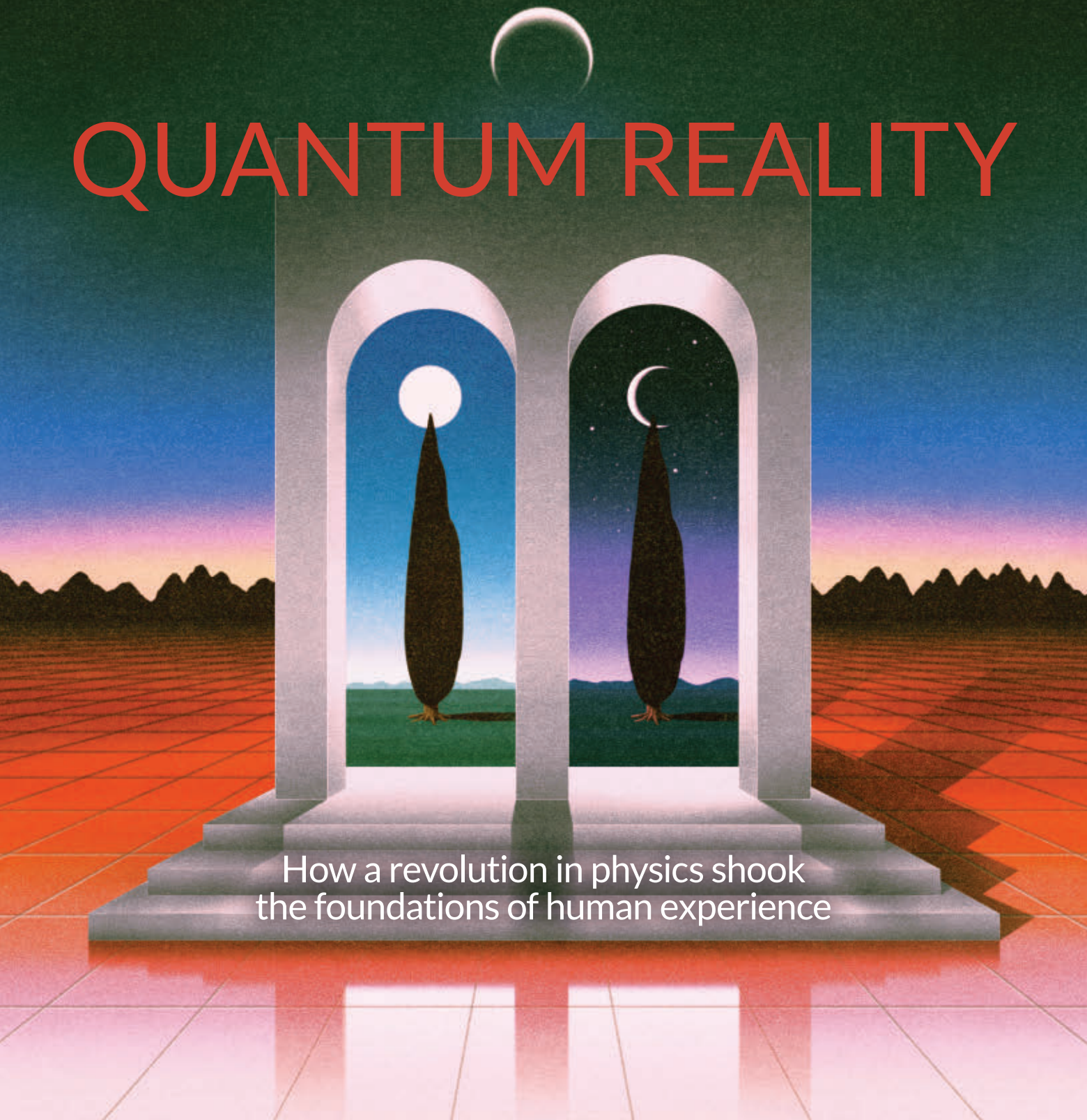
Tiny Living Machines Reproduce | Albatross Divorce

ScienceNews

MAGAZINE OF THE SOCIETY FOR SCIENCE ■ JANUARY 15, 2022

QUANTUM REALITY



How a revolution in physics shook the foundations of human experience

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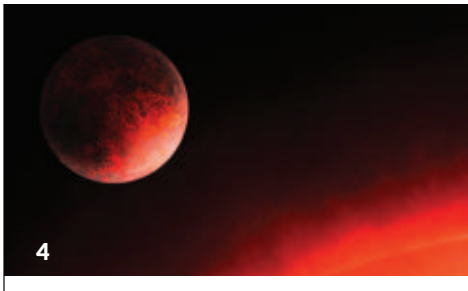
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Departments

COVER Quantum theory describes a reality ruled by probabilities. How to reconcile that reality with everyday experiences is still unclear. *Max Löffler*

FROM TOP: CHASE STUDIO/SCIENCE SOURCE; SPP 1992 (PATRICIA KLEIN); KATERYNA KON/SCIENCE PHOTO LIBRARY/GETTY IMAGES PLUS

Science explores the nature of time and space

We tend to treat time as a quantifiable commodity — something that can be managed, saved and retrieved for future use, like a stick of butter in the freezer. But our perceptions of past and present are often not so solid.

Archaeologists try to reconstruct ancient history from artifacts, and those clues often allow enough leeway to imagine alternative pasts. Take the current controversy over whether the ancient Clovis people, who lived in North America around 13,000 years ago, killed mammoths and other large mammals. Dioramas of these brave hunters felling massive beasts with stone-tipped spears have been a staple of natural history museums for decades. But new research reported by behavioral sciences writer Bruce Bower suggests that those elegant stone points lacked the oomph to inflict a lethal blow (Page 22). Scientists tested that hypothesis with experiments that included reconstructing a mammoth-foot analog and attempting to inflict "wounds." These findings could shift the long debate over how much humans are at fault for mammoth extinctions, compared with climate or other environmental changes.

I'm content to marvel at the beauty of those Clovis points, be they mammoth killers or simple butchering tools. But this issue also provides deeper questions to consider, in an essay by contributing correspondent Tom Siegfried (Page 16).

In the last century, discoveries in quantum physics have challenged our understanding of space and time — and the very nature of reality. It's as if that stick of butter in my freezer could be simultaneously baked into a croissant in Paris. Or that both butter and croissant could be mere human perceptions and not a fundamental feature of reality. Or what our brains and senses perceive on the human scale of time and space may be just one of multiple realities.

Exploration of the quantum realm promises to bring more challenges to our imaginations in the years to come, as well as dazzling realities like practical applications for quantum computing. For now, I'll presume that both Clovis points and a fresh-baked croissant deserve to be real. — *Nancy Shute, Editor in Chief*

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Excerpt from the January 15, 1972 issue of *Science News*

50 YEARS AGO

The decision on the shuttle is 'go'

President Nixon's announcement last week of the decision to begin development of a space shuttle system may prove to be nearly as crucial to the future of the manned space program as the 1961 Kennedy challenge to land a man on the moon.

UPDATE: The shuttle program was NASA astronauts' ticket to space for 30 years. Beginning in 1981, five reusable spacecraft carried out many important missions, including helping to build the International Space Station and carrying the Hubble Space Telescope into orbit. Despite initial hopes that the shuttles would usher in an era of low-cost spaceflight, the program was deemed too expensive to continue and ended in 2011. Recently, NASA has begun working with private companies to transport astronauts to low Earth orbit. In 2020, SpaceX flew six astronauts to the International Space Station (*SN: 12/19/20 & 1/2/21, p. 36*). Last April, NASA announced it had tapped SpaceX to ferry astronauts to the surface of the moon as part of the upcoming Artemis program.

