figure out how to treat the symptoms of long COVID when the cause is still unknown. And talking with Hankins. "I thought it was extraordinary that [she] let me into her appointment," Rosen said. "It's just so generous and so brave."

I share Rosen's gratitude. Asking someone in the midst of a life-altering illness to talk with a journalist is a big request. I always worry that people might feel pressure to participate, and I want to be sure that they've had time to think through the implications of going public with personal information. Hankins was clear about why she said yes. "She wanted to share her story because a lot of people in her life don't know what long COVID is and why she's still so sick," Rosen said.

In reporting, Rosen brings both her empathy and her serious science chops. She has a Ph.D. in biochemistry and molecular biology and is a graduate of the science journalism program at the University of California, Santa Cruz. She explored careers in biotech but decided that wasn't the right fit. She wanted to write about health and medicine.

This is actually Rosen's third stint at *Science News*: first as an intern, then as a reporter, and now back on the beat after five years of doing communications work for the Howard Hughes Medical Institute. We're glad she's back. Not only is she tackling complex issues surrounding COVID-19, including how U.S. public health guidelines affect kids in school (*SN Online*: 8/19/22), she's also been sharing her delight in science. That includes stories on genetic variants linked to uncombable hair in children (*SN*: 10/8/22 & 10/22/22, *p.* 5); an unusual "snough" call that zoo gorillas appear to have invented to get zookeepers' attention (*SN Online*: 8/10/22); and a new robotic pill designed to deliver drugs by scrubbing away mucus in the intestines (see Page 5).

Yes, science is serious and important, but it's also crazy fun. I don't think I'm ready to sign up for the robotic intestinal scrub brush, but I sure do enjoy finding out about it. —*Nancy Shute, Editor in Chief*

Upper Class Just Got Lower Priced

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Excerpt from the November 11, 1972 issue of *Science News*

50 YEARS AGO

Was Stonehenge a crematorium?

The monument consisted of a circle of immense, finely tooled stone archways surrounded by a range of 56 equally spaced [holes].... The precisely proportioned placement of the stones and holes has led archaeologists to presume that the monument had some great astrological significance.... As an alternate explanation, the researchers say perhaps there were 56 families, clans or social units who built Stonehenge and who were entitled to dig one of the [holes] and use it to inter cremated remains.

UPDATE: Stonehenge's purpose remains murky, but the monument's origin is becoming clearer thanks to science. For at least the first 500 years of its existence, Stonehenge was a cemetery. A chemical analysis of remains at the site suggests that some of the people interred there came from Wales, more than 200 kilometers west of where Stonehenge stands in southern England (*SN Online: 8/2/18*). The monument's first building blocks also may have come from Wales, repurposed from a stone circle there, but that hypothesis is debated (*SN: 3/13/21, p. 12*).

Red foxes are the first known foxes to fish for food. They join wolves in North America as the only known fishing canids.

FIRST

A cunning fox catches fish, stunning researchers

The fox froze. Inches from its paws, frenzied carp writhed in a reservoir's shallows. Suddenly, the fox dove nose-first into the water, emerging with a large carp in its mouth.

In 2016, two researchers in Spain watched as this male red fox (*Vulpes vulpes*) stalked and caught 10 carp over a couple of hours. The event, described August 18 in *Ecology*, is the first recorded instance of a fox fishing, the pair says. The discovery makes red foxes just the second type of canid—the group that includes wolves and dogs—known to hunt fish (*SN Online: 2/11/20*).

"Seeing the fox hunting carp one after another was incredible," says ecologist Jorge Tobajas of the University of Córdoba. "We never expected something like this."

Tobajas and Francisco Díaz-Ruiz of the University of Málaga came across the fishing fox while surveying a site for a different

FOR DAILY USE

How to put babies to bed without waking them up

It's a frustration many parents know all too well: You've finally lulled your crying baby to sleep in your arms, so you put them in their crib only for the wailing to begin again. Science may have a trick for you.

Carrying a crying infant for five minutes, then sitting for at least another five to eight minutes can calm and lull the baby to sleep long enough to allow a caregiver to put the child down without waking them, scientists report September 13 in *Current Biology*.

Developmental psychologist Gianluca Esposito of the University of Trento in Italy and colleagues monitored the heart rates of 21 crying babies, ranging in age from newborns to 7 months old, and filmed them as their mothers carried them around a room, sat holding them and laid them in a crib. That let the team assess how the infants responded to different environments, whether they were crying, fussy, alert or drowsy, heartbeat by heartbeat.

"We tested the physiology behind these things that tend to be kind of common knowledge, though it's not really well understood why they work," Esposito says.

The babies' heart rates slowed and they stopped crying when their mothers carried them for five minutes. Some infants even fell asleep. But sleeping babies tended to respond to their parents' movements. For instance, a baby's heart rate quickened if mom turned fast while walking or tried to lay the baby down.

Sitting for at least five minutes smooths the transition from walking to bed, the team found. Hearts settled at slower rates and the babies stayed asleep once they were put in their crib. Six babies whose moms sat for less than five minutes had increased heart rates once they were laid down and woke up soon after. Overall, the method isn't foolproof, Esposito says, but it's something that caregivers can try. —*Deborah Balthazar*

PICTURE BY TAMBAKO THE JAGUAR/MOMENT/GETTY IMAGES PLUS

Watch a video of a fox fishing for carp at **bit.ly/SN_FishingFox**

project. The fox caught their attention because it didn't flee when it spotted the researchers. Tobajas and Díaz-Ruiz hid nearby to see what the animal was up to.

Their curiosity turned into excitement when they witnessed the fox catch the first fish. "The fox hunted many carp without making any mistakes," Tobajas says. "This made us realize that it was surely not the first time he had done it."

The fox hid most of its catch and appeared to share at least one fish with a female fox, possibly its mate.

Fish remains have previously turned up in fox scat. But it was unclear whether foxes had caught the fish or scavenged carcasses. The new work confirms that some foxes fish for food, says wildlife ecologist Thomas Gable of the University of Minnesota in Minneapolis. "I would be shocked if this was the only fox to have learned how to fish," Gable says.

Wolves in North America are the only other canids known to fish. That two types of canids on separate continents both fish suggests that the behavior might be more common than previously thought, Gable says. —*Freda Kreier*

TEASER

This new robotic pill helps medicine go down

A mucus-wicking robotic pill may offer a new way to deliver medication.

The multivitamin-sized device houses a motor and a cargo hold for drugs, including ones that are typically given via injections or intravenously, such as insulin and some antibiotics. If people could take such drugs orally, they could avoid shots or a hospital stay, which would be "a huge game changer," says MIT biomedical engineer Shriya Srinivasan.

But drugs that enter the body via the mouth face a tough journey. They encounter churning stomach acid, raging digestive enzymes and sticky slicks of mucus in the gut. Intestinal mucus "sort of acts like Jell-O," Srinivasan says. The goo can trap drug particles, preventing them from entering the bloodstream.

The new device, dubbed RoboCap, whisks away this problem. The pill uses surface grooves, studs and fins to scrub away intestinal mucus. In tests in pigs, RoboCap tunneled through mucus in the small intestine to deposit insulin or the antibiotic vancomycin, Srinivasan and colleagues report September 28 in *Science Robotics*. After churning for about 35 minutes, the pill made its way through the rest of the digestive tract.

RoboCap, shown resting on a pig intestine, can sweep away mucus in the gut and leave behind drugs to be absorbed by the body.

RoboCap is the latest gadget made to be swallowed. In 2019, some of the same scientists who developed RoboCap debuted a pill-like device that injects drugs inside of the stomach. That injector wasn't designed to work in the small intestine, where some drugs are most easily absorbed. RoboCap may also be able to deliver larger drug payloads, Srinivasan says. —*Meghan Rosen*

PICTURE THIS

Here is the first direct look at Neptune's rings in more than 30 years

Neptune and its rings glow in infrared light in this image from the James Webb Space Telescope.

Humankind is seeing Neptune's rings in a whole new light thanks to the James Webb Space Telescope, or JWST. In an infrared image released September 21, Neptune and its gossamer diadems of dust glow against the inky backdrop of space. The stunning portrait is a huge improvement over the rings' previous close-up, which was taken in 1989 by NASA's Voyager 2 spacecraft. In those grainy photos, shot in visible light at a distance of some 1 million kilometers, the rings are thin, concentric arcs. In the new image, snapped from 4.4 billion kilometers away, the rings shine while Neptune looks darker. Methane gas in the planet's atmosphere absorbs much of its infrared light. A few bright patches mark where high-altitude methane ice clouds reflect sunlight. As for the rings, they have "lots of ice and dust in them, which are extremely reflective in infrared light," says JWST project scientist Stefanie Milam of NASA's Goddard Space Flight Center in Greenbelt, Md. Upcoming JWST observations of Neptune should provide new intel on the rings, Milam says. "There's more to come." —*Christopher Crockett*

FROM TOP: S. SRINIVASAN, MATTHEW PICKETT; NASA, ESA, CSA, STSCI, JOSEPH DEPASQUALE/STSCI

BODY & BRAIN

Human nerve cells thrive in rat brains

Implanted organoids offer a peek at human development

BY LAURA SANDERS

To coax human nerve cells in a laboratory to thrive, there are three magic words: location, location, location.

Many experiments grow human nerve cells in lab dishes. But a new study enlists some real estate that's a bit more unconventional: the brain of a rat. Implanted clusters of human neurons grow bigger and more complex than their cohorts grown in dishes, researchers report in the Oct. 13 *Nature*.

Not only that, but the human cells also appear functional, albeit in very limited ways. The implanted human cells can both receive signals from rat cells and influence the rat's behavior, connections that "demonstrate more substantial integration of the transplanted neurons," says Arnold Kriegstein, a developmental neuroscientist at the University of California, San Francisco who wasn't involved in the study. "This is a significant advance."

Over the last decade, neuroscientists have been building increasingly complex organoids, 3-D clusters of nerve cells derived from stem cells that grow and mimic the human brain (*SN*: 3/3/18, *p.* 22). These organoids don't re-create the full complexity of human neurons that develop in an actual brain. But they can be windows into an otherwise inscrutable process — human brain development, and how it can go awry (*SN*: 9/25/21, *p.* 14). "Even if they're not entirely perfect, [these models] are surrogates for human cells in a way that animal cells are not," Kriegstein says.

Neuroscientist Sergiu Pasca of the Stanford School of Medicine and colleagues surgically implanted human organoids into the brains of newborn rat pups. Along with their hosts, the human organoids began to grow. Three months later, the organoids were about nine times their starting volume, ultimately making up about a third of one side of the rat cortex, the outer layer of the brain. "It pushes the rat cells aside," Pasca says. "It grows as a unit."

These human cells flourished because a rat brain offers perks that lab dishes can't, such as a blood supply, a precise mix of nutrients and stimulation from nearby cells. This environmental support coaxed individual human neurons to grow bigger — six times as large by one measure — than the same sort of cells grown in lab dishes. Cells grown in the rat brains were also more complex, with more elaborate branching patterns and more cell connections called synapses.

The cells looked more mature, but Pasca and his colleagues wanted to know if the neurons would behave that way too. Tests of electrical properties showed that implanted neurons behaved more similarly to cells that develop in human brains than cells grown in dishes.

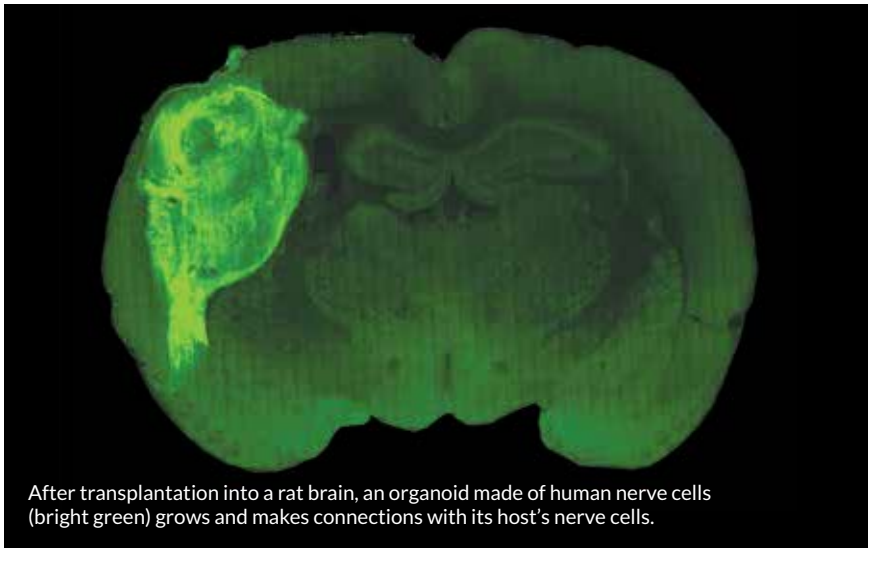
Over months of growth, human neurons made connections with their rat host cells. The human organoids were implanted on the somatosensory cortex, a part of the rat brain that handles whisker input. When researchers puffed air at the whiskers, some of the human cells responded.

What's more, the human cells could influence rat behavior. In further experiments, the team genetically tweaked organoids to respond to blue light. Prompted by a flash of light, the neurons fired signals, and researchers rewarded the rats with water. Soon, the rats learned to move to the water spout when the organoid cells sent signals.

In behavioral tests, rats with human implants didn't show signs of higher intelligence or memory; in fact, researchers were worried about potential deficits. The organoids were nudging out their hosts' brains, after all. "Will there be memory deficits? Will there be motor deficits? Will there be seizures?" Pasca asked. But after extensive tests, no differences were found.

Other experiments included nerve cells from people with a genetic disorder called Timothy syndrome, a severe developmental disorder that affects brain growth. Growing organoids created with these patients' cells in rat brains might reveal differences that other techniques would not, the researchers reasoned. Sure enough, neurons in these organoids had less complex message-receiving dendrites than those from organoids derived from people without the syndrome.

Organoids made from patient-specific cells could one day even serve as test subjects for treatments, Pasca says. "Challenging disorders will require bold approaches," he says. "We will need to build human models that recapitulate more aspects of the human brain to study these uniquely human conditions." ■



After transplantation into a rat brain, an organoid made of human nerve cells (bright green) grows and makes connections with its host's nerve cells.