The town of Tangier on Virginia's Tangier Island has seen more and more frequent flooding, leaving some residents with no choice but to raise their houses and walkways.

SOAPBOX

Time is running out to save Virginia's Tangier Island

Tangier Island is rapidly disappearing. Rising sea levels are exacerbating erosion and flooding, and could make this speck of Virginia land in the Chesapeake Bay uninhabitable within the next few decades. For years, island residents, policy makers and others have debated whether to attempt to save the island or relocate its small community elsewhere. But time to decide is running out, says David Schulte, a marine biologist with the U.S. Army Corps of Engineers.

MYSTERY SOLVED

Sulfur compounds skunk up cannabis plants

Scientists have finally sniffed out the molecules behind marijuana's skunky aroma. Within fresh weed's heady bouquet, a group of sulfur compounds accounts for the funky ganja note, chemists report in the Nov. 30 *ACS Omega*.

Analytical chemist Iain Oswald of Abstrax Tech, a private company in Tustin, Calif., that develops scent compounds for cannabis products, and colleagues had a hunch that the culprit behind the scent may contain sulfur, a stinky element also found in hops and skunk defensive spray. So the team started by rating the skunk factor of flowers harvested from more than a dozen varieties of *Cannabis sativa* on a scale from zero to 10, with 10 being the most pungent. Next, the team created a chemical fingerprint of the airborne components that contributed to each cultivar's unique scent. Small amounts of several fragrant sulfur compounds lurked in the olfactory profiles of the smelliest cultivars. The most dominant, a molecule called prenylthiol, gives "skunked beer" its flavor (*SN: 12/3/05, p. 362*).

Sulfur compounds newly found in cannabis give it a skunky aroma.

Smell psychologist Avery Gilbert of Headspace Sensory, a Colorado-based company that quantifies cannabis scents, is excited to see the molecules added to marijuana's chemical repertoire. The discovery of prenylthiol in weed, Gilbert says, is the first step to masking or maximizing its stink. —*Ariana Remmel*

FROM TOP: PATRICK BLOODGOOD/NORFOLK DISTRICT/USACE; MARTIN DEJA/MOMENT/GETTY IMAGES

Crucially, that choice will signal how other U.S. groups most at risk from climate change "will have their needs addressed — or ignored," Schulte and his son, Zehao Wu, write in a new study.

The island's sole town, Tangier, is located on three upland ridges. By analyzing aerial photographs of the area from 1967 to 2019, Schulte and Wu, a student researcher at Biogenic Solutions Consulting in Newport News, Va., found that nearly 62 percent of the ridge area has been lost to sea level rise. What's left will turn into wetland by 2051 — about a decade earlier than anticipated — the pair reports November 8 in *Frontiers in Climate*.

Already, frequent flooding has turned the front yards of many Tangier homes into marshes, Schulte says. Elevated homes, schools and sidewalks "are all signs of just how bad it is out there."

The island's population of 436 people could drop to zero by 2053, Schulte and Wu's analysis suggests. Protecting and restoring Tangier Island might persuade some residents to stay, but it comes with a hefty price tag: between $250 million and $350 million, the team estimates. That money would fund interventions such as installing stone along shorelines to fight erosion and raising the ridges using sand from the Chesapeake Bay.

Sea level rise could make Virginia's Tangier Island, shown in 2019, uninhabitable by 2051.

Relocating Tangier residents is about $150 million cheaper, Schulte and Wu calculate. That estimate is based on others from the U.S. government to relocate coastal communities such as the towns of Shishmaref, Kivalina and Newtok in Alaska, the Quinault Indian Nation village of Taholah in Washington and Isle de Jean Charles in Louisiana.

Keeping such communities intact means possibly relocating infrastructure, including schools, medical facilities and grocery stores, along with the people and their homes. For Tangier, the cost of moving is high because it all must be done by boat, Schulte says.

More U.S. coastal towns and cities will probably face similar choices as the planet keeps warming. Ones inhabited by Native Americans, minorities or low-income groups often are the first to bear the brunt of sea level rise, which makes drawing attention to these overlooked communities even more essential, Wu says. — *Trishla Ostwal*

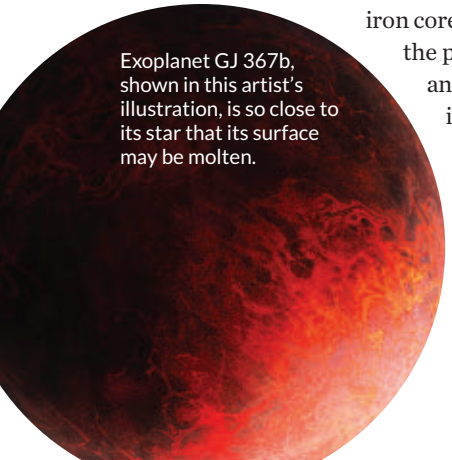
HOW BIZARRE

Exoplanet may sizzle in metallic lava

An exoplanet 31 light-years from Earth is so metal. Planet GJ 367b is smaller than our planet, denser than iron and hot enough to melt, Kristine Wai Fun Lam and colleagues report in the Dec. 3 *Science*.

"The surface of this exoplanet could be molten," says Lam, an astronomer at the Institute of Planetary Research in Berlin.

The small world, which clocks in at about 0.72 times Earth's radius and 0.55 times Earth's mass, swings around its host star every 7.7 hours, data from NASA's TESS space telescope and La Silla Observatory in Chile show. That makes GJ 367b the first ultrashort-period planet — a class of worlds with years shorter than one Earth day — known to be smaller and lighter than Earth. At about 8.1 grams per cubic centimeter, GJ 367b's density rivals that of iron. An iron core could make up 86 percent of the planet's interior, a computer analysis suggests. Since GJ 367b is so close to its star, the planet is almost certainly covered in metallic lava. "At 1400° Celsius, I don't think it would be very nice to stand on it," Lam says. — *Lisa Grossman*



Exoplanet GJ 367b, shown in this artist's illustration, is so close to its star that its surface may be molten.

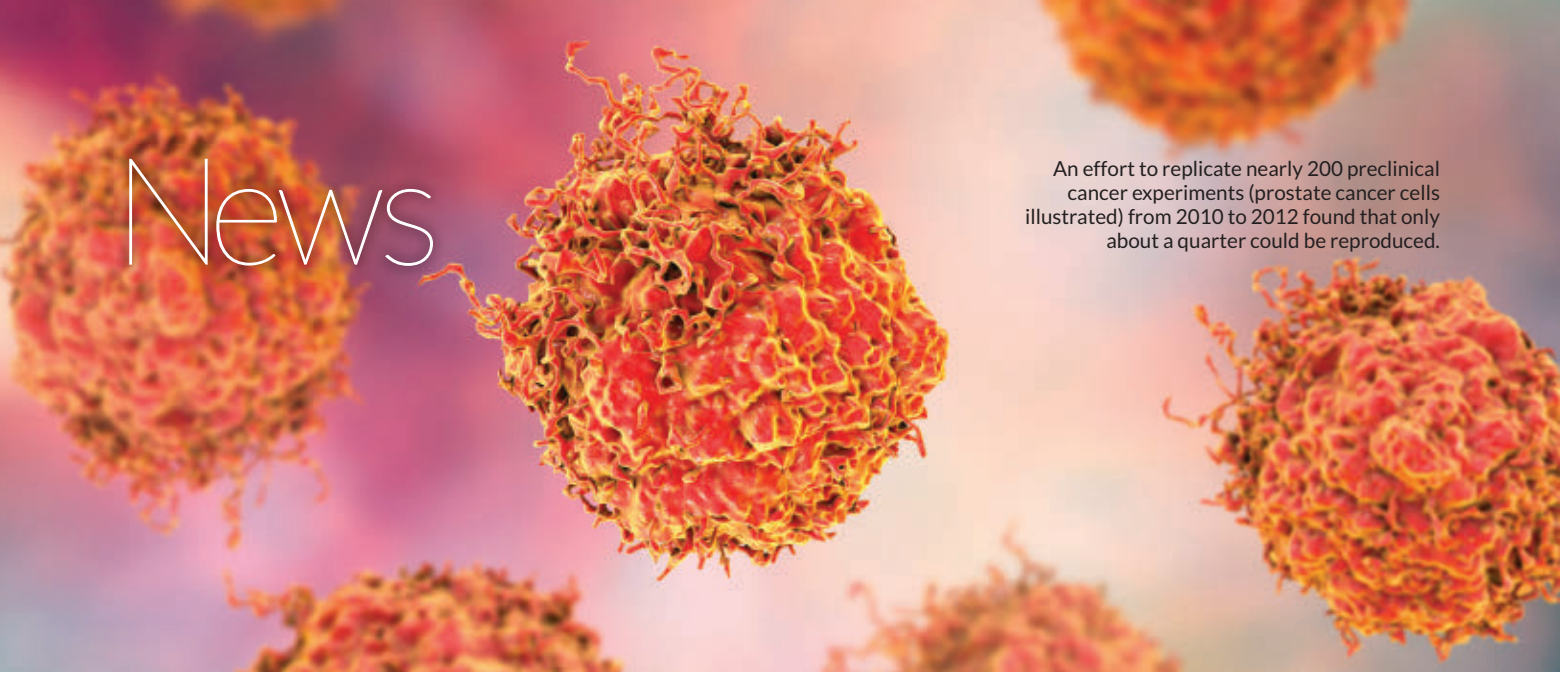
A species of ankylosaur (depicted in a 3-D model) uncovered in Chile had an odd, flat club on its tail.

INTRODUCING

New dinosaur had a weird weapon

A newly discovered ankylosaur had a bizarre club on its tail unlike that of any known dinosaur. With a flat surface and sharp blades along the sides, the structure at the back end of *Stegouros elengassen* strongly resembles an Aztec war club called a macuahuitl, scientists report in the Dec. 9 *Nature*. Paleontologist Sergio Soto-Acuña of the University of Chile in Santiago and colleagues identified *S. elengassen* based on a nearly complete skeleton from the Patagonian region of Chile. Slender limbs and a short tail set the creature apart from other ankylosaurs, the heavily armored tanks of the dinosaur world, but the skull pegged it as a primitive member of the group. *S. elengassen*, which lived between 72 million and 75 million years ago, and the few other known ankylosaurs from the Southern Hemisphere may make up a branch that split early in ankylosaur history, the team says. — *Carolyn Gramling*

FROM TOP: ENVIRONMENTAL SYSTEMS RESEARCH INSTITUTE; LUCAS JAYMEZ; SPP 1992 (PATRICIA KLEIN)



An effort to replicate nearly 200 preclinical cancer experiments (prostate cancer cells illustrated) from 2010 to 2012 found that only about a quarter could be reproduced.

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BODY & BRAIN

Many cancer studies can't be replicated

Unreliable preclinical research could impede drug development

BY TARA HAELLE

After eight years, a project that tried to reproduce the results of key cancer biology studies has finally concluded. And its findings suggest that like research in the social sciences, cancer research has a replication problem.

Researchers with the Reproducibility Project: Cancer Biology aimed to replicate 193 experiments from 53 top cancer papers published from 2010 to 2012. But only a quarter of those experiments were able to be reproduced, the team reports in two papers published December 7 in *eLife*.

The researchers couldn't complete the majority of experiments because the team couldn't gather enough information from the original papers or their authors about methods used, or obtain the necessary materials needed to attempt replication.

What's more, of the 50 experiments from 23 papers that were reproduced, effect sizes were, on average, 85 percent lower than those reported in the original experiments. Effect size indicates how big an effect found in a study is. For example, two studies might find that a certain chemical kills cancer cells, but the chemical kills 30 percent of cells in one experiment and 80 percent of cells in a different experiment. The first experiment has less than half the effect size seen in the second one.

The team determined if a replication was successful using five criteria. Four focused on effect sizes, and the fifth looked at whether both the original and the replicated experiments had similarly positive or negative results, and if both sets of results were statistically significant, meaning the difference was not likely due to chance. The team was able to apply those criteria to 112 tested effects from the experiments they could reproduce. Ultimately, just 46 percent, or 51 effects, met more criteria than they failed, the researchers report.

"The report tells us a lot about the culture and realities of the way cancer biology works, and it's not a flattering picture at all," says Jonathan Kimmelman, a bioethicist at McGill University in Montreal. He coauthored a commentary in *eLife* on the project exploring the ethical aspects of the findings.

It's worrisome if experiments that can't be reproduced are used to launch clinical trials or drug development efforts, Kimmelman says. If it turns out that the science on which a drug is based is not reliable, "it means that patients are needlessly exposed to drugs that are unsafe and that really don't even have a shot at making an impact on cancer," he says.

At the same time, he cautions against overinterpreting the findings as suggesting that the current cancer research system is broken. "We actually don't know how well the system is working," he says. One of the many questions left unresolved is what an appropriate rate of replication is in cancer research, since replicating all studies perfectly isn't possible. "That's a moral question," he says. "That's a policy question. That's not really a scientific question."

The project's overarching lessons suggest that substantial inefficiency in preclinical research may be hampering the drug development pipeline later on, says project leader Tim Errington. He is the director of research at the Center for Open Science in Charlottesville, Va., which cosponsored the research.

As many as 14 out of 15 cancer drugs that enter clinical trials never receive approval from the U.S. Food and Drug Administration. Sometimes that's because the drugs lack commercial potential, but more often it is because they do not show the level of safety and effectiveness needed for approval.

Much of that failure is expected. "We're humans trying to understand complex disease, we're never going to get it right," Errington says. But given the cancer reproducibility project's findings, perhaps "we should have known that we were failing earlier, or maybe we don't

understand actually what's causing [an] exciting finding," he says.

Still, it's not that failure to replicate means that a study was wrong or that replicating it means that the findings are correct, says Shirley Wang, an epidemiologist at Brigham and Women's Hospital in Boston and Harvard Medical School. "It just means that you're able to reproduce," she says, a point that the reproducibility project also stresses.

Scientists still have to evaluate whether a study's methods are unbiased and rigorous, says Wang, who was not involved in the project but reviewed its findings. And if the results of original experiments and their replications do differ, it's a learning opportunity to find out why and what the implications are, she adds.

Obstacles to replication

Errington and colleagues have reported on subsets of the cancer reproducibility project's findings before, but this is the first time that the effort's entire analysis has been released (*SN: 2/18/17, p. 10*).

During the project, the researchers faced a number of obstacles, particularly that none of the original experiments included enough details in their published papers about methods to attempt reproduction. So the reproducibility researchers contacted the studies' authors for additional information.