STANFORD UNIV.

The Milky Way (shown) may have grown from a population of millions of stars near the center of the galaxy, researchers say.

TERENCE DICKINSON, ESA

ATOM & COSMOS

Milky Way's protogalaxy discovered

Astronomers identify the galaxy's oldest known group of stars

BY KEN CROSWELL

The Milky Way left its "poor old heart" in and around the constellation Sagittarius, astronomers report. New data from the Gaia spacecraft reveal the full extent of what seems to be the galaxy's original nucleus — the ancient stellar population that the rest of the Milky Way grew around — which came together more than 12.5 billion years ago.

"People have long speculated that such a vast population [of old stars] should exist in the center of our Milky Way, and Gaia now shows that there they are," says astronomer Hans-Walter Rix of the Max Planck Institute for Astronomy in Heidelberg, Germany.

The Milky Way's ancient heart is a round protogalaxy that spans nearly 18,000 light-years, Rix and colleagues report in a study posted September 7 at arXiv.org. Its stars possess roughly 100 million times the mass of the sun in stars, or about 0.2 percent of the Milky Way's current stellar mass.

"This study really helps to firm up our understanding of this very, very, very young stage in the Milky Way's life," says Vasily Belokurov, an astronomer at the University of Cambridge who was not involved in the work. "Not much is really known about this period of the Milky Way's life," he says. "We've seen glimpses of this population before," but the new study gives "a bird's-eye view of the whole structure."

Most stars in the Milky Way's central region abound with metals. These stars originated in a crowded metropolis that earlier stellar generations had enriched with those metals through supernova explosions. But Rix and colleagues wanted to find the exceptions to the rule, stars so metal-poor they must have been born well before the rest of the galaxy's stellar denizens came along — what Rix calls "a needle-in-a-haystack exercise."

His team turned to data from Gaia, which launched in 2013 on a mission to chart the Milky Way. The astronomers searched about 2 million stars within a broad region around the galaxy's center, which lies in the constellation Sagittarius, looking for stars with metal-to-hydrogen ratios no more than 3 percent of the sun's.

The astronomers then examined how those stars move through space, eliminating the ones that dart off into the vast halo of metal-poor stars engulfing the Milky Way's disk because those stars are likely from the halo. The end result: a sample of 18,000 ancient stars that represents the kernel around which the entire galaxy blossomed, the researchers say. By accounting for stars obscured by dust, Rix estimates that the protogalaxy is between 50 million and 200 million times as massive as the sun.

"That's the original core," Rix says, and it harbors the Milky Way's oldest stars, which he says are probably more than 12.5 billion years old. The protogalaxy formed when several large clumps of stars and gas conglomerated long ago, before the Milky Way's first disk — the so-called thick disk — arose (SN: 4/23/22, p. 15).

The protogalaxy is compact, which means little has disturbed it since its formation. Smaller galaxies have crashed into the Milky Way, augmenting its mass, but "we didn't have any later mergers that deeply penetrated into the core and shook it up, because then the core would be larger now," Rix says.

The new data on the protogalaxy even capture the Milky Way's initial spin-up — its transition from an object that didn't rotate into one that does. The oldest stars in the proto–Milky Way barely revolve around the galaxy's center, instead diving in and out of it, whereas slightly younger stars show more and more movement around the galactic center. "This is the Milky Way trying to become a disk galaxy," says Belokurov, who saw the same spin-up in research that he and a colleague published in July.

Today, the Milky Way is a giant galaxy that spins rapidly; each hour our solar system speeds through 900,000 kilometers of space as we race around the galaxy's center. But the new study shows that the Milky Way got its start as a modest protogalaxy whose stars still shine today, stars that astronomers can now scrutinize for further clues to the galaxy's birth and early evolution. ■

MATTER & ENERGY

Superconductivity claim isn't dead yet

Experiment may support retracted room temperature study

BY JAMES R. RIORDON

It may be too soon to mourn the demise of a room temperature superconductivity claim.

On September 26, *Nature* retracted a paper describing a material that seemed to turn into a superconductor at a cozy 15° Celsius (SN: 11/7/20, p. 6). The notice rattled many people in the field. But a new experiment performed just days after the retraction supports the world-record temperature claim, say an eyewitness and others familiar with the experiment.

Superconductors carry electricity with no resistance, which means they're useful for efficiently transmitting energy. They could save enormous amounts of energy that's wasted in conventional metal wires. Currently superconductors are used to create powerful magnetic fields for medical imaging and particle physics experiments, as well as serving as components in high-performance circuitry and even levitating high-speed trains. But to work, superconducting materials generally must be cooled to far below 0° C, and many to temperatures close to absolute zero, or -273° C.

When researchers announced in 2020 that a sample made of hydrogen, sulfur and a bit of carbon became a superconductor at record-shattering temperatures, dreams of room temperature superconducting seemed to be on the verge of coming true (SN: 12/19/20 & 1/2/21, p. 34). One hitch was that the material had to be under enormous pressures, about 2.6 million times atmospheric pressures — roughly the pressure found in parts of Earth's core. Still, the discovery hailed a potential scientific and technological revolution.

In the two years since, controversy has swirled around the report. The maelstrom is centered on the way the researchers prepared and processed data that showed changes in a magnetic property known as susceptibility. Ultimately, editors at *Nature* took the unusual step of retracting the paper despite the researchers' objections. "We have now established that some key data processing steps … used a non-standard, user-defined procedure," the editors wrote in the retraction. "The details of the procedure were not specified in the paper and the validity of the [analytical method] has subsequently been called into question."

A new experiment might bolster a recently retracted claim of room temperature superconductivity in a blend of hydrogen, sulfur and a bit of carbon squeezed to enormous pressures in a diamond anvil like this one.

The new experiment isn't a duplicate of the one reported in the retracted paper, but the researchers say they replicated a portion of their research that had raised red flags in the scientific community.

Ranga Dias, a physicist at the University of Rochester in New York who headed the research on the now-retracted paper, led the new measurements at Argonne National Laboratory's Advanced Photon Source in Lemont, Ill. "We have been working on this experiment for almost six months, building and reconfirming the correct methodology," Dias says. "I would say the data we obtained at Argonne is more compelling, not just comparable" to, the data in the retracted paper.

"The experiment took place over two days, September 27 and 28," says physicist Nilesh Salke of the University of Illinois Chicago, who was not affiliated with the original research. Salke's role at Argonne involved probing a sample of the material in question with X-rays while it was exhibiting magnetic susceptibility associated with high-temperature superconductivity. "We saw the first susceptibility signal on September 27, consistent with the claims reported in the retracted *Nature* paper."

This latest twist is unlikely to put an end to the controversy that came with the initial claim, at least in the mind of physicist Jorge Hirsch of the University of California, San Diego. Hirsch has been one of the most vocal critics of the room temperature superconductivity claim.

"I didn't know it would be retracted, but was hoping it would be retracted," Hirsch says. He says he asked the authors for the raw data from the earlier study one month after it was published, but he was refused. "The authors said, 'No we cannot give you the data because our lawyers said that it would affect our patent rights,'" he says.

With intervention from *Nature*, Hirsch eventually got the numbers. What he saw disturbed him. Hirsch is skeptical that high temperature superconductivity is possible in these sorts of hydrogen-based materials in general, but says he is objecting based on the way the data were handled.

"There were real problems between the raw data and the published data," Hirsch says. He believes that *Nature*'s retraction doesn't go far enough. "It's not that the data were not properly processed." Along with physicist Dirk van der Marel of the University of Geneva, Hirsch delves into problems with the data in a paper published September 15 in the *International Journal of Modern Physics B*. "Our analysis proves mathematically that the raw data were not measured in the laboratory. They were fabricated," he says.

Dias and colleagues deny any impropriety in their data or analysis and are moving forward with experiments like the one at Argonne. But that work awaits peer review. For now, *Nature*'s retraction bolsters existing doubts around room temperature superconductivity.

"In the end, all of this has to be validated by different groups getting the answer," Hirsch says. ■

ADAM FENSTER

SCIENCE & SOCIETY

2022 Nobel Prizes announced

Ancient DNA, click chemistry, quantum physics lauded

This year's Nobel Prizes celebrate research feats and findings that many scientists had once thought impossible.

The Nobel Prize in physiology or medicine honored geneticist Svante Pääbo for figuring out how to extract and analyze DNA from ancient bones. Pääbo's work established a new field of science, paleogenomics, which has led to many insights into what makes humans unique from our extinct relatives.

DNA breaks down over time, so many scientists had thought there would be none remaining in fossils tens of thousands of years old. Not to mention that DNA from microbes and from living people contaminate the ancient genetic material. Yet Pääbo managed to stitch together fragments of Neandertal DNA into readable sequences. Eventually, he assembled a complete genetic instruction book, or genome, for a Neandertal.

"Just the mere fact that he did it was so improbable," says Leslie Vosshall, a neuroscientist at Rockefeller University in New York City and vice president and chief scientific officer of the Howard Hughes Medical Institute.

From ancient DNA, Pääbo and other scientists have, for instance, learned that our ancestors interbred with Neandertals, discovered human relatives called Denisovans, and studied how DNA passed down from Neandertals and Denisovans has influenced human health today.

Discoveries with implications for health were also honored by this year's chemistry prize. Chemists Carolyn Bertozzi, Morten Meldal and K. Barry Sharpless were recognized for developing a toolkit for snapping together molecules like Lego building blocks. Applications include creating new drugs, polymers and materials, and tracking biomolecules among cells.

"We're kind of at the tip of the iceberg already in terms of applications," says the American Chemical Society's president, Angela Wilson. "This chemistry is going to revolutionize medicine in so many areas."

About 20 years ago, Sharpless introduced "click chemistry" — a way to simply and quickly attach two compounds using certain connector molecules. But finding connector molecules that can bond together in a chemical reaction wasn't easy. Working independently, Sharpless and Meldal discovered a solution. By adding a smidge of copper to a mixture containing two other small molecules, the scientists could rapidly snap the two molecules together into a ring-shaped chemical.

Catalyzing reactions with copper may work fine in a glass beaker, but the metal can harm living cells. Bertozzi discovered a way to do copper-free click chemistry, so scientists can design chemical reactions inside of organisms without mucking up cellular functions.

She tricked cells into incorporating a click chemical into sugars decorating the cell's surface. When scientists expose these cells to a different click chemical, the two can snap together.

Bertozzi's specialty has been studying sugar molecules. By targeting specific sugars on cell surfaces, scientists can develop new disease treatments. For instance, Bertozzi and colleagues were able to neutralize sugars that help tumor cells hide from T cells in the body.

The Nobel Prize in physics also recognized research that has some real-world applications. Physicists Alain Aspect and John Clauser confirmed that the laws of quantum mechanics, as weird and difficult to believe as they are, really do rule the world, while physicist Anton Zeilinger took advantage of quantum behavior to develop rudimentary applications that no conventional technology can match.

The discovery of quantum behavior revolutionized physics at the beginning of the 20th century. Many leading scientists, most famously Einstein, acknowledged that quantum theories worked, but argued they couldn't be the true description of the world because they involved, at best, calculating the probabilities that something would happen. To Einstein, this meant that there was some hidden information that experiments were too crude to uncover.

In the 1960s, physicist John Stewart Bell proposed a test to prove that there were no hidden channels of communication among quantum objects. Clauser was the first to develop a practical experiment to confirm Bell's test. Aspect took the idea further to eliminate any chance that quantum mechanics had some hidden underpinnings of classical physics. Clauser's and Aspect's work involved pairs of photons, or particles of light, that were entangled, meaning that they were essentially a single object. As the photons move in different directions, they remain entangled. Measuring the characteristics of one instantly reveals characteristics of the other, no matter how far apart they are.

Zeilinger's experiments take advantage of entanglement. He has extended the experiments from the lab to intercontinental distances, opening up the possibility that entanglement can be put to practical use. Because interacting with one of a pair of entangled particles affects the other, they can become key components in secure communications and encryption. An outsider trying to listen in would be revealed because they would break the entanglement. Quantum computers, which rely on entangled particles to encode information, have also become a hot topic. Zeilinger's quantum teleportation experiments offer a route to transfer the information that such computers rely on. — *Aimee Cunningham, Nikk Ogasa, James R. Riordon, Meghan Rosen, Tina Hesman Saey, Maria Temming*

2022 Nobel laureates

PHYSIOLOGY OR MEDICINE

Svante Pääbo
Max Planck Institute for Evolutionary Anthropology

CHEMISTRY

Carolyn Bertozzi
Stanford University

Morten Meldal
University of Copenhagen

K. Barry Sharpless
Scripps Research

PHYSICS

Alain Aspect
Université Paris-Saclay and École Polytechnique

John Clauser
J.F. Clauser & Assoc.

Anton Zeilinger
University of Vienna

BODY & BRAIN

Malaria uptick tied to amphibian losses

Die-offs in Central America may have led to more mosquitoes

BY AIMEE CUNNINGHAM

In the 1990s and 2000s, Costa Rica and Panama experienced spikes in malaria cases. The massive loss of amphibians in the region from a fungal disease may have contributed to the malaria uptick.

The spread of chytridiomycosis was a slow-motion disaster, leading to a decades-long wave of amphibian declines globally. From the 1980s to the 2000s, the wave moved from northwest to southeast across Costa Rica and Panama, hitting different places at different times. An analysis of ecological surveys, public health records and satellite data suggests a link between the amphibian die-offs and an increase in human malaria cases as the wave passed through, researchers report in the October *Environmental Research Letters*.

Teasing out ways that biodiversity losses "ripple through ecosystems and affect humans" can help make a case for preventive actions in the face of other ecological threats, says environmental economist Michael Springborn of the University of California, Davis.

On average, each county in Costa Rica and Panama had 0.8 to 1.1 additional cases of malaria per 1,000 people per year for about six years, beginning a couple of years after the amphibian losses, Springborn and colleagues found.

Other research suggests that amphibians keep mosquito populations in check. Amphibian larvae eat mosquito larvae, and the animals compete for resources.

So the missing frogs, toads and salamanders may have led to more mosquitoes and potentially more malaria transmission. But it's unclear whether mosquito populations actually increased, Springborn says, because those data don't exist.