While authors for 41 percent of the experiments were extremely or very helpful, authors for another third of the experiments did not reply to requests for more information or were not otherwise helpful, the project found. For example, one of the experiments that the group was unable to replicate required the use of a mouse model specifically bred for the original experiment. Errington says that the scientists who conducted that work refused to share some of these mice with the reproducibility project, and without those rodents, replication was impossible.

Some researchers were outright hostile to the idea that independent scientists wanted to attempt to replicate their work, says Brian Nosek, executive director of the Center for Open Science and a coauthor of both studies in *eLife*. That attitude is a product of a research culture that values innovation over replication, and that prizes the academic publish-or-perish system over cooperation and data sharing, Nosek says.

> "If replication is normal and routine, people wouldn't see it as a threat."
>
> **BRIAN NOSEK**

Some scientists may feel threatened by replication because it is uncommon. "If replication is normal and routine, people wouldn't see it as a threat," Nosek says. But replication may also feel intimidating because scientists' livelihoods and even identities are often so deeply rooted in their findings, he says. "Publication is the currency of advancement, a key reward that turns into chances for funding, chances for a job and chances for keeping that job," Nosek says. "Replication doesn't fit neatly into that rewards system."

Even authors who wanted to help couldn't always share their data for various reasons, including lost hard drives or intellectual property restrictions or data that only former graduate students had.

Concerns about science's "reproducibility crisis" have been growing for years, perhaps most notably in psychology. Then in 2011 and 2012, pharmaceutical companies Bayer and Amgen reported difficulties in replicating findings from preclinical biomedical research.

But not everyone agrees on solutions, including whether replication of key experiments is actually useful or possible, or even what exactly is wrong with the way science is done or what needs to improve (*SN: 1/24/15, p. 20*).

At least one clear, actionable conclusion emerged from the new findings, says Yvette Seger, director of science policy at the Federation of American Societies for Experimental Biology. That's the need to provide scientists with as much opportunity as possible to explain exactly how they conducted their research.

"Scientists should aspire to include as much information about their experimental methods as possible to ensure understanding about results on the other side," says Seger, who was not involved in the reproducibility project.

Ultimately, if science is to be a self-correcting discipline, there needs to be plenty of opportunities not only for making mistakes but also for discovering them, including by replicating experiments, the project's researchers say.

"In general, the public understands science is hard, and I think the public also understands that science is going to make errors," Nosek says. "The concern is and should be, is science efficient at catching its errors?" The cancer project's findings don't necessarily answer that question, but they do highlight the challenges of trying to find out. ■

Much of the basic science research related to cancer is done on laboratory mice (one shown). But if the mice used in an experiment aren't available to other researchers, it's difficult or impossible to try to replicate the results of a study using those mice.

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HUMANS & SOCIETY

Lucy's kind had mysterious neighbors

Ancient footprints in Tanzania can't be tied to any known hominid

BY BRUCE BOWER

An individual from an enigmatic hominid species strode across a field of wet, volcanic ash in East Africa about 3.66 million years ago, leaving behind five footprints.

Those ancient impressions, largely ignored since their partial excavation at Tanzania's Laetoli site in 1976, show hallmarks of upright walking by a hominid, a study finds. Researchers had previously considered them hard to classify, possibly produced by a young bear that took a few steps while standing.

Nearby footprints unearthed at Laetoli in 1978 look more clearly like those of hominids and have been attributed to Lucy's species, *Australopithecus afarensis* (*SN: 1/21/17, p. 8*). The shape and positioning of the newly identified hominid footprints differ enough from *A. afarensis* to qualify as marks of a separate *Australopithecus* species, an international team reports December 1 in *Nature*.

"Different [hominid] species walked across this East African landscape at about the same time, each moving in different ways," says Ellison McNutt, a paleoanthropologist at Ohio University Heritage College of Osteopathic Medicine in Athens.

The species identity of the Laetoli printmaker is unknown.

A species dubbed *A. deyiremeda* lived near Lucy's crowd more than 3 million years ago, but no foot fossils or footprints of that species have been found to compare with the Laetoli finds (*SN: 6/27/15, p. 7*). And 3.4-million-year-old foot fossils from an unnamed East African hominid that had a grasping big toe and no arch, as well as the odd fossil feet of 4.4-million-year-old *Ardipithecus ramidus* aren't matches (*SN: 5/5/12, p. 18*; *SN: 3/27/21, p. 11*). So neither of those hominids could have made the prints, says McNutt, who started the research as a Dartmouth College graduate student supervised by paleoanthropologist Jeremy DeSilva.

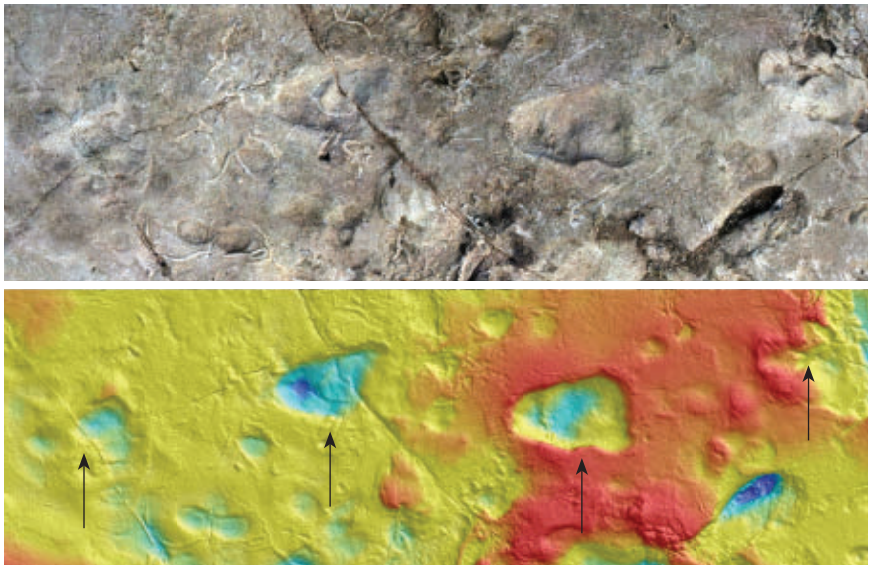
McNutt, DeSilva and colleagues excavated and cleaned the five footprints in June 2019, and then measured, photographed and 3-D scanned them. Print sizes indicate the impressions were made by a relatively short individual, possibly one that had not yet reached maturity.

The group focused on two consecutive footprints that were particularly well-preserved. Foot shapes, proportions and stride characteristics of the individual differ in various ways from those of *A. afarensis* individuals at the same site. The prints also don't match those from modern juvenile black bears and modern chimps walking upright; present-day East African Daasanach people who typically don't wear shoes; or preserved footprints of East African hunter-gatherers dating to between about 12,000 and 10,000 years ago (*SN: 6/20/20, p. 11*).

The Laetoli individual possessed a wider, more chimplike foot than *A. afarensis* or humans, the researchers say. Its big toe stuck out slightly from the second toe, but not to the degree observed in chimps. Signs of a balanced, upright gait in the ancient footprints resulted from humanlike knees positioned underneath the hips, humanlike hips oriented to stabilize a two-legged stride or both.