Chytridiomycosis, caused by the fungus *Batrachochytrium dendrobatidis*, has led to the largest recorded loss of biodiversity due to a disease. It's caused the decline of at least 500 species globally (SN: 4/27/19, *p.* 5). The international trade in amphibians has spread the fungus.

Springborn and colleagues wondered if the impacts stretched to humans. The team turned to Costa Rica and Panama, where the fungus moved through ecosystems in a somewhat uniform way along the narrow strip of land on which the two countries sit, Springborn says. The researchers worked out when the fungus arrived at a given place and then looked at the number of malaria cases in those places before and after the die-offs.

Malaria cases rose in the first couple of years after the decline and remained elevated for six years or so before going down again for unknown reasons.

Studies on the connections between biodiversity loss and health might "help motivate conservation by highlighting the direct benefits of conservation to human well-being," says Hillary Young, a community ecologist at the University of California, Santa Barbara. "Humans are causing wildlife to be lost at a rate similar to that of other major mass extinction events," she says. "We are increasingly aware that these losses can have major impacts on human health and well-being—and, in particular, on risk of infectious disease." ■

The Panamanian golden frog used to call forests in its namesake country home, until a deadly fungus appeared. The extinction of the frog from the wild and the loss of other amphibians may have contributed to a rise in malaria.

BRIAN GRATWICKE/WIKIMEDIA COMMONS (CC BY 2.0)

EARTH & ENVIRONMENT

Warming puts blue lakes at risk

Climate change could turn waters green or brown

BY JENNIFER SCHMIDT

Some picturesque blue lakes may not be so blue in the future due to climate change.

In the first global tally of lake color, researchers estimate that roughly one-third of Earth's lakes are blue. But should average summer air temperatures rise by a few degrees, some of those crystal waters could turn a murky green or brown, the team reports in the Sept. 28 *Geophysical Research Letters*.

The changing hues could alter how people use those waters and offer clues about the stability of lake ecosystems. Lake color depends in part on what's in the water, but factors such as water depth and surrounding land use also matter. Compared with blue lakes, green or brown lakes have more algae, sediment and organic matter, says Xiao Yang, a hydrologist at Southern Methodist University in Dallas.

Yang and colleagues used satellite photos from 2013 to 2020 to analyze the color of more than 85,000 lakes around the world. Because storms and seasons can temporarily affect a lake's color, the researchers focused on the most frequent color observed for each lake over the seven-year period.

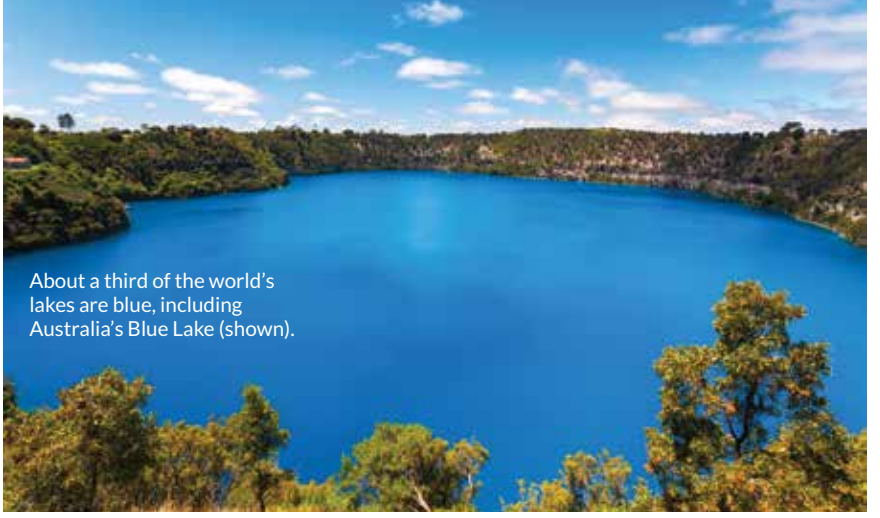
The scientists then looked at local climates during that time to see how they may be linked to lake color. For many small or remote water bodies, records of temperature and precipitation don't exist. Instead, the researchers relied on climate "hindcasts" calculated for every spot on the globe, which are pieced together from relatively sparse records.

Lakes in places with average summer air temperatures that were below 19° Celsius were more likely to be blue than lakes with warmer summers, the researchers found. Up to 14 percent of the blue lakes studied are near that threshold. If average

summer temperatures increase another 3 degrees C, those 3,800 lakes could turn green or brown. That's because warmer water helps algae bloom more, which changes the properties of the water, giving it a green-brown tint, Yang says.

Extrapolating beyond this sample of lakes is tricky. "We don't even know how many lakes there are in the world," says study coauthor Catherine O'Reilly, an aquatic ecologist at Illinois State University in Normal. Many lakes are too small to reliably detect via satellite, but by some estimates, tens of thousands of larger lakes could lose their blue hue.

If some lakes do become less blue, people will probably lose some of the resources they have come to value, O'Reilly says. Lakes are often used for drinking water, food or recreation. If the water is more clogged with algae, it could be unappealing for play or more costly to clean for drinking.



About a third of the world's lakes are blue, including Australia's Blue Lake (shown).

But the color changes wouldn't necessarily mean that the lakes are any less healthy. Humans "don't value lots of algae in a lake, but if you're a certain type of fish species, you might be like, 'This is great,'" O'Reilly says.

Lake color can hint at the stability of a lake's ecosystem, with shifting shades indicating changing conditions for the plants and animals living in the water. One benefit of the new study is that it gives scientists a baseline for assessing how climate change is affecting Earth's freshwater resources. Continued monitoring of lakes could help scientists detect future changes.

The study "sets a marker that we can compare future results to," says Mike Pace, an aquatic ecologist at the University of Virginia in Charlottesville, who was not involved with the study. "That's, to me, the great power of this study." ■

LIFE & EVOLUTION

How spores know when to wake up

Internal counting helps dormant bacteria sense safe conditions

BY DARREN INCORVAIA

Bacteria go to extremes to handle hard times. Some build a fortress-like shell around their DNA and turn off all signs of life. When times improve, these dormant spores can rise from the seeming dead.

"You gotta be careful when you decide to come back to life," says Peter Setlow, a biochemist at UConn Health in Farmington. "Because if you get it wrong, you die." How is a spore to tell?

For spores of the bacterium *Bacillus subtilis*, the solution is simple: They count. These "living rocks" sense it's time to revive, or germinate, by "counting" how often they encounter nutrients, researchers report in the Oct. 7 *Science*.

Spores "appear to have literally no measurable biological activity," says Gürol Süel, a microbiologist at the University of California, San Diego. But Süel and his colleagues knew that spores' cores contain positively charged potassium atoms, and because these atoms can move around without the cell using energy, the team suspected that potassium could be involved in shocking the cells awake.

So the team exposed *B. subtilis* spores to nutrients and used colorful dyes to track the movement of potassium out of the core. With each exposure, more potassium left the core, shifting the core's electric charge to be more negative. Once the spores' cores were negatively charged enough, germination was triggered, like a champagne bottle finally popping its cork.

The number of exposures it took to trigger germination varied by spore, just like some corks require more or less twisting to pop. Spores whose potassium movement was hamstrung showed limited change in electric charge and were less likely to "pop" back to life no matter how many nutrients they were exposed to, the experiments showed.

Changes in the electric charge of a cell are important across the tree of life, from determining when brain cells zip off messages to each other to the snapping of a Venus flytrap. Finding that spores also use electric charges to set their wake-up calls excites Süel. "You want to find principles in biology," he says, "processes that cross systems, that cross fields and boundaries."

Spores are not only interesting for their extreme biology, but also for practical applications. Some spores "can cause some rather nasty things," from food poisoning to anthrax, says Setlow, who was not involved in the study. Since spores are resistant to most antibiotics, understanding germination could lead to a way to bring the bacteria back to life to kill them for good.

Still, there are many unanswered questions about the black box of how spores start germination, like whether it's possible for the spores to reset their potassium count. "We really are in the beginnings of trying to fill in that black box," says study coauthor Kaito Kikuchi, a biologist now at Reveal Biosciences in San Diego. But discovering how spores track their environment while more dead than alive is an exciting start. ■

IANWOOL/ISTOCK/GETTY IMAGES PLUS

MATH & TECHNOLOGY

Scientists spin superstrong silk

Researchers disagree over what gives the fibers strength

BY MEGHAN ROSEN

Superstrong artificial silk? That's so metal.

Giving revamped silkworm silk a metallic bath may make the strands strong and stiff, scientists report October 6 in *Matter*. Some strands were more than 70 percent stronger than silk spun by spiders.

The work is the latest in the decades-long quest to create fibers as strong, lightweight and biodegradable as spider silk. If such material could be mass-produced, sutures, artificial ligaments and tendons, and even sporting equipment could get an arachnid-inspired enhancement.

"If you've got a climbing rope that weighs half of what it normally does and still has the same mechanical properties, then obviously you're going to be a happy climber," says Randy Lewis, a silk scientist at Utah State University in Logan who was not involved with the study.

Scrounging up enough silky material to make these superstrong products has been a big hurdle. Silk from silkworms is simple to harvest but not all that strong. And spider silk, the gold standard for hand spun strength and toughness, is not easy to collect. "Unlike silkworms, spiders cannot be farmed due to their territorial and aggressive nature," study coauthor Zhi Lin, a structural biologist at Tianjin University in China, and colleagues write.

Scientists have tried to spin sturdy artificial strands in the lab using silkworm cocoons as a starting point. The first step is to strip off the silk's gummy outer coating. Scientists can do this by boiling the fibers in a chemical bath, but that can be like taking a hatchet to silk proteins. If the proteins get too damaged, it's hard to respin them into high-quality strands, says Chris Holland, a materials scientist at the University of Sheffield in England who was not involved in the study.

Lin's team tried gentler approaches, including using lower temperatures and a papaya enzyme. That mild-mannered method seemed to work. "They don't have little itty-bitty pieces of silk protein," Lewis says. "That's huge because the bigger the proteins that remain, the stronger the fibers are going to be."

After some processing steps, the researchers forced the resulting silk sludge through a tiny tube, like squeezing out toothpaste. Then they bathed the extruded silk in a solution containing zinc and iron ions, eventually stretching the strands like taffy to make long, skinny fibers. The metal dip could be why some of the strands were so strong; Lin's team detected zinc ions in the finished fibers.

But Holland and Lewis aren't so sure. The real innovation may be that "they've managed to unspin silk in a less damaging way," Holland says. Lewis agrees: "In my mind, that's a major step forward." ■

ATOM & COSMOS

Martian lake may just be rock and ice

New analysis adds more doubt to detections of liquid water

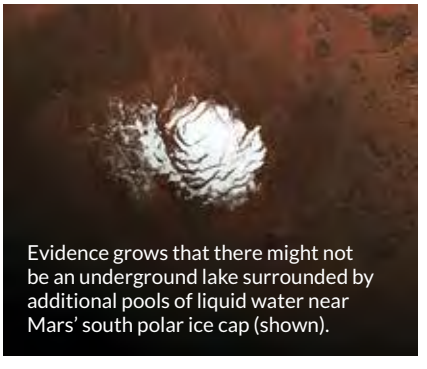
BY KATHERINE KORNEI

There's new evidence that a potential discovery of liquid water on Mars might not be watertight, researchers report in the October *Nature Astronomy*.

In 2018, scientists announced the detection of a large subsurface lake near Mars' south pole (*SN: 8/18/18 & 9/1/18, p. 6*). That claim — and follow-up observations suggesting additional buried pools of liquid water (*SN: 11/7/20, p. 8*) — fueled excitement about finding an extraterrestrial locale possibly conducive to life.

But researchers have since suggested that those discoveries don't hold up to scrutiny. In 2021, one group proposed that clay minerals and frozen brines, rather than liquid water, might be responsible for the strong radar signals that researchers observed (*SN: 8/14/21, p. 8*). Spacecraft orbiting Mars beam radio waves toward the Red Planet and measure the timing and intensity of the reflected waves to infer what's beneath the surface.

And now another team has shown that ordinary layers of rock and ice can produce many of the same radar signals previously attributed to liquid water. Planetary scientist Dan Lalich of Cornell University and colleagues calculated how flat layers of bedrock, water ice and carbon dioxide ice — all known to be plentiful on Mars — reflect radio waves.



Evidence grows that there might not be an underground lake surrounded by additional pools of liquid water near Mars' south polar ice cap (shown).

ESA, DLR, FU BERLIN (CC BY-SA 3.0 IGO)

The researchers reproduced some of the anomalously strong radar signals thought to be due to liquid water. Individual radar signals from different layers of rock and ice add together when the layers are a certain thickness, Lalich says. That produces a stronger signal, which is then picked up by a spacecraft's instruments. But those instruments can't always tell the difference between a radio wave coming from one layer and one that's the result of multiple layers, he says. "They look like one reflection to the radar."

The results don't rule out liquid water, Lalich and colleagues acknowledge. "This is just saying that there are other options," he says.

It's "a plausible scenario," says Aditya Khuller, a planetary scientist at Arizona State University in Tempe. Until scientists get a lot more data from the Red Planet, it'll be difficult to know whether there is truly liquid water there, Khuller says. "It's important to be open-minded at this point." ■

Mosquitoes hunt with extendable neck

High-speed video reveals how mosquito larvae eat other larvae

BY SUSAN MILIUS

A kind of teenage mosquito can suddenly shoot its head forward from its body — stretching its neck into a skinny cord — to bite into another youngster. And that's just one of the ways young mosquitoes kill other mosquitoes, a new study shows.

For decades, scientist-cinematographer Robert Hancock and colleagues have filmed attacks by these *Psorophora ciliata* and two other kinds of predatory mosquito larvae in unusual detail. Launching heads evolved independently in two of the kinds, he and colleagues say in their new study.

The third kind, a type of *Sabethes* mosquito larva, uses its other end. Often hanging from the water surface head downward, it needs only 15 milliseconds to grip prey with a hooking sweep of the breathing tube on its predatory butt, the researchers report October 4 in the *Annals of the Entomological Society of America*.

The most dramatic pounce on film may be the neck-stretching snatch by the *Psorophora* larva. It might power this lunge by squeezing a rush of fluid to the head. When Hancock watches the mosquito's body, segmented a bit like a string of alphabet-block beads, he can see two segments scrunching inward "accordion-like," as if squirting fluid forward as the head shoots out.