On one step, the Laetoli individual's left leg crossed in front of the right leg, leaving a left footprint directly in front of the previous impression. People may cross-step in this way when trying to regain balance. But McNutt's team doubts that the newly analyzed Laetoli footprints represent smudged impressions made by an *A. afarensis* individual that cross-stepped, perhaps to stay upright. That's in part because footprints of people walking as usual and then cross-stepping look largely the same, McNutt's team found. And bears and chimps assume a relatively wide stance due to knee and hip arrangements that prevent them from walking like the Laetoli individual and probably from cross-stepping, the scientists say.

Given that only two of the ancient footprints are complete enough to analyze thoroughly, the possibility that an ape other than a hominid made the impressions can't be ruled out, says William Harcourt-Smith, a paleoanthropologist at Lehman College and the American Museum of Natural History in New York City. But evidence of cross-stepping points to a hominid track maker, he says. ■



Scientists reanalyzed five footprints (four are shown in a photo, top, and in a 3-D contour map, bottom) discovered at Tanzania's Laetoli site in 1976. The work suggests that the prints were made by a hominid species that lived alongside Lucy's species around 3.66 million years ago.

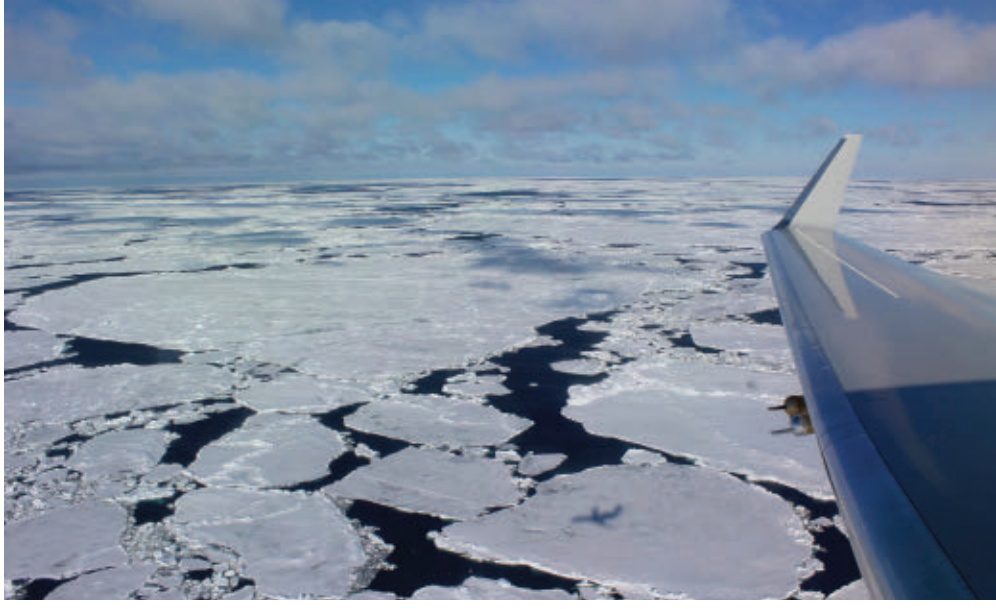
AUSTIN C. HILL, CATHERINE MILLER

EARTH & ENVIRONMENT

Southern Ocean may be a carbon sink after all

Study counters claim that the ocean is a carbon emitter

BY CAROLYN GRAMLING



Equipped with sensors to measure carbon dioxide in the atmosphere, airplanes flew over sea ice in the Southern Ocean (shown) in 2016 to measure how much CO_2 the water emitted.

REBECCA HORNBROOK/NCAR

The Southern Ocean is still absorbing large amounts of the carbon dioxide emitted by humans' fossil fuel burning, a new study suggests. The results counter a 2018 report that claimed that the ocean surrounding Antarctica might not be taking up as much of the emissions as previously thought, and in some regions, might actually be adding CO_2 to the atmosphere.

The news that the Southern Ocean is still absorbing the greenhouse gas is not exactly a reprieve for the planet. The oceans are already becoming more acidic and storing record-breaking amounts of heat due to global warming (*SN: 2/13/21, p. 5*). But "in many ways, [the conclusion] was reassuring," says Matthew Long, an oceanographer at the National Center for Atmospheric Research in Boulder, Colo.

Previously, scientists had thought that the Southern Ocean alone is responsible for nearly half of the global ocean uptake of humans' CO_2 emissions each year. The 2018 report, however, estimated that over the course of a year, the Southern Ocean was actually a net source of CO_2 rather than a sink, emitting about 300 million metric tons of the gas into the atmosphere annually.

In contrast, the new findings, published in the Dec. 3 *Science*, suggest that from 2009 through 2018, the Southern Ocean was still a net sink, taking up about 550 million metric tons of carbon, or almost 2 billion metric tons of CO_2, each year.

The differing conclusions come down to differences in how CO_2 was measured.

The 2018 study used newly deployed deep-diving ocean floats that are part of the Southern Ocean Carbon and Climate Observations and Modeling, or SOCCOM, project. Calculations based on data collected from 2014 through 2017 by 35 floats suggested that parts of the ocean were releasing a great deal of CO_2 during December, January and February (*SN: 6/8/19, p. 24*). The finding sparked concerns that the Southern Ocean is not the robust buffer of the impacts of climate change that people thought it was.

Long says he and other researchers were somewhat skeptical about that takeaway, however. The floats measure temperature, salinity and pH in the water down to about 2,000 meters, and scientists use those data to calculate the CO_2 concentration in the water. But those calculations rest on several assumptions about the water's properties, as actual data are scarce. That may skew the calculations a bit, leading to estimates of higher CO_2 emitted from the water than actually occurs, Long says.

Airborne measurements can help determine how much CO_2 is moving between air and sea. In the new study, Long and colleagues amassed CO_2 data collected over large swaths of the Southern Ocean during three series of aircraft flights — one series lasting from 2009 to 2011, one in early 2016 and a third in several periods from 2016 to 2018. The team used those data to create simulations of how much CO_2 could possibly be moving between the ocean and atmosphere each year.

The 2018 float-based and 2021 aircraft-based studies estimate different overall amounts of CO_2 moving out of the Southern Ocean, but both identified a seasonal pattern of less CO_2 absorbed from December through February. The commonality indicates that both types of data are picking up a real trend, says Ken Johnson, an author of the 2018 report and an ocean chemist at the Monterey Bay Aquarium Research Institute in Moss Landing, Calif.

It's not yet clear whether the SOCCOM findings were off. To better understand what sorts of biases might affect the calculations, researchers must compare direct measurements of CO_2 in the water taken from ships with pH-based calculations from the same location. Such studies are under way right now off the coast of California, Johnson says.

The big takeaway, he says, is that both datasets — as well as direct shipboard measurements of Southern Ocean chemistry, which are few and far between — will be essential for understanding what role these waters play in the carbon cycle. While the airborne studies can help scientists discern the big picture of CO_2 emissions from the Southern Ocean, the floats, now numbering more than 100, are more widely distributed, and thus able to identify local and regional CO_2 variability.

"The Southern Ocean is the flywheel of the climate system," the part of an engine's machinery that keeps things chugging along, Johnson says. "If we don't get our understanding of the Southern Ocean right, we don't have much hope for understanding the rest of the world." ■

GENES & CELLS

Living robots can self-replicate

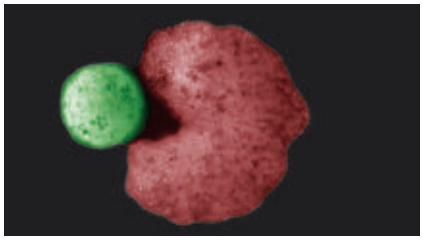
Blobs of frog cells exhibit surprising, complex behavior

BY LAURA SANDERS

Tiny "living machines" made of frog cells can replicate themselves, making copies that can then go on to do the same. This newly described form of renewal offers insights into how to design biological machines that are self-perpetuating.

"This is an incredibly exciting breakthrough," says Kirstin Petersen, an electrical and computer engineer at Cornell University. Robots that can copy themselves are an important step toward systems that don't need human operators, she says.

Last March, researchers described the behaviors of the lab-made living robots, called xenobots (*SN: 4/24/21, p. 8*). Plucked from frog embryos, small clumps of skin stem cells knitted themselves into small spheres and began to move. Cellular extensions called cilia served as motors that powered the xenobots as they cruised around lab dishes.



A microscopic xenobot "parent," shaped like a hungry Pac-Man (shown in red false color), created an "offspring" xenobot (green sphere) by gathering loose cells in its opening.

That cruising can have a bigger purpose, the team reports in the Dec. 7 *Proceedings of the National Academy of Sciences*. As xenobots bumble about, they can gather loose frog cells into spheres, which coalesce into new xenobots.

This type of movement-created reproduction, what the researchers call kinematic self-replication, appears to be new for living cells. Usually, organisms contribute some parental material to their offspring, says study coauthor Douglas Blackiston, a developmental biologist at Tufts University in Medford, Mass. Sexual reproduction, for instance, requires parental sperm and egg cells to get started. Other types of reproduction involve cells splitting or budding off from a parent.

"This is different," Blackiston says. Xenobots are "finding loose parts, sort of like robotics parts in the environment, and cobbling them together." Those collections grow into "a second generation of xenobots that can move around like their parents," Blackiston says.

Left to their own devices, spheroid xenobots could generally create only one more generation before dying out. But with the help of an artificial intelligence program that predicted an optimal shape for the original xenobots, the replication could be pushed to four generations.

The AI program predicted that a C shape, much like an openmouthed Pac-Man, would be a more efficient progenitor. Sure enough, when improved xenobots were let loose in a dish, they

EARTH & ENVIRONMENT

Wildfires may boost urban ozone levels

When smoke and city air pollution meet, toxic ozone can form

BY ARIANA REMMEL

Wildfire smoke and urban air pollution bring out the worst in each other.

Wildfires release a complex chemical cocktail of smoke. Many of these airborne compounds, including ozone, cause air quality to plummet as wind carries the haze over cities. But exactly how, and to what extent, wildfire emissions contribute to ozone levels downwind has been up for debate, says atmospheric scientist Joel Thornton of the University of Washington in Seattle.

A new study reveals the elusive chemistry behind ozone production in wildfire plumes. The findings suggest that mixing wildfire smoke with nitrogen oxides — toxic gases found in car exhaust — could pump up ozone levels, especially in urban areas, researchers report December 8 in *Science Advances*.

Atmospheric ozone is a major component of smog that can trigger respiratory problems. Many ingredients for making ozone — such as volatile organic compounds and nitrogen oxides — can be found in wildfire smoke, says Lu Xu, an atmospheric chemist at the National Oceanic and Atmospheric Administration's Chemical Sciences Laboratory in Boulder, Colo. But a list of ingredients isn't enough to replicate a wildfire's ozone recipe. So Xu and colleagues took to the sky to observe the chemistry in action.

Through a joint project with NASA and NOAA, the team worked with the Fire Influence on Regional to Global Environments and Air Quality flight campaign. In July and August 2019, a team aboard a jet collected air samples from smoldering landscapes across the western United States. As the plane passed through plumes, instruments recorded the amounts of each molecule detected. By weaving in and out of the smoke drifting downwind from the flames, the team analyzed how the chemical composition changed over time.

Using these measurements along with the wind patterns and fuel from each wildfire sampled, the researchers created an equation to calculate ozone production from wildfire emissions.

As expected, wildfire emissions contain a dizzying array of organic compounds and nitrogen oxide species, among other molecules that contribute to ozone formation. Yet the concentration of nitrogen oxides decreases in the daylight hours after the plume is swept downwind, and ozone production slows substantially.

Air pollution in urban areas is full of noxious gases. So when smoke wafts over cities, a boost of nitrogen oxides could jump-start ozone production, Xu says.

began scooping up loose cells into their gaping "mouths," forming more sphere-shaped bots. A mobile offspring took shape once about 50 cells had glommed together in a parent's opening, Blackiston says. A full-bodied xenobot consists of about 4,000 to 6,000 frog cells.

Xenobots' size is an advantage, Petersen says. "The fact that they were able to do this at such a small scale just makes it even better, because you can start to imagine biomedical application areas." Xenobots may be able to sculpt tissues for implantation or go inside bodies to deliver therapeutics to specific spots.

Beyond those possibilities, the research advances a science that has existential importance — that is, "the science of trying to anticipate and control the consequences of complex systems," says study coauthor Michael Levin, a developmental biologist at Tufts. "No one would have predicted any of this." With xenobots, researchers can push the limits of the unexpected, he says. "This is about a safe way to explore and advance the science of being less surprised by things." ■

In a typical fire season, mixes like these could increase ozone levels by roughly 3 parts per billion throughout the U.S. West, the researchers say. This concentration alone is far below the U.S. Environmental Protection Agency's health safety standard of 70 ppb, but the incremental increase could still pose a health risk to people who are regularly exposed to smoke, says Xu, who did the work while at Caltech.

With climate change increasing the frequency and intensity of wildfires, this ozone production mechanism has important implications for urban air quality, says Qi Zhang, an atmospheric chemist at the University of California, Davis who wasn't involved with the study.

The findings may pose a challenge for policy makers, says Thornton, who also wasn't involved. Even with strict regulations to limit atmospheric ozone, he says, wildfire smoke may make it more difficult for cities, especially in the West, to meet EPA ozone standards. ■

LIFE & EVOLUTION

Warming drives albatrosses to divorce

Climate change may increase partner breakups among the birds

BY RICHARD KEMENY

When it comes to fidelity, birds fit the bill: Over 90 percent of bird species are monogamous. Take albatrosses. The seabirds tend to stick with the same partner year after year. But when the ocean is warmer than usual, more couples split up.

Among albatrosses on the Falkland Islands, the divorce rate — typically less than 4 percent — rose to nearly 8 percent in a year when the water was unusually warm, researchers report in the Nov. 24 *Proceedings of the Royal Society B*. Higher instances of divorce in albatrosses and perhaps other monogamous animals may be "an overlooked consequence" of climate change, the researchers write.

Albatrosses sometimes spend years out on the ocean searching for food, returning to land only to breed. If breeding doesn't work out, many birds, mostly females, leave their partner. Breeding is more likely to fail in years with more difficult conditions, with knock-on effects on divorce rates the following years. But conservation biologist Francesco Ventura of the University of Lisbon in Portugal and colleagues wanted to see whether the environment has a direct impact on divorce, regardless of how breeding goes.

Ventura's team analyzed data collected from 2004 to 2019 on a colony of black-browed albatrosses (*Thalassarche melanophris*). The team recorded nearly 2,900 breeding attempts in 424 females and tracked breakups. Then, accounting for previous breeding success, the team checked to see if the environment had any noticeable further impact on pairings.