Launching the head to reach the prey is one thing, but catching hold is another problem. The newly released video gives a clear view of a pair of brushes, one on each side of the head, that help with the grasp. As the head nears its victim, the brushes fan out into what the researchers call a "flimsy basketlike arrangement" that folds around the doomed prey.

Such an attack may startle people thinking of mosquito bites just as stealthy hypodermic blood-sucks. That's the adult bite from females craving a nutritional supplement for egg-laying. Mosquito eggs, however, hatch in water, and larvae often don't assume their dandelion-wisp flying form for weeks. During the aquatic phase, these larvae don't look, or dine, like adult forms at all.

Larvae don't bite people, and many just filter out edible crumbs afloat in water. The meat eaters, however, pounce so fast that the human brain can't parse it. Hancock has been fascinated ever since he was in a class in the 1980s seeing only a blur through the microscope as he tried to describe the feeding behavior. The *Toxorhynchites* mosquitoes that frustrated him then have turned out to be one of the groups that evolved head-launching larvae.

> "If there's any mosquito for all the mosquito haters to actually maybe not love but like, it's *Toxorhynchites*."
>
> **ROBERT HANCOCK**

"If there's any mosquito for all the mosquito haters to actually maybe not love but like, it's *Toxorhynchites*," says Hancock, now at Metropolitan State University of Denver. As iridescent adults, they're vegans, feeding largely on flower nectar. For their larvae, it's all meat, mostly other mosquitoes. Plus, he says, "they're large, and they're gorgeous."

The new study found that the launch doesn't extend as far as a head length, but *Toxorhynchites amboinensis* attacks the prey larva vigorously. In the videos, "by the time you would catch sight of it, there would be like a half of larva … as it shoved this thing in like it was a hot dog–eating contest," Hancock says.

He and colleagues also caught on film a third kind of meat-eating mosquito, *Sabethes cyaneus*, which is more flexitarian than carnivore. It still bites into meals at its head end, but the danger of getting snagged comes from the rear, the researchers' videos show. Like many mosquito larvae, they often dangle head down in the water, but take in oxygen through a flexible siphon on its rump. It turns out that the breathing tube doubles as a type of food hook, capable of snaring a target in only several milliseconds.

In an extreme pounce, a *Psorophora* mosquito larva (left) can shoot its blocky head forward to grab and gulp another young mosquito.

"The thing about *Sabethes* is that they're probably more like murderers because they really don't ingest and consume entire prey larvae like the other two," Hancock says. Feeding tests show that the insects do gain at least some nutrition from the nibbling.

A human watching the larvae hunt may wonder why we put so much money and chemistry into trying to kill the pests when they do it so brilliantly themselves. For one thing, mosquito larvae stay underwater, says entomologist Don Yee of the University of Southern Mississippi in Hattiesburg, who wasn't involved in the study. *Toxorhynchites* and *Sabethes* can't lift into the air and fly to the next water-filled tire or tree hole. There, a *Toxorhynchites*, for instance, "likely would consume all other larvae," he says. "However, there may be hundreds of such containers in the area."

In contrast, *Psorophora* mosquitoes live in larger bodies of water and could theoretically have more of an effect at knocking back mosquito numbers, Yee says. But under natural circumstances, the predators are unlikely to crash mosquito populations as humans would want. Yee compares it to the African savanna. In photos, "you can see how many wildebeest there are. The lions can't really control them." In nature, after all, predators that thrive don't wipe out their own prey. ■

R.G. HANCOCK ET AL/ANN. ENTOMOL. SOC. AM. 2022

Watch young mosquitoes hunt one another at **bit.ly/SN_MosquitoLarvae**

This image from the Hubble Space Telescope shows a split stream of dust and rock coming off the asteroid Dimorphos nearly 12 days after the DART spacecraft smashed into it.

ATOM & COSMOS

NASA's DART mission is a success

The spacecraft's intentional crash altered an asteroid's path

BY LISA GROSSMAN

It worked! Humankind has for the first time purposely moved a celestial object.

As a test of a potential asteroid-deflection scheme, NASA's DART spacecraft shortened the orbit of asteroid Dimorphos by 32 minutes — a far greater change than astronomers expected.

The Double Asteroid Redirection Test, or DART, rammed into the tiny asteroid at about 22,500 kilometers per hour on September 26. The goal was to move Dimorphos slightly closer to the larger asteroid it orbits, Didymos.

Neither Dimorphos nor Didymos pose any threat to Earth; the asteroids were about 11 million kilometers from the planet at the time of impact. The DART mission was intended to help scientists figure out if a similar impact could someday nudge a potentially hazardous asteroid out of the way before it hits Earth.

Before the impact, Dimorphos orbited Didymos every 11 hours and 55 minutes. Afterward, the orbit was 11 hours and 23 minutes, NASA announced in a news briefing on October 11.

Four telescopes in Chile and South Africa observed the asteroids every night after the impact. The telescopes can't see the asteroids separately but can detect periodic changes in brightness as the asteroids eclipse each other. All four telescopes saw eclipses consistent with an 11-hour, 23-minute orbit. The result was confirmed by two planetary radar facilities, which bounced radio waves off the asteroids to measure their orbits directly,

GENES & CELLS

Sperm in groups outswim loners

Clustering helps them travel more directly to an egg

BY JAMES R. RIORDON

Even sperm gotta stick together.

Bull sperm swim more effectively when in clusters, a new study shows, potentially offering insight into fertility in humans. In simulated reproductive tracts, bovine sperm in cooperative groups will outpace meandering loners as they race to fertilize an egg, physicist Chih-kuan Tung and colleagues report September 22 in *Frontiers in Cell and Developmental Biology*.

The benefits of clustering don't come down to flat-out speed. "In terms of speed, they are comparable or slower" than sperm traveling alone, says Tung, of North Carolina A&T State University in Greensboro. Like the sperm equivalent of herds of tortoises racing individual hares, the winners are the ones that can stay on target.

On their own, the sperm tend to follow curved paths, which is a problem because the shortest distance between two points is a straight line. But when the sperm gather in groups of two or more, they swim along straighter routes. It's behavior that Tung and one of his coauthors had noted in a previous study where they tracked bull sperm swimming in stationary fluids (*SN: 4/16/16, p. 12*). Although that might give sperm clusters an advantage, it would only help if they happen to be going in the right direction. Other benefits of sperm clustering weren't clear until the researchers developed an experimental setup that introduced flowing fluid into the experiments.

In creatures including humans and cattle, sperm make their way to the ovum by swimming against a current of mucus that streams through the cervix and away from the uterus. It's difficult to study sperm swimming inside a living being. So Tung and colleagues created an analog: a shallow, narrow, 4-centimeter-long channel filled with a thick fluid that mimics natural mucus and flows at rates the researchers could control.

Whether alone or in groups, sperm naturally tend to swim upstream. However, clusters of sperm in the experiment did a better job heading upstream into the mucus flow, while individual sperm were more likely to head off in other directions. Despite the speedier travels of some individual sperm, a poorer ability to point upstream hampered the progress of sperm loners compared with slower-moving clusters.

Clusters also stayed the course in the face of rapidly flowing mucus. When the researchers turned up the flow, many individual sperm were washed away. Sperm clusters were less likely to get swept downstream.

While sperm in the study were bovine, the advantages of clustering should also apply to human sperm, Tung says. Sperm of both species have similar dimensions. Both swimmers typically compete to

NASA, ESA, STSCI, HUBBLE

said Nancy Chabot, a planetary scientist at the Johns Hopkins University Applied Physics Laboratory in Laurel, Md., who works on the DART team.

The minimum change for the DART team to declare success was 73 seconds — a hurdle the mission overshot by more than 30 minutes. The team thinks the spectacular plume of debris that the impactor kicked up gave the extra oomph. The impact itself gave some momentum to the asteroid, but the debris flying off in the other direction pushed it even more, like a temporary rocket engine.

"This is a very exciting and promising result for planetary defense," Chabot said. Still, the change in orbital period was about 4 percent — "a small nudge," she said — so knowing an asteroid is coming is crucial to future success.

For something similar to work on an asteroid headed for Earth, "you'd want to do it years in advance," Chabot said. An upcoming space telescope called the Near-Earth Object Surveyor is one of many projects intended to give that early warning. ■

fertilize a single ovum. And unlike in pigs or other animals where semen is deposited directly in the uterus, both human and bovine sperm start out in the vagina and travel through the cervix to get to the uterus.

Studying sperm in fluids that closely resemble the flowing mucus in reproductive tracts could reveal problems that don't turn up in conventional observations of sperm in stationary fluids, Tung says. "One hope is that this sort of knowledge can help us do better diagnoses" and provide clues to understand human infertility.

Subjecting sperm to realistic settings in the lab may soon offer practical help for people who have trouble conceiving, says fertility researcher Christopher Barratt of the University of Dundee in Scotland. "How a sperm cell responds to its surroundings and how that may change its behavior is a very important subject," says Barratt. "This type of technology could be used, or adapted, to select better quality sperm" for people in need of fertility assistance. "That would be a very big deal." ■

LIFE & EVOLUTION

Mystery fossils clarify pterosaur origins

The fliers may have evolved from tiny two-legged runners

BY CAROLYN GRAMLING

A mysterious ground-dwelling reptile unearthed in Scotland over 100 years ago turns out to be part of a famous flying family. Tiny *Scleromochlus taylori* was a close relative of pterosaurs, the winged reptiles that lived alongside the dinosaurs, researchers report in the Oct. 13 *Nature*.

The finding lends support to the idea that pterosaurs — the first vertebrates to master powered flight — evolved from small, speedy, two-legged ancestors.

S. taylori is known entirely from seven individuals preserved in rocks discovered in 1907, fossils that have been difficult to interpret. For one thing, there aren't any actual bones, just impressions on the surrounding rock.

What had been clear was that the reptile, which lived about 230 million years ago, had very odd body proportions, says Davide Foffa, a paleontologist at National Museums Scotland in Edinburgh. At less than 20 centimeters long, "it would fit on the palm of your hand," he says, but its head was very large for its body size. It also had a short neck and long hind limbs. That rough outline wasn't enough to properly identify the creature's closest relatives.

So Foffa and colleagues used a non-invasive scanning technology called microcomputed tomography to collect previously inaccessible data from the fossils, from the length of the tail to the size of the foot bones to the shape of the jawline.

Some of the creature's features, like its disproportionately large head, are similar to those of pterosaurs. Others, like the orientation of the lower jaw, aren't much like pterosaur features at all. *S. taylori* didn't have any identifiable adaptations for flying, jumping or living in trees, the team says. Instead, it was probably a runner.

A small ground-dwelling reptile named *Scleromochlus taylori* (illustrated) was a close relative of pterosaurs, a new study suggests.

GABRIEL UGUETO

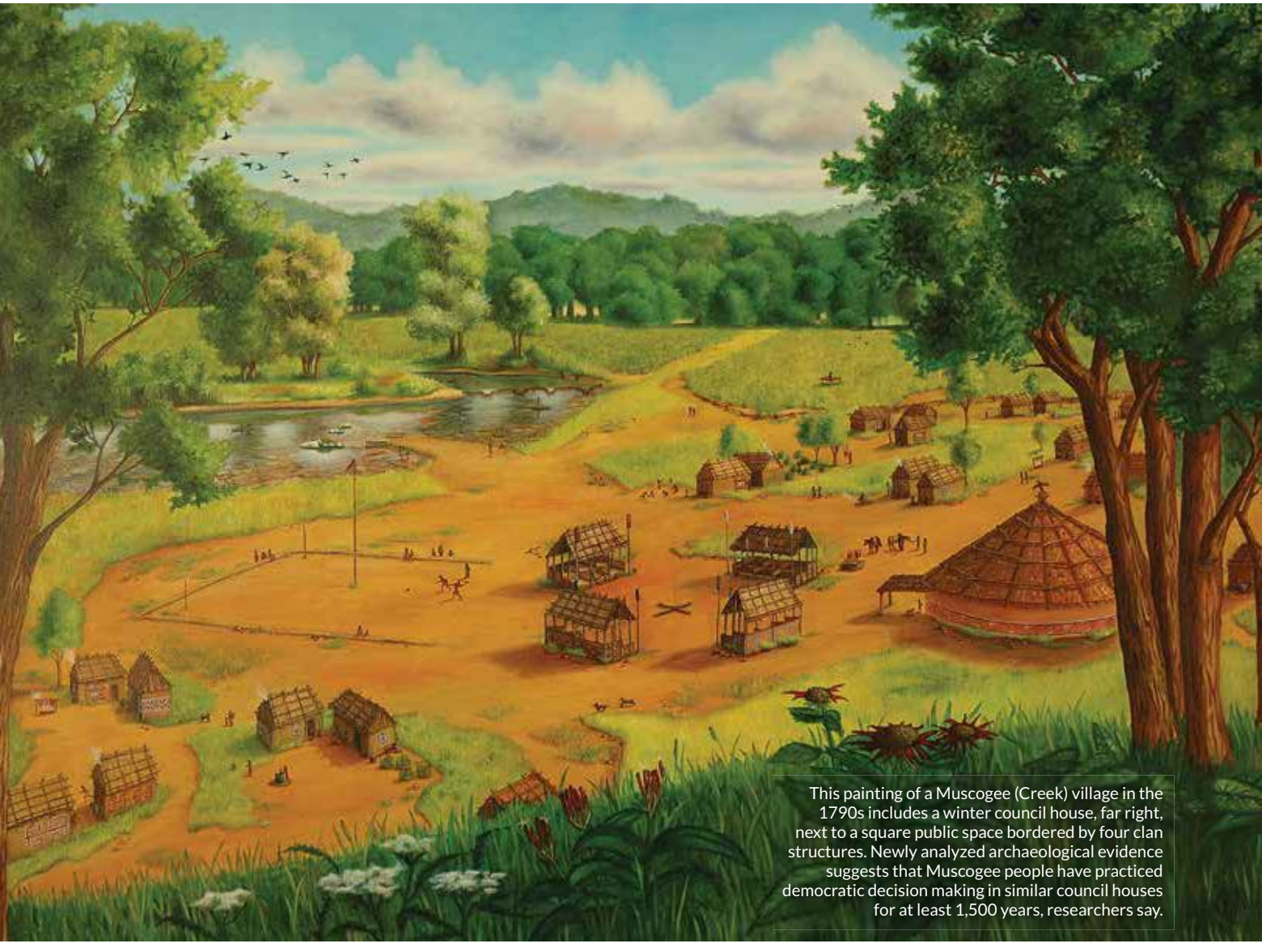
One of the most important new insights is about the femur. It bore strong similarities to both pterosaurs and a group of small ground-dwelling reptiles called lagerpetids. The bottom of the femur, where it would have connected to the lower leg, had a structure that is a hallmark of lagerpetids, Foffa says.