Breeding failure was the main cause of divorce: Birds whose eggs didn't hatch were over five times as likely to separate from their partner as birds whose chicks hatched and survived. In some years, the divorce rate was less than 1 percent. But this rate trended upward with average water temperature, reaching 7.7 percent in 2017, a particularly warm year. When temps dropped in 2018 and 2019, so did divorce rates. Females in successful pairs were more likely to divorce due to temperature than birds that didn't breed or whose eggs didn't hatch.

Warmer water means fewer nutrients, so some birds may be fueling up out at sea for longer, delaying their return to land. If members of pairs return at different times, breakups can occur. And bad conditions might raise stress-related hormones. A bird may attribute the stress to its partner, rather than the harsher environment, and separate even if hatching was successful, the researchers say.

Such misreading between cues and reality could make separation a less-effective behavior, says Antica Culina, an evolutionary ecologist at the Netherlands Institute of Ecology in Wageningen. If animals divorce for the wrong reason and do worse the next season, that can lead to lower breeding success overall and possibly population decline. ■

Albatrosses are monogamous, but new evidence suggests that breeding success isn't always enough to keep some couples together.

F. VENTURA

NASA's Ingenuity helicopter (shown in the foreground of this artist's illustration) is now helping the Perseverance rover (background) scout driving routes and pick out areas for further study on Mars.

JPL-CALTECH/NASA

ATOM & COSMOS

Ingenuity's Mars flight plan extended

The NASA helicopter is pushing limits and doing science

BY LISA GROSSMAN

The Ingenuity Mars helicopter was never supposed to last so long. NASA engineers built and tested the first self-powered aircraft to fly on another planet to answer a simple question: Could the helicopter fly at all? The goal was to take five flights in 30 Martian days or break the aircraft trying.

By mid-December, over 200 Martian days past that experiment window, Ingenuity was still flying and doing things no one ever expected. The helicopter, which took its first flight on April 19, has broken its own records for distance and speed, and navigated changing seasons — something it wasn't designed to do. More importantly, it has helped the Perseverance rover explore Jezero crater, near an ancient river delta that may hold signs of past Martian life.

"It's gotten into a good groove," says Ingenuity's original chief engineer Bob Balaram of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "It's in its element and having fun."

Ingenuity has lifted itself a maximum of 12 meters above the Martian surface, zipped along at up to 5 meters per second (about half as fast as record-setting sprinter Florence Griffith-Joyner) and in a single flight covered 625 meters (roughly a third the length of the Kentucky Derby). These extremes give engineers valuable information about the limits of flying on Mars.

"Flight after flight, we're learning the boundaries of performance," says Teddy Tzanetos, a robotics engineer at the Jet Propulsion Lab and a team leader for the Ingenuity mission.

Early on, Ingenuity tested its limits in a way that the flight team didn't plan for. During the helicopter's sixth flight, on May 22, its navigation system suffered a glitch that made Ingenuity roll and sway.

The helicopter's navigation software keeps track of the craft's position by taking an image, reading the time stamp on that image and predicting what the cameras should see next based on landmarks from previous photos. If the next image doesn't match that prediction, the software corrects the helicopter's position and velocity to match up better.

Less than a minute into the May 22 flight, a single image got lost on its way from Ingenuity's cameras to the helicopter's onboard computer. That meant that the time stamps on all subsequent images were slightly off. In trying to correct the perceived errors, Ingenuity "went on a wild joyride," Balaram says.

Luckily, the helicopter touched down safely within five meters of its intended landing spot. The anomaly was a blessing in disguise, Balaram says. It put the helicopter through extremes of movement that the engineers would not have asked it to do on purpose, and did perfectly fine, he says.

"It's a serendipitous thing that we got that flight experience under our belt," Balaram says. "We have much more confidence in the vehicle."

Originally, the helicopter team wanted to push the vehicle until it broke. But now the researchers are flying more cautiously and less often. That's because the helicopter is supporting the Perseverance rover in doing science. "We're a small part of a much larger team," Tzanetos says.

The helicopter has already proven its worth by telling the rover where not to go. Ingenuity's ninth flight, on July 5, took the helicopter over a dune field called South Séítah that would have been difficult for the rover to drive through safely. There, Ingenuity photographed rock outcrops and raised ridges that had looked interesting in images taken from an orbiting spacecraft. Scientists thought those ridges could record details of the deepest water environments in the lake that filled the crater long ago.

In 3-D images from the helicopter, those ridges did not show the layers that would have indicated that the rocks formed in deep water. The rover team decided to move on, saving Perseverance

a long and potentially dangerous drive.

The Mars duo's next task is a race to the long-dry river delta at the mouth of Jezero crater. The Perseverance team hopes to cover hundreds of meters each Martian day. But with the planet's notoriously thin air getting even thinner in the crater as the season changes from spring to summer (*SN: 7/4/20 & 7/18/20, p. 24*), it'll be challenging for Ingenuity to keep up, Tzanetos says.

Since mid-September, air density in the crater has gone from about 1.5 percent of Earth's at sea level to less than 1 percent. That's enough of a difference that Ingenuity has had to spin its rotor blades faster to stay aloft. In October, the helicopter increased its rotor speed to 2,700 revolutions per minute, compared with a previous maximum of 2,537 rpm.

At that faster spin speed, the helicopter can fly for only 130 seconds at a time instead of the 170 seconds it managed before, without running the risk of the motors overheating.

There's no technical reason why Ingenuity can't make the trip, though, Balaram says. "It's certainly possible that one day it just won't wake up. Or a landing will be a failure and we'll never hear from it again because it tipped over," he admits. "Those are rolls of the dice," and none are inevitable. Ingenuity "should keep working for many months," he says.

Meanwhile, engineers are already dreaming of the next Martian aircraft. Current blueprints include a scaled-up version of Ingenuity that could carry more equipment and work alone or with a rover, and a large hexacopter with six rotors arranged around a central ring. A craft like that could cover more ground more quickly than a rover, traveling distances in just a few months that would take Perseverance years to cover.

A white paper submitted to the 2023–2032 planetary science and astrobiology decadal survey — a review of the fields' goals and priorities — suggests several possible missions for a Mars Science Helicopter. In one, the craft could take samples of clay minerals at a site like Mawrth Vallis, a channel thought to be carved by a long-ago flood. Clays can preserve organic material on Earth, so a mission to Mawrth could search for signs of life.

A helicopter could also explore craters with water ice deposits with slopes too steep for rover wheels. And by taking measurements at several altitudes, the helicopter could help figure out how the atmosphere exchanges gases with the ground, which could help solve the mystery of when and how Mars lost its liquid water (*SN: 12/5/20, p. 14*). Or a helicopter could map the magnetic field of large swaths of the Martian surface, revealing when and how the Red Planet lost its molten core.

And whenever astronauts get around to visiting Mars, "it might be useful to have fleets of drones zipping around the skies, carrying loads or scouting ahead," Tzanetos says. "That's the exciting future I'm looking forward to." ■

GENES & CELLS

Viruses can help disarm bacteria

Evolving to evade a virus made some bacteria less virulent

BY ERIN GARCIA DE JESÚS

When some bacteria manage to escape being killed by a virus, the short-term gain may be a long-term weakness that researchers could use to fight bacterial infections.

Shigella flexneri, one cause of the disease shigellosis, is a bacterium that can spread within cells that line the gut by propelling itself through the cells' barriers. The resulting tissue damage can lead to symptoms like bloody diarrhea. But when *S. flexneri* in lab dishes evolved to elude a type of bacteria-killing virus, the bacterium couldn't spread cell to cell anymore, making it less virulent, researchers report November 17 in *Applied and Environmental Microbiology*.