Taken together, the data suggest that *S. taylori* was a lagerpetid. Though lagerpetids didn't fly, they and pterosaurs have recently been recognized as being close relatives, probably sharing a common ancestor that was small and fast-running.

S. taylori may be a very early lagerpetid, evolving soon after the group split from pterosaurs. That the species has so many features present in both groups is "kind of a surprise," says Martín Ezcurra, a paleontologist at the Argentine Museum of Natural Sciences in Buenos Aires. But the conclusion that *S. taylori* was an early lagerpetid makes sense, he says.

Pterosaurs, which first appear in the fossil record about 220 million years ago, had distinct anatomy, including massive heads for their body sizes and super-elongated fourth digits that were part of their wings. *S. taylori* had the big head, but its hands were small, Ezcurra says. "We're missing several intermediate forms in between that bear features related to active flight," he says.

It's difficult to say what a proto-pterosaur might have looked like, says Hans Sues, a paleontologist at the Smithsonian Institution in Washington, D.C. "*Scleromochlus* is a tiny animal, and it is conceivable that a related small-bodied form climbed around in trees and eventually gave rise to a proto-pterosaur, perhaps through an intermediate gliding stage." ■



This painting of a Muscogee (Creek) village in the 1790s includes a winter council house, far right, next to a square public space bordered by four clan structures. Newly analyzed archaeological evidence suggests that Muscogee people have practiced democratic decision making in similar council houses for at least 1,500 years, researchers say.

DORI DECAMILLIS

Early American Democracies

Several societies in North America practiced political consensus building long before the U.S. Constitution existed

By Bruce Bower

On warm summer days, powerboats pulling water-skiers zip across Georgia's Lake Oconee, a reservoir located about an hour-and-a-half drive east of Atlanta. For those with no need for speed, fishing beckons.

Little do the lake's visitors suspect that here lie the remains of a democratic institution that dates to around 500 A.D., more than 1,200 years before the founding of the U.S. Congress.

Construction of a nearby dam flooded the Oconee Valley in 1979. The resulting reservoir partly covers remnants of a 1,500-year-old plaza once bordered by flat-topped earthen mounds and at least three large, circular buildings. Such structures, which have been linked to collective decision making, are known from other southeastern U.S. sites that date to as early as around 1,000 years ago.

At the Oconee site, called Cold Springs, artifacts were excavated before the valley became an aquatic playground. Now, older-than-expected radiocarbon dates from recent analyses of those museum-held finds push back the origin of democratic institutions in the Americas by several centuries, a team led by archaeologist Victor Thompson of the University of Georgia in Athens reported May 18 in *American Antiquity*.

Institutions such as these highlight a growing realization among archaeologists that early innovations in democratic rule emerged independently in many parts of the world. Cold Springs findings add to evidence that Native American institutions devoted to promoting broad participation in political decisions emerged in various regions, including what's now Canada, the United States and Mexico, long before 18th century Europeans took up the cause of democratic rule by the people.

That conclusion comes as no surprise to members of some Indigenous groups today. "Native people have been trying to convey for centuries that many communities have long-standing institutions [of] democratic and/or republican governance," says S. Margaret Spivey-Faulkner, an archaeologist at the University of Alberta in Canada and a citizen of the Pee Dee Indian Nation of Beaver Creek in South Carolina.

Democratic innovations

Scholars have traditionally thought that democracy—generally referring to rule by the people, typically via elected representatives—originated around 2,500 years ago in Greece before spreading in Europe and elsewhere. From that perspective, governments in the Americas that qualified as democratic didn't exist before Europeans showed up.

That argument is as misguided as Christopher Columbus' assumption that he had arrived in the East Indies, not the Caribbean, in 1492, says archaeologist Jacob Holland-Lulewicz of Penn State, a coauthor of the Cold Springs report. Institutions that enabled representatives of large communities to govern collectively, without kings or ruling chiefs, characterized an unappreciated number of Indigenous American societies long before the Italian explorer's fateful first voyage, Holland-Lulewicz asserts.

In fact, collective decision-making arrangements that kept anyone from amassing too much power and wealth go back thousands, and probably tens of thousands of years in many parts of the world. Anthropologist David Graeber and archaeologist David Wengrow of University College London describe evidence for that scenario in their 2021 book *The Dawn of Everything* (SN: 11/6/21, p. 34).

But only in the last 20 years have archaeologists begun to take seriously claims that ancient forms of democratic rule existed. Scientific investigations informed by Indigenous partners will unveil past political realities that, Spivey-Faulkner says, "most of us in Indian Country take for granted."

Early consensus

Thompson's Cold Springs project shows how such a partnership can work.

Ancestors of today's Muscogee people erected the structures at Cold Springs within their original homelands, which once covered a big chunk of the southeastern United States before the government-forced exodus west along the infamous Trail of Tears. Three members of the Muscogee (Creek) Nation's Department of Historic and Cultural Preservation in Okmulgee, Okla., all study coauthors, provided archaeologists with firsthand knowledge of Muscogee society. They emphasized

Indigenous council houses in many parts of what's now the southeastern United States, such as this reconstructed example from the late 1600s in Tallahassee, Fla., hosted public meetings and ceremonies.

UGA LABORATORY OF ARCHAEOLOGY

Researchers plan to track the geographic origins of ancestral Muscogee groups that met in council houses at a Georgia site by comparing stamped designs on pottery unearthed there with regionally distinctive stamped pottery, such as the fragments above, found across the southeastern United States.

to the researchers that present-day Muscogee councils, where open debate informs consensus decisions, carry on a tradition that goes back hundreds of generations.

A set of 44 new radiocarbon dates going back 1,500 years for material previously unearthed at the Georgia site, including pieces of wood from the buildings, made perfect sense in light of the Muscogee participants' input. Earlier analyses in the 1970s of excavated pottery and six radiocarbon dates from two earthen mounds at Cold Springs suggested that they had been constructed at least 1,000 years ago.

Based on the new dating, Thompson's team found that from roughly 500 A.D. to 700 A.D., Indigenous people at Cold Springs constructed not only earthen mounds, but at least three council-style roundhouses — each 12 to 15 meters in diameter — and several smaller structures possibly used as temporary housing during meetings and ceremonies.

Small communities spread across the Oconee Valley formed tight-knit social networks called clans that gathered at council houses up through the 1700s, Thompson's group suspects. Spanish expeditions through the region from 1539 to 1543 did not cause those societies and their traditions to collapse, as has often been assumed, the researchers contend.

Excavations and radiocarbon dating at another Oconee Valley Muscogee site called Dyar support that view. A square public space near Dyar includes remains of a council house. Activity at the site began as early as 1350 and continued until as late as about 1670, or about 130 years after first encounters with the Spanish, Holland-Lulewicz and colleagues reported in the October 2020 *American Antiquity*.

Spanish historical accounts mistakenly assumed that powerful chiefs ran Indigenous communities in what have become known as chiefdoms. Many archaeologists have similarly, and just as wrongly, assumed that starting around 1,000 years ago, chiefs monopolized power in southeastern Native American villages, the scientists argue.

Today, members of the Muscogee (Creek) Nation in Oklahoma gather, sometimes by the hundreds or more, in circular structures called council houses to reach collective decisions about various community issues. Council houses typically border public square grounds. That's a modern-day parallel to the story being told by the ancient architecture at Cold Springs. "Muscogee councils are the longest-surviving democratic institution in the world," Holland-Lulewicz says.

Indigenous influencers

The early Muscogee people were not alone in finding ways to build political consensus. Across different regions of precontact North America, institutions that enabled broad participation in democratic governing characterized Indigenous societies that had no kings, central state governments or bureaucracies, Holland-Lulewicz and colleagues reported March 11 in *Frontiers in Political Science*.

The researchers dub such organizations keystone institutions. Representatives of households, communities, clans and religious societies, to name a few, met on equal ground at keystone institutions, the researchers propose. Here, all manner of groups and organizations followed common rules to air their opinions and hammer out decisions about, say, distributing crops, organizing ceremonial events and resolving disputes.

For example, in the early 1600s, nations of the neighboring Wendat (Huron) and Haudenosaunee peoples in northeastern North America had formed political alliances known as confederacies, says coauthor Jennifer Birch, a University of Georgia archaeologist. Each population contained roughly 20,000 to 30,000 people. These confederacies did not hold elections in which individuals voted for representatives to a central governing body. Governing consisted of negotiations among intertwined segments of society orchestrated by clans, which claimed members across society.

Clans, in which membership was inherited through the female line, were — and still are — the social glue holding together Wendat (Huron) and Haudenosaunee politics. Residents of different villages or nations among, say, the Haudenosaunee, could belong to the same clan, creating a network of social ties. Excavations of Indigenous villages in eastern North America suggest that the earliest of these clans date to at least 3,000 years ago, Birch says.

Within clans, men and women held separate council meetings. Some councils addressed civil affairs. Others addressed military and foreign policy, typically after receiving counsel from senior clan women.

Clans controlled seats on confederacy councils of the Wendat (Huron) and Haudenosaunee. But decisions hinged on negotiation and consensus. A member of a particular clan had no right to interfere in the affairs of any other clan. Members of villages or nations could either accept or reject a clan leader as their council representative. Clans could also join forces to pursue political or military objectives.

CERAMIC TECHNOLOGY LABORATORY/FLORIDA MUSEUM OF NATURAL HISTORY/UNIV. OF FLORIDA

Some researchers, including Graeber and Wengrow, suspect a Wendat philosopher and statesman named Kandiaronk influenced ideas about democracy among Enlightenment thinkers in France and elsewhere. A 1703 book based on a French aristocrat's conversations with Kandiaronk critiqued authoritarian European states and provided an Indigenous case for decentralized, representative governing.

Although Kandiaronk was a real person, it's unclear whether that book presented his actual ideas or altered them to resemble what Europeans thought of as a "noble savage," Birch says.

Researchers also debate whether writers of the U.S. Constitution were influenced by how the Haudenosaunee Confederacy distributed power among allied nations. Benjamin Franklin learned about Haudenosaunee politics during the 1740s and 1750s as colonists tried to establish treaties with the confederacy.

Colonists took select political ideas from the Haudenosaunee Confederacy without grasping its underlying cultural framework, says University of Alberta anthropological archaeologist Kisha Supernant, a member of an Indigenous population in Canada called Métis. The U.S. Constitution stresses individual freedoms, whereas the Indigenous system addressed collective responsibilities to manage the land, water, animals and people, she says.

Anti-Aztec equality

If democratic institutions are cultural experiments in power sharing, one of the most interesting examples emerged around 700 years ago in central Mexico.

In response to growing hostilities from surrounding allies of the Aztec Empire, a multiethnic confederation of villages called Tlaxcallan built a densely occupied city of the same name. When Spaniards arrived in 1519, they wrote of Tlaxcallan as a city without kings, rulers or wealthy elites.

Until the last decade, Mexican historians had argued that Tlaxcallan was a minor settlement, not a city. They dismissed historical Spanish accounts as exaggerations of the newcomers' exploits.

Opinions changed after a team led by archaeologist Lane Fargher of Mexico's Instituto Politécnico Nacional in Merida surveyed and mapped visible remains of Tlaxcallan structures between 2007 and 2010. Excavations followed from 2015 through 2018, revealing a much larger and denser settlement than previously suspected.

The ancient city covers a series of hilltops and hillsides, Fargher says. Large terraces carved out of hillsides supported houses, public structures, plazas, earthen mounds and roadways. Around 35,000 people inhabited an area of about 4.5 square kilometers in the early 1500s.

Artifacts recovered at plazas indicate that those open spaces hosted commercial, political and religious activities. Houses clustered around plazas. Even the largest residences were modest in size, not much larger than the smallest houses. Palaces of kings and political big shots in neighboring societies, including the Aztecs, dwarfed Tlaxcallan houses.

Excavations and Spanish accounts add up to a scenario in which all Tlaxcallan citizens could participate in governmental affairs. Anyone known to provide good advice on local issues could be elected by their neighbors in a residential district to a citywide ruling council, or senate, consisting of between 50 and 200 members. Council meetings were held at a civic-ceremonial center built on a hilltop about one kilometer from Tlaxcallan.

As many as 4,000 people attended council meetings regarding issues of utmost importance, such as launching military campaigns, Fargher says.

Those chosen for council positions had to endure a public ceremony in which they were stripped naked, shoved, hit and insulted as a reminder that they served the people. Political officials who accumulated too much wealth could be publicly punished, replaced or even killed.

Tlaxcallan wasn't a social utopia. Women, for instance, had limited political power, possibly because the main route to government positions

L. FARGHER

Excavations at the ancient Mexican city of Tlaxcallan unearthed remnants of rooms of a roughly 90-square-meter house. House size was modest throughout the development. Evidence suggests the city had no ruler or wealthy elite, and all citizens participated in government affairs.

An 1869 painting by Mexican artist Rodrigo Gutiérrez depicts the Tlaxcallan senate meeting to discuss a potential alliance with Spanish conquistador Hernán Cortés against the Aztec Empire.

PAINTING/ALAMY STOCK PHOTO

involved stints of military service. But in many ways, political participation at Tlaxcallan equaled or exceeded that documented for ancient Greek democracy, Fargher and colleagues reported March 29 in *Frontiers in Political Science*. Greeks from all walks of life gathered in public spaces to speak freely about political issues. But commoners and the poor could not hold the highest political offices. And again, women were excluded.

Good government

Tlaxcallan aligned itself with Spanish conquerors against their common Aztec enemy. Then in 1545, the Spanish divided the Tlaxcallan state into four fiefdoms, ending Tlaxcallan's homegrown style of democratic rule.

The story of this fierce, equality-minded government illustrates the impermanence of political systems that broadly distribute power, Fargher says. Research on past societies worldwide "shows us how bad the human species is at building and maintaining democratic governments," he contends.

Archaeologist Richard Blanton of Purdue University in West Lafayette, Ind., and colleagues, including Fargher, analyzed whether 30 premodern societies dating to as early as around 3,000 years ago displayed signs of "good government." An overall score of government quality included evidence of systems for providing equal justice, fair taxation, control over political officials' power and a political voice for all citizens.

Only eight societies received high scores, versus 12 that scored low, Blanton and colleagues reported in the February 2021 *Current Anthropology*. The remaining 10 societies partly qualified as good governments. Many practices of societies scoring highest on good government mirrored policies of liberal democracies over the last century, the researchers concluded.

That's only a partial view of how past governments operated. But surveys of modern nations suggest that no more than half feature strong democratic institutions, Fargher says.

Probing the range of democratic institutions that societies have devised over the millennia may inspire reforms to modern democratic nations facing growing income disparities and public distrust of authorities, Holland-Lulewicz suspects. Leaders and citizens of stressed democracies today might start with a course on power sharing in Indigenous societies. School will be in session at the next meeting of the Muscogee (Creek) National Council. ■

Explore more

- Victor D. Thompson *et al*. "The early materialization of democratic institutions among the Ancestral Muskogean of the American Southeast." *American Antiquity*. May 18, 2022.

Tears From a Volcano

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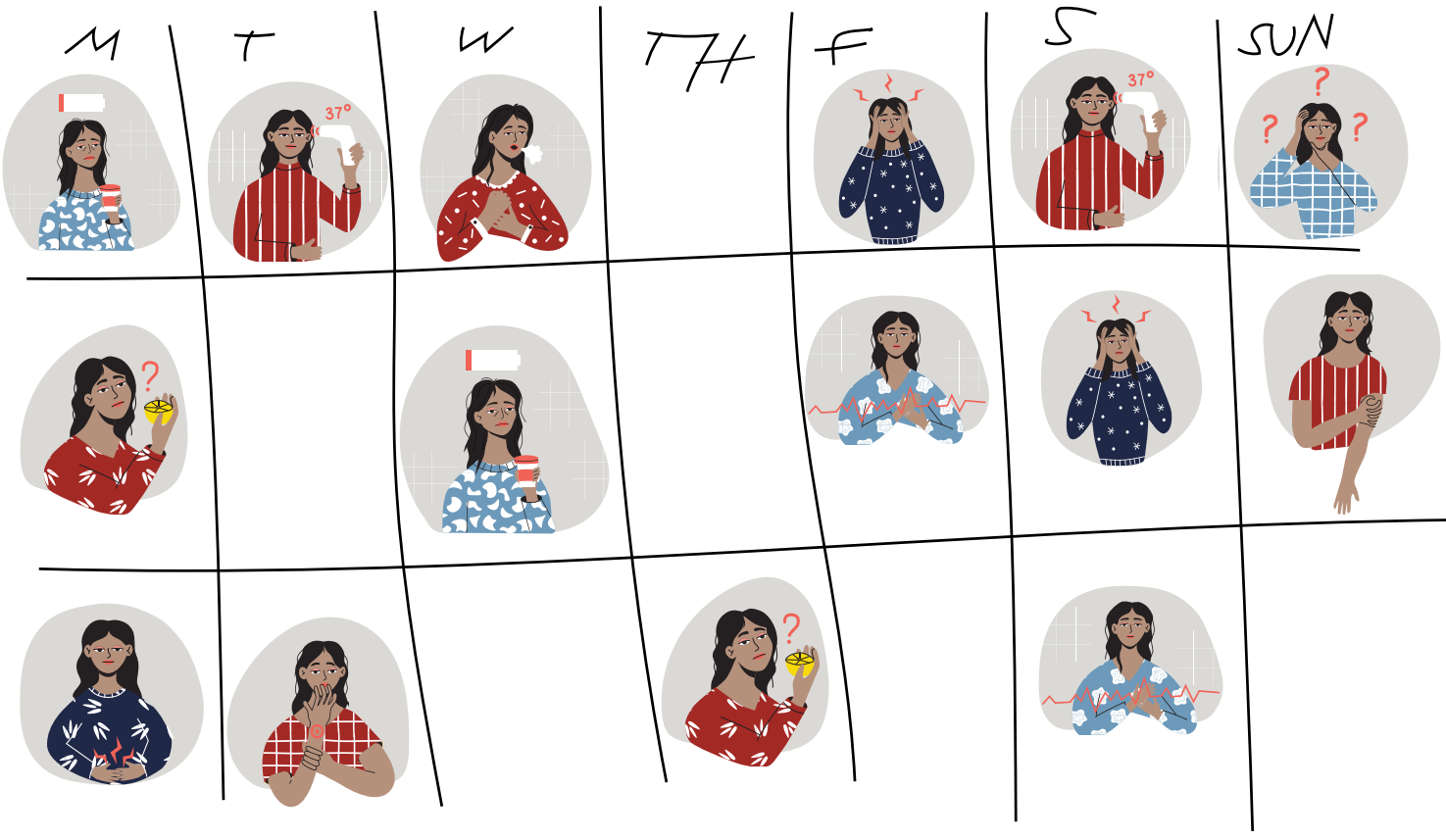


LONG COVID REALITIES

A visit to one long COVID clinic shows what doctors and patients are up against

By Meghan Rosen

Belinda Hankins first grappled with COVID-19 in the spring of 2020. She had a fever, chills and trouble breathing, but the real clincher was her loss of smell. Hankins remembers opening a canister of Tony Chachere's creole seasoning, lowering her nose to take a whiff, and not smelling a thing. "That stuff usually clears the kitchen," she says.

Her second infection, two years later, was worse. After 12 long weeks of endless fatigue and aching joints, her doctor suggested she seek treatment for long COVID. The lingering, sometimes full-body condition can plague people for months or years after a COVID-19 infection (*SN Online*: 7/29/22).

In late August, I joined Hankins, age 64, in a small exam room for her first in-person consultation at the Johns Hopkins Post-Acute COVID-19 Team clinic. Wearing a navy dress and a blue surgical

T. TIBBITTS, ASIYA HOTAMAN/ISTOCK/GETTY IMAGES PLUS

mask, Hankins is sitting in a chair across from physician Alba Azola. As they discuss Hankins' symptoms, doctor and patient face each other, Azola occasionally swiveling her stool to tap notes into a computer.

Hankins' symptoms are extensive. Brain fog, fatigue and pain top the list. She's depressed. Sleep doesn't feel restful. She has trouble focusing, is often light-headed and regularly loses her balance. Even walking to the clinic from the parking lot left her winded and in pain. "I'm extremely exhausted," she says. "I have not felt good in a long time." Hankins pauses, wiping away a tear. "I wasn't like this before."

Hankins, a retired digital media consultant, used to be an avid skier and a cyclist. She loved to travel and dance and was planning to learn how to play golf. She's not sure what the future holds, though she tells me she still has faith she can be active again.

Treating people with long COVID can be complicated — especially for Hankins and those who have other medical conditions. She has pulmonary hypertension, fibromyalgia and the connective tissue disease scleroderma. It's tricky to tease out which symptoms come from the viral infection. Azola's approach is to listen, ask questions and listen some more. Then she'll zero in on a patient's most pressing concerns. Her goal: Manage her patients' symptoms. "How can we make their quality of life better?" she asks.

System overload

On the afternoon of Hankins' visit, it's a warm summer day in Baltimore, blue skies with fleecy clouds. Inside the labyrinthine halls of Johns Hopkins Bayview Medical Center, the vibe is not quite as sunny: bright lights, shiny floors, people in line and people in scrubs. Everyone I see is masked.

Azola meets me in the waiting area, walking briskly and wearing bright red glasses. Before the pandemic, Azola, a rehabilitation physician, treated patients recovering from strokes, spinal cord injuries and other disorders. Most mornings, she still works with these patients. But for the last two years, her afternoons have been booked with people laid low by COVID-19.

She's squeezed me in to talk about the Johns Hopkins PACT clinic, which opened in April 2020, around the time when the world hit 1 million confirmed cases. "To be honest, we didn't know what to expect," Azola says. Back then, most of the clinic's patients were recovering from COVID-19 after a stay in the hospital's intensive care unit. Now, at least half of the patients never got sick enough with COVID-19 to be hospitalized — yet still have symptoms they can't shake. In a single week, Azola and her colleagues may get 30 referrals. "It's constant," she says, "more than we can provide service to."

B. HANKINS

Belinda Hankins has been experiencing long COVID symptoms for months.

As those referrals pile up, patient wait times can stretch. The PACT clinic expanded last summer and now has more than a dozen people on staff, including therapists, physicians and other specialists. They try to keep the wait to around two months, Azola says, but sometimes it takes up to four months for a patient to be seen.

The demand here and at clinics across the country isn't likely to let up. As of mid-October, the United States has reported more than 96.5 million cases of COVID-19. Though long COVID numbers can be hard to pin down, nearly half of people infected with SARS-CoV-2 haven't fully recovered six to 18 months after their infection, according to a large study in Scotland, published in *Nature Communications* on October 12. A more conservative estimate posted on medRxiv.org on September 6 suggests that, in the United States alone, more than 18 million adults may have long COVID.

"We are in the middle of a mass disabling event," says Talya Fleming, a physician at the JFK Johnson Rehabilitation Institute in Edison, N.J.

> "We are in the middle of a mass disabling event."
>
> **TALYA FLEMING**

Scattershot solutions

In the United States, some 400 clinics have popped up from coast-to-coast to care for the growing wave of long COVID patients (see Page 25). Clinics, with varying levels of expertise, operate in every state.

Although the American Academy of Physical Medicine and Rehabilitation has published some guidance, no gold-standard therapies exist and there are no formal criteria for what long COVID clinics do or how they do it. The Academy brought together more than 40 post-COVID clinics, including the Hopkins PACT clinic, to share experiences and discuss best practices for long COVID treatment. "We're kind of guiding each other,"

To hear Belinda Hankins talk about her experience, visit **bit.ly/SN_longCOVID**

Azola says. Other clinics in the United States are more or less forging their own paths.

Azola and colleagues are focusing on their patients' symptoms, a strategy other long COVID doctors and clinics are using too. "There is no one, singular long COVID experience," says pulmonologist Lekshmi Santhosh. Doctors need to take a "customized, symptom-directed approach."

Santhosh founded the OPTIMAL clinic at the University of California, San Francisco to provide follow-up care for people who had COVID-19. Since 2020, she's seen hundreds of patients, who can wait weeks to months for an appointment. One main question Santhosh hears from patients: When am I going to get better? That's hard to answer, she admits.

Scientists can't yet predict how or when a patient will recover, and they don't know why long COVID strikes some people and spares others. Right now, there are no obvious patterns. "If you are young, you can get long COVID. If you have no preexisting health conditions, you can get long COVID. If you've had COVID before, you still can get long COVID," Fleming says. The list goes on.

At UC San Francisco, Santhosh says she's seen it all. Long COVID can affect a 75-year-old patient who was hospitalized for COVID-19, or a 35-year-old marathoner whose stubborn symptoms developed after just a mild infection. One patient can be hit with a hailstorm of health conditions, another patient, just a few.

For Azola, several experiences have stood out. "I've heard some weird things." She remembers one patient who felt as if a phone were vibrating deep inside their bones. Another described a sensation of heaviness, like their legs were made of lead.

Long COVID's scattershot symptoms require a smorgasbord of solutions. For headaches, a doctor might prescribe a combo of pain relievers. For shortness of breath, an inhaler to open the airways could help. For brain fog, patients might visit a therapist who can help them with word-finding issues. Such symptom management is necessary, Azola says, because "we don't have strong, randomized controlled trials to support the use of specific medications or treatments."

Developing effective therapies has been "frustratingly slow," Santhosh says. Scientists are still trying to understand what's happening in the body that spurs long COVID and lets symptoms simmer away unchecked. "The underlying biology is unclear," she says. That makes it "unclear exactly what treatments might work."

Long COVID's biological underpinnings are a hot topic among researchers, says Mike VanElzakker, a neuroscientist at Harvard Medical School and Massachusetts General Hospital, and part of the Long COVID Research Initiative, a group working to study and treat the condition. Scientists have scads of hypotheses for what causes long COVID symptoms, including lungs scarred by SARS-CoV-2 or the reawakening of some other, long-slumbering virus. One idea posits that COVID-19 might sabotage the immune system, inviting other microbes to do harm. Another idea pins long COVID on caches of coronavirus hiding within the body's tissues.

"It really does matter what's causing these problems," VanElzakker says. If doctors knew what's driving a patient's symptoms, they might be able to offer personalized treatments aimed at the illness's root.

Filling the void

On Facebook pages and websites around the internet, purported long COVID treatment options abound.

Vitamins, supplements, alternative medicines: General internist Aileen Chang in Washington, D.C., used to hear all the time from long COVID patients about therapies they've tried. In the fall of 2020, Chang and others started the George Washington Medical Faculty Associates COVID-19 Recovery Clinic, which later closed its doors due to a staffing shortage. She recalls patients who flew to different countries to have their blood filtered and others who took "every sort of supplement you can imagine," she says. "They're looking for solutions."

Chang worries that such unproven treatments could have serious side effects; they can also drain patients financially. "They're spending all this money on things they think will make them better," Chang says, "but the truth is ... we don't know."

What scientists do know is that efforts to develop treatments for long COVID are still in their early days. There's some evidence that getting a

Most commonly reported symptoms of long COVID

General

- Fatigue that interferes with daily life
- Symptoms that get worse after physical or mental effort (also known as post-exertional malaise)
- Fever
- Joint or muscle pain
- Rash
- Changes in menstrual cycles

Lungs and heart

- Difficulty breathing or shortness of breath
- Cough
- Chest pain
- Fast-beating or pounding heart

Brain

- Difficulty thinking/brain fog
- Headache
- Sleep problems
- Dizziness when standing up
- Pins-and-needles feelings
- Change in smell or taste
- Depression or anxiety

Gut

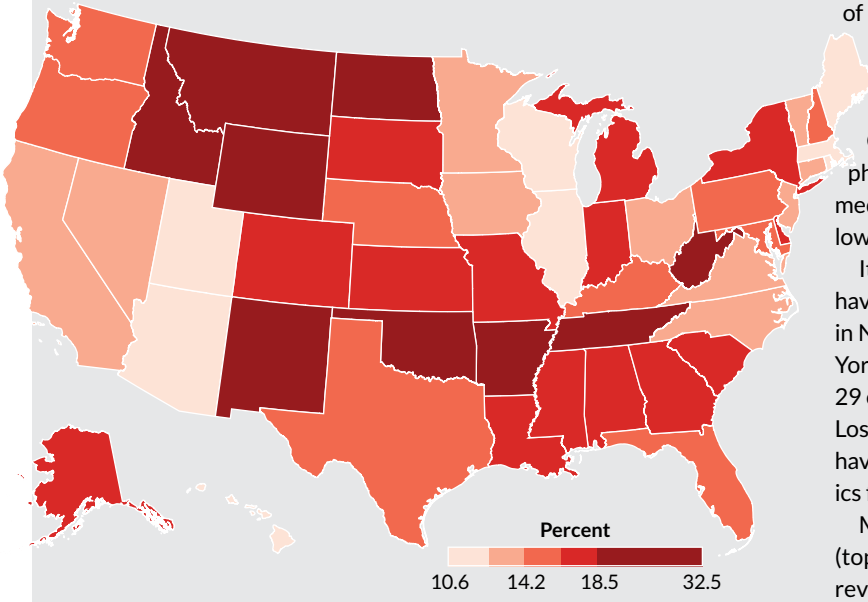
- Diarrhea
- Stomach pain

SOURCE: CDC

ASIYA HOTAMAN/ISTOCK/GETTY IMAGES PLUS

Where are the long COVID clinics?

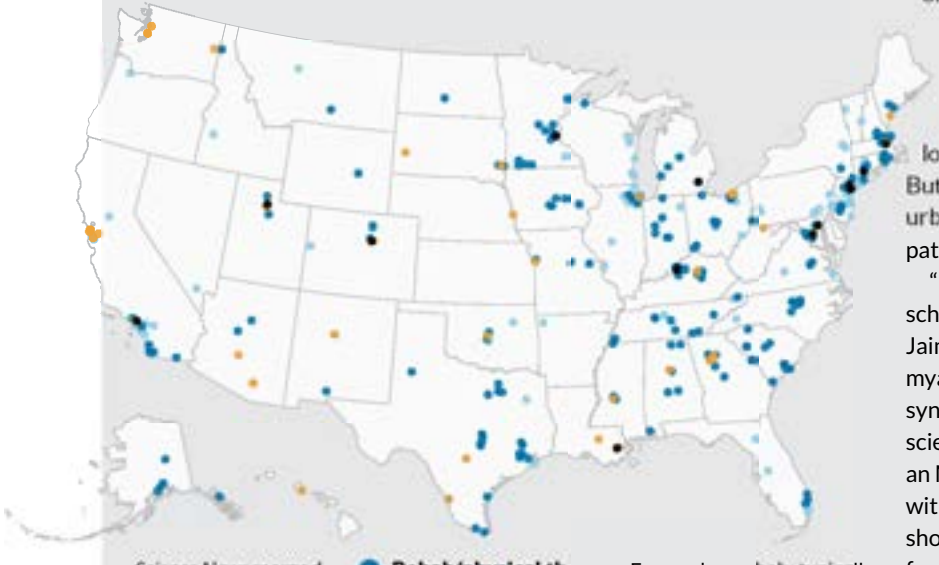
Long COVID prevalence by state



Shading reflects the share of adults who reported experiencing long COVID in mid-September, as a percentage of adults who ever had COVID-19. For this survey, long COVID is defined as symptoms lasting three months or longer.

SOURCE: NATIONAL CENTER FOR HEALTH STATISTICS HOUSEHOLD PULSE SURVEY

Long COVID clinics and research sites



Science News merged three crowdsourced lists, plus the 53 NIH RECOVER research sites (one not shown is in Puerto Rico), confirming that all were active as of early October.

- **Rehab/physical therapy**: Focused on rehab; typically does not offer other kinds of specialists
- **Specialist clinic**: Offers comprehensive care from physicians in one or more long COVID–related specialties
- **NIH RECOVER:** Academic research site included in the NIH RECOVER adult study
- **Pediatric clinic:** Treats long COVID in children

B. LADYZHETS

For the millions of people in the United States with long COVID, getting help comes down to where they live. Clinic accessibility and the kind of care offered vary wildly.

The COVID-19 Longhauler Advocacy Project, a patient support group, compiled a crowdsourced list of more than 400 long COVID clinics, ranging from rehabilitation or physical therapy practices to comprehensive medical centers with multiple specialists. The lower map combines this list plus two others.

It's no surprise that people living in big cities have the most clinics to choose from. Out of 37 in New York state, all but three are in the New York City metropolitan area. California's 29 clinics are concentrated in the Bay Area, Los Angeles and San Diego. Seventeen states have fewer than five clinics. Fourteen U.S. clinics focus on children with long COVID.

Maps of long COVID prevalence by state (top) and long COVID clinic locations (bottom) reveal a mismatch between need and availability of relevant medical care. In mid-September, about 1 in 5 adults in Idaho, North Dakota, Oklahoma and Wyoming who had had COVID-19 reported experiencing long COVID, defined here as symptoms lasting three months or more. North Dakota and Wyoming each have just one long COVID clinic. Idaho has three. Oklahoma has six.

Many of the RECOVER sites, funded by the National Institutes of Health to study long COVID, also treat adults with long COVID. But most RECOVER sites are clustered in urban areas: Out of 53 locations serving adult patients, six are in the city of Boston.

"It would be great if we could get medical schools to begin teaching these diseases," says Jaime Seltzer, referring to long COVID and myalgic encephalomyelitis/chronic fatigue syndrome, or ME/CFS. Seltzer is director of scientific and medical outreach at #MEAction, an ME/CFS advocacy group that also works with long COVID patients. For Seltzer, clinics should offer comprehensive care from doctors familiar with the intense fatigue, pain, breathing problems and brain fog that can occur with postviral conditions. With expanded education, long COVID patients might one day be able to receive care from their primary care doctors rather than waiting months for specialists.

— Betsy Ladyzhets

For interactive versions of these maps, visit **bit.ly/SN_longCOVIDclinics**

COVID-19 vaccine might improve long COVID patients' symptoms, though this idea is controversial, researchers reported this month in *eClinicalMedicine*. And repeated sessions of breathing 100 percent oxygen in a hyperbaric chamber might relieve fatigue and brain fog, small studies of patients have suggested.

Last year, the U.S. National Institutes of Health launched a massive research project on the long-term effects of COVID-19. Called the RECOVER Initiative, the project aims to uncover why some people get long COVID and to identify underlying causes. As of mid-October, RECOVER had enrolled more than half of the estimated 17,680 adults needed.

It's a great initiative, Santhosh says, but it got rolling relatively late — well after long COVID had already upended many people's lives. "We need ... a lot more funding and a lot more therapeutic trials," she says. Santhosh is hopeful that, in the coming months and years, doctors will have solid answers on what treatments actually work. "There are a lot of tantalizing biological leads," she says. Though, she acknowledges, this timeframe can feel agonizingly long to patients and their doctors.

> "The most important thing is to listen to patients and keep an open mind."
>
> ALBA AZOLA

Real life

In the meantime, Santhosh, Azola and other physicians are borrowing strategies that help for other disorders — like myalgic encephalomyelitis/chronic fatigue syndrome. Many of the symptoms of that enigmatic illness overlap with those of long COVID, a symmetry that could bring answers for both disorders, scientists suggested September 8 in *Science*.

One common approach isn't a treatment like pills or surgery — it's more of a shift in behavior: Don't overdo it, Santhosh says. "We talk to our long COVID patients about this all the time, about the need to rest, to pace yourself and how to gently bring back your aerobic fitness."

Long COVID patients with fatigue can be tempted to try and push through, to keep speeding through life as they had before their diagnosis. But that doesn't seem to work for people with chronic fatigue, and "for some long COVID patients, it can actually make things worse," she's found.

Azola has similar advice for Hankins. About a half hour into the appointment, Azola slides away from the computer desk and turns toward her patient. "This is the part where people want to punch me in the face," she tells Hankins, pushing her glasses up onto her head. "We don't have a magic wand that makes [you] feel better."

Instead, Hankins will need to check her body's battery every day, conserve energy where she can, and build in opportunities to recover. Little tricks, like sitting in a chair while showering or prepping food, can help patients save enough juice to make it through the day. Azola hopes to get Hankins off the "corona coaster," where patients can feel relatively good one day, and the next day, crash. Having energy levels repeatedly crater can erode a patient's ability to live their lives, Azola says.

For the next 20 minutes, doctor and patient talk about how Hankins' life has changed and what her next steps will be. In a week, she'll meet with a neuropsychologist who will help her cope with her new reality. Azola also refers Hankins to a pain specialist.

The two women have spent about an hour together — a near-eternity for a medical appointment. For Azola, it's time well spent. "The most important thing is to listen to patients and keep an open mind," she says.

When I speak with Hankins nearly three weeks later, she's still feeling hopeful. She's met with the neuropsychologist and will continue to receive follow-up care. Having a care plan that factors in all of her conditions, including long COVID, she says, may one day let her feel like herself again.

For now, Hankins is hoping that sharing her story will help others struggling with the illness. When she tells people she has long COVID, she says, "some of them don't even think it's real." ■

JOHNS HOPKINS POST-ACUTE COVID-19 TEAM (PACT)

Alba Azola (left), a rehabilitation physician at Johns Hopkins Medicine, focuses on managing the symptoms of her patients with long COVID.

Explore more

- NIH RECOVER Initiative: recovercovid.org/
- Sonya Marshall-Gradisnik and Natalie Eaton-Fitch. "Understanding myalgic encephalomyelitis." *Science*. September 8, 2022.

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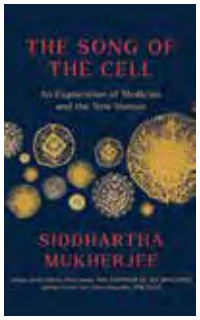


The Song of the Cell
Siddhartha Mukherjee
SCRIBNER, $32.50

BOOKSHELF

Scientist, doctor and patient stories enliven the history of cell biology

In the summer of 1960, doctors extracted "crimson sludge" from 6-year-old Barbara Lowry's bones and gave it to her twin.

That surgery, one of the first successful bone marrow transplants, belied the difficulty of the procedure. In the early years of transplantation, scores of patients died as doctors struggled to figure out how to use one person's cells to treat another. "Cell therapy for blood diseases had a terrifying birth," Siddhartha Mukherjee writes in his new book, *The Song of the Cell*.

The transplant story is one of many Mukherjee uses to put human faces and experiences at the heart of medical progress. But what radiates off the pages is the author himself. An oncologist, researcher and Pulitzer Prize–winning author, Mukherjee's curiosity and wisdom add pep to what, in less dexterous hands, might be dry material. He finds wonder in every facet of cell biology, inspiration in the people working in this field and "spine-tingling awe" in their discoveries.

It's no surprise that Mukherjee is so seduced by science. This is a man who built a microscope from scratch during the pandemic and has spent years probing biology and its history with luminaries in the field. *The Song of the Cell* lets readers eavesdrop on these conversations, which can be intimate and enlightening.

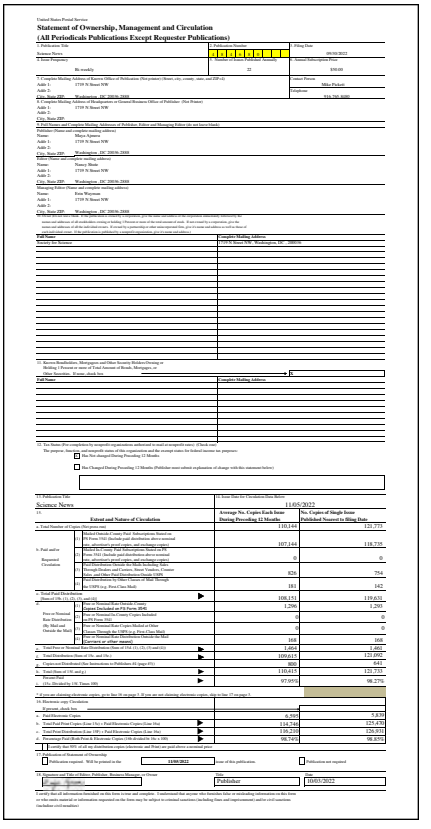
On a car ride across the Netherlands, Mukherjee chats with geneticist Paul Nurse, who tells him about the cell division work that ultimately netted Nurse a Nobel Prize (*SN*: 3/27/21, *p.* 28). On a walk at Rockefeller University in New York City, Mukherjee discusses his depression with another Nobel Prize–winning researcher, neuroscientist Paul Greengard. Mukherjee's vivid imagery lends heft to his feelings. He tells Greengard about experiencing a "soupy fog of grief" after his father's death and describes "drowning in a tide of sadness."

In these memories, which Mukherjee uses to segue into the science of depression, and elsewhere in the book, hints of poetry shimmer among the prose. A cell observed under a microscope is "refulgent, glimmering, alive." A white blood cell's slow creep is like the "ectoplasmic movement of an alien."

Mukherjee weaves his experiences into the story of cell biology, guiding readers through the lives and discoveries of key figures in the field. We meet the "father of microbiology," Antonie van Leeuwenhoek, a 17th century cloth merchant who ground globules of Venetian glass into microscope lenses and spied a "marvelous cosmos of a living world" within a raindrop. Mukherjee also teleports us to the present to introduce He Jiankui, the disgraced biophysicist behind the world's first gene-edited babies (*SN*: 12/22/18 & 1/5/19, *p.* 20). Along the way, we also meet Frances Kelsey, the Food and Drug Administration medical officer who refused to approve thalidomide, a drug now known to cause birth defects, for use in the United States, and Lynn Margulis, the evolutionary biologist who argued that mitochondria and other organelles were once free-living bacteria (*SN*: 8/8/15, *p.* 22).

Mukherjee traverses a vast landscape of cell biology, and he's not afraid to pull over and go exploring in the weeds. He describes in detail the flux of ions in nerve cells and introduces a considerable cast of immune system characters. For an even deeper dive, readers can check the footnotes; they are abundant.

What stands out most, though, are Mukherjee's stories about people: scientists, doctors, patients and himself. As a researcher and a physician, he steps deftly between the scientific and clinical worlds, and, like the microscope he assembled, offers a glimpse into a universe we might not otherwise see. —*Meghan Rosen*



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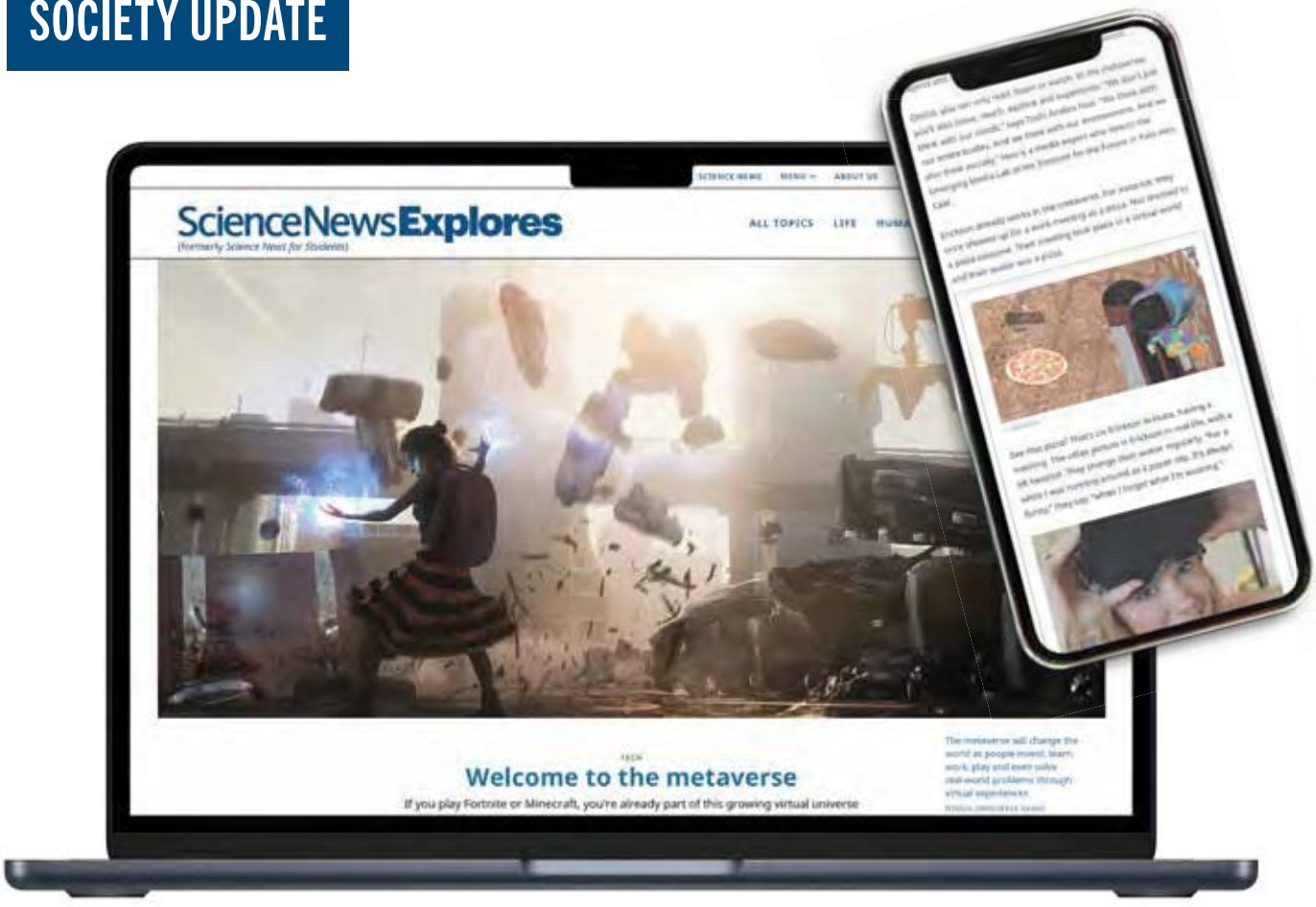

WELCOME TO THE METAVERSE

A teen with spiky white hair races his car past an enormous *Tyrannosaurus rex*. Later, he dances to some catchy music—while spinning and floating in midair. These scenes from *Ready Player One*, a 2018 hit movie, take place in a virtual world—the metaverse. That movie was a work of science fiction. But in the very real here and now, engineers, and even kids, have begun building an actual metaverse.

Today, it's mostly on screens. And it's not very much like the immersive, realistic virtual worlds of science fiction. Eventually, though, the metaverse will surround us. Virtual reality headsets will transport us to completely virtual worlds.

Augmented reality projectors will make hologram-like virtual objects and characters appear in the real, physical world. Join *Science News Explores* as we explore what's in store.

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SEPTEMBER 10, 2022

What's the matter?

The proposed Windchime experiment plans to use only gravity to detect some types of dark matter. Ultrasensitive sensors would be jostled by the gravitational forces of a dark matter "wind" passing by Earth, ***James R. Riordon*** *reported in "Gravity could aid dark matter search"* (SN: 9/10/22, p. 14). Since dark matter is affected by gravity, reader **David Goldberg** asked if dark matter orbits the Milky Way's center just like our solar system does. If the two move together, how would there be a dark matter wind to detect?

It's possible that dark matter circles the Milky Way's center at least a little, though it's hard to say for sure because no one has been able to measure the elusive stuff yet, **Riordon** says. But to search for dark matter using the Windchime method, it doesn't really matter whether the mysterious substance moves with the galaxy, he says. That's because as the sun circles the Milky Way's center, Earth is also orbiting the sun. Even if the sun happens to move with the same velocity as nearby dark matter, the direction of Earth's velocity changes over the course of a year, **Riordon** says. So we should sense the pull of a dark matter wind that shifts with Earth's seasons.

What's more, as the planet spins on its axis, the direction of the surface's movement relative to the galaxy changes throughout the day. "It's a little like a fish swimming in the ocean," **Riordon** says. "Even though the water in general moves with Earth, as a fish swims in various directions, the creature will experience a flow of water relative to its own motion."

Reader **Jack Ryan** wondered why, despite its gravitational attraction, dark matter doesn't form stars, planets and other celestial bodies.

"Because no one knows what dark matter is, we can't say for certain that it can or cannot form globs or come in very massive particles," **Riordon** says. "It's something that researchers like those on the Windchime team are looking out for."

For normal matter to create asteroids or planets, it must experience some force beyond gravity, **Riordon** says. For instance, if two rocks collide in space, electromagnetic forces would prevent them from simply passing through each other. This would then allow gravity to hold the two rocks together. And if the concentration of matter continues to build up, then an asteroid or a planet could eventually form.

Some physicists hope that dark matter experiences other forces, but gravity is currently the only one known to affect it. "If a dark matter particle that only experiences gravity approaches a rock, a planet or another dark matter particle, it would glide right through because there is no force that can stop it," **Riordon** says. "Gravity can pull dark matter into a halo, but on its own, it probably can't stick dark matter together."

Correction

A line dropped from our feature "Island lessons" (SN: 9/24/22, p. 22). At the end of Page 26, the full sentence should have read: Saban native Dahlia Hassell-Knijff got a degree in biology in Mississippi, then returned to the island, where she oversees projects at the regional Dutch Caribbean Nature Alliance.

READER SNAPSHOTS

Raving about rovers

In "25 years of Mars rovers," **Alexandra Witze** described how remotely controlled rovers have helped scientists better understand the Red Planet's history (*SN: 8/13/22, p. 20*).

"Thank you for a great 25-year review of the Mars rovers," reader **Leslie Hruby** wrote. "With your pictures and short descriptions of the Mars rovers, my grandsons [shown at left], ages 3 ½ and 5, made their own Mars rover … in our four-wheeled wagon (not six like the rovers) with boxes, tape and drinking cups, with a little help from grandma in taping."

"Cups at rear are the engines. Other cups are cameras, and side boxes are for collecting rocks. Note their design for oxygen tanks (packing bubbles) taped on their chests," **Hruby** wrote. "They ran their rover wagon down the hill in gales of laughter, proving that science can be great fun, as it broke apart."

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A glimpse inside a gecko's hand

Life can be beautiful at all scales, from big to small. Sometimes that splendor is concealed by literal scales.

A mesmerizing peek beneath the developing scales on the hand of an embryonic Madagascar giant day gecko (*Phelsuma grandis*) won first place in the 2022 Nikon Small World photomicrography competition. The winning image, stitched together from hundreds of images taken over two days with a confocal microscope, was crafted by University of Geneva researchers Grigorii Timin and Michel Milinkovitch. They study the genetics and physics of embryonic development.

The hand is artificially colored to show budding nerves (cyan); blood cells (yellow); and collagen-containing structures such as new bone, tendons and ligaments (oranges and yellows). Collagen, Milinkovitch says, is a building block of life. Knowing where collagen is in an embryo can help researchers understand how bodies and tissues develop.

Parts of bones that have started to calcify shine brightest in the image, Timin says. Developing tendons and ligaments stretch as orange branches. Flanking the new bones, blood cells form clusters or line up inside blood vessels at the tips of the gecko's digits.

The image highlights beauty of all sizes, Milinkovitch says. The snapshot is "beautiful as a hand, you see this beautiful pattern of the fingers. Then you zoom, you see the spongy bones. And you zoom, you see the tendons. And you zoom, and you see the fibers that [make up] the tendons. Then you zoom, and you see the blood cells."

The image is one of 92 recognized in this year's competition. The winners — showcasing fluorescent coral, slime mold, a snuffed-out candle wick and more — were announced October 11. — *Erin Garcia de Jesús*

G. TIMIN AND M. MILINKOVITCH/UNIV. OF GENEVA, NIKON SMALL WORLD

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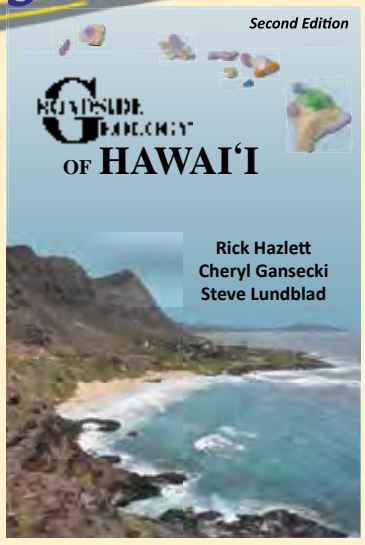

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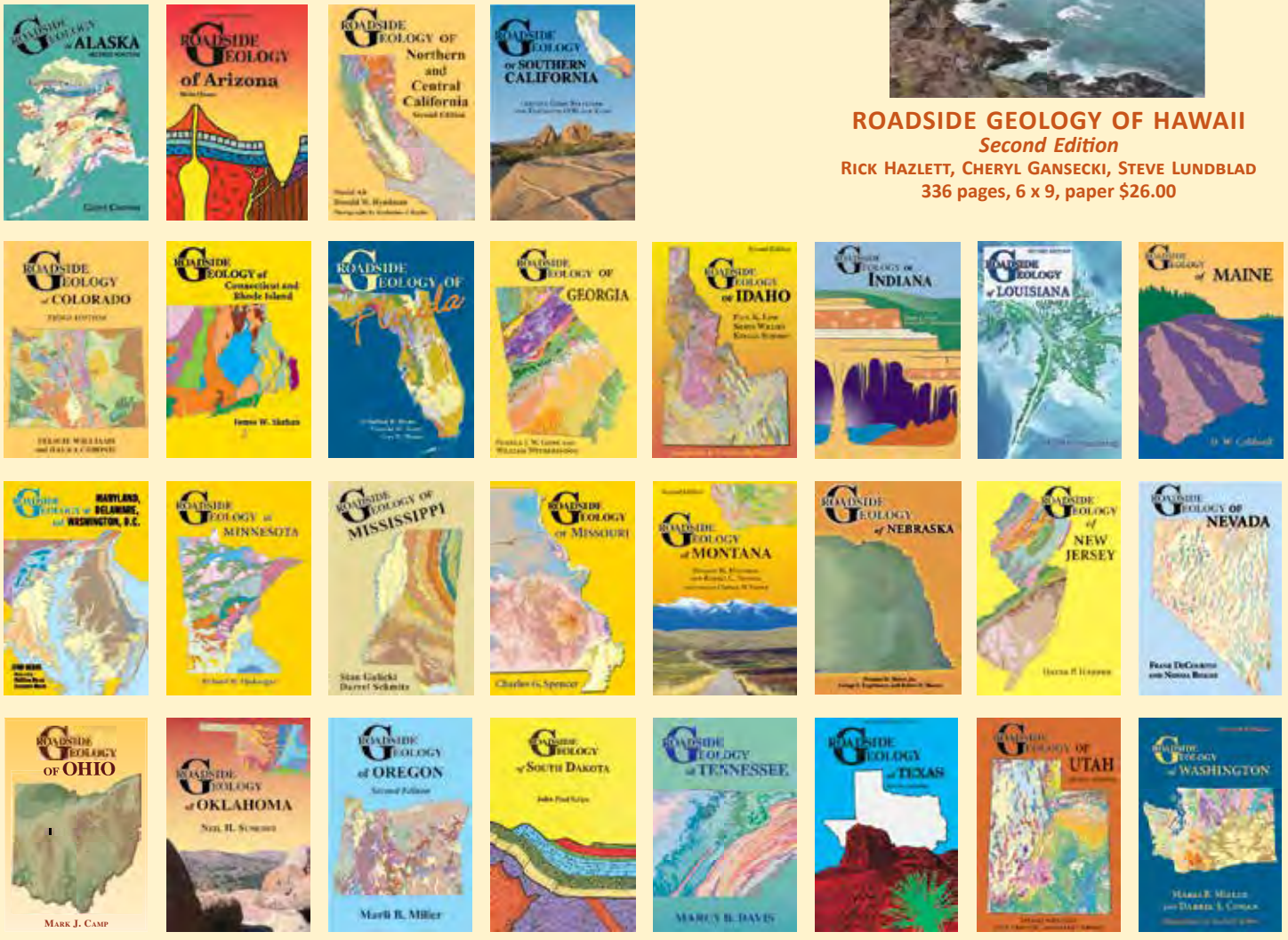

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