The research is a hopeful sign for what's known as phage therapy (*SN: 6/3/00, p. 358*). With antibiotic-resistant microbes on the rise, some researchers see viruses that infect and kill only bacteria, known as bacteriophages or just phages, as a potential option to treat antibiotic-resistant infections. With phage therapy, infected people are given doses of a particular phage, which kill off the problematic bacteria. The problem, though, is that over time, those bacteria can evolve to be resistant to the phage too.

"We're kind of expecting phage therapy to fail, in a sense," says Paul Turner, an evolutionary biologist and virologist at Yale University. "Bacteria are very good at evolving resistance to phages."

But that doesn't mean the bacteria emerge unscathed. Some phages attack and enter bacteria by latching onto bacterial proteins crucial for a microbe's function. If phage therapy treatments relied on such a virus, that could push the bacteria to evolve over time in such a way that not only helps them escape the virus but also impairs their abilities and makes them less deadly. People infected with these altered bacteria might have less severe symptoms or may not show symptoms at all.

Some researchers see viruses that infect and kill only bacteria as a potential option to treat antibiotic-resistant infections.

Previous studies with *Pseudomonas aeruginosa* bacteria, for instance, have found that phages and bacteria can engage in evolutionary battles that drive the bacteria to be more sensitive to antibiotics. The new study hints that researchers could leverage the arms race between *S. flexneri* and a newly identified phage called A1-1, discovered in Mexican wastewater, to treat shigellosis.

S. flexneri in contaminated water is a huge problem in parts of the world where clean water isn't always available, such as sub-Saharan Africa and southern Asia, says Kaitlyn Kortright, a microbiologist also at Yale. In 2016, roughly 212,000 people died from shigellosis, which is caused by four *Shigella* species. More than a quarter of those deaths were in children younger than 5 years old. What's more, antibiotics to treat shigellosis can be expensive and hard to get in those places. And *S. flexneri* is becoming resistant to many antibiotics. Phage therapy could be a cheaper, more accessible option to treat the infection.

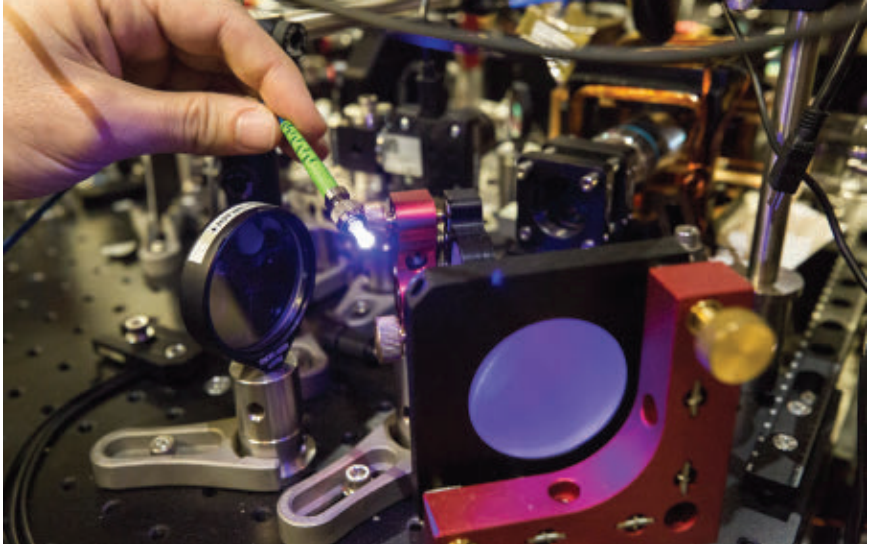
The blow to cellular spread comes because A1-1 targets a protein called OmpA, which *S. flexneri* relies on to rupture host cell membranes. The researchers found two types of mutations that made *S. flexneri* resistant to A1-1. Some bacteria had mutations in the gene that encodes the instructions for OmpA, damaging the protein's ability to help the bacteria spread from cell to cell. Other bacteria had changes to a structural component of bacterial cells called lipopolysaccharide.

The mutations in lipopolysaccharide were surprising, Kortright says, because the relationship between that structural component and OmpA isn't fully worked out. One possibility is that those mutations distort OmpA's structure in a way that the phage no longer recognizes it and can't enter bacterial cells.

One lingering question is whether *S. flexneri* evolves in the same way outside of a lab dish, says Saima Aslam, an infectious diseases physician at the University of California, San Diego. Still, the findings show that it's "not always a bad thing" when bacteria become phage-resistant, she says. ■

When bacteria evolve to become resistant to bacteria-killing viruses known as bacteriophages (several illustrated attacking a bacterium), it doesn't always end well for the bacteria.

KATERYNA KON/SCIENCE PHOTO LIBRARY/GETTY IMAGES PLUS



JON CHASE/HARVARD STAFF PHOTOGRAPHER

Physicists used lasers (one shown) to trap rubidium atoms in a quantum simulator, coaxing them to act like a strange substance called a quantum spin liquid.

MATTER & ENERGY

Elusive form of matter comes into view

Ultracold atoms exhibit the properties of a quantum spin liquid

BY EMILY CONOVER

An elusive form of matter called a quantum spin liquid isn't a liquid, and it doesn't spin — but it sure is quantum.

Predicted nearly 50 years ago, quantum spin liquids have long evaded definitive detection in the laboratory. But now, a lattice of ultracold atoms held in place with lasers has shown hallmarks of the long-sought form of matter, researchers report in the Dec. 3 *Science*.

Quantum entanglement goes into overdrive in the newly fashioned material. Even atoms on opposite sides of the lattice share entanglement, or quantum links, meaning that the properties of distant atoms are correlated with one another. "It's very, very entangled," says physicist Giulia Semeghini of Harvard University, a coauthor of the new study. "If you pick any two points of your system, they are connected to each other through this huge entanglement." This strong, long-range entanglement could prove useful for building quantum computers, the researchers say.

The new material matches predictions for a quantum spin liquid, though its makeup strays a bit from conventional expectations. While the traditional idea of a quantum spin liquid relies on the quantum property of "spin," which gives atoms magnetic fields, the new material is based on different atomic quirks.

A standard quantum spin liquid should arise among atoms whose spins are in conflict. Spin causes atoms to act as tiny magnets. Normally, at low temperatures, those atoms would align their magnetic poles in a regular pattern. For example, if one atom points up, its neighbors point down. But if atoms are arranged in a triangle, for example, each atom has two neighbors that themselves point in opposite directions. That arrangement leaves the third one with nowhere to turn — it can't oppose both of its neighbors at once.

So atoms in quantum spin liquids refuse to choose. Instead, the atoms wind up in a superposition, a quantum combination of spin up and down, and each atom's state is linked with those of its compatriots. The atoms are constantly fluctuating and never settle down into an orderly arrangement of spins. This is similar to how atoms in a normal liquid are scattered about rather than arranged in a regularly repeating pattern, hence the name.

Conclusive evidence of quantum spin liquids has been hard to come by in solid materials. In the new study, the researchers took a different tack: They created an artificial material composed of 219 trapped rubidium atoms cooled to a temperature of about 10 microkelvins (about −273.15° Celsius). The array of atoms, known as a programmable quantum simulator, allows scientists to fine-tune how atoms interact to investigate exotic forms of quantum matter.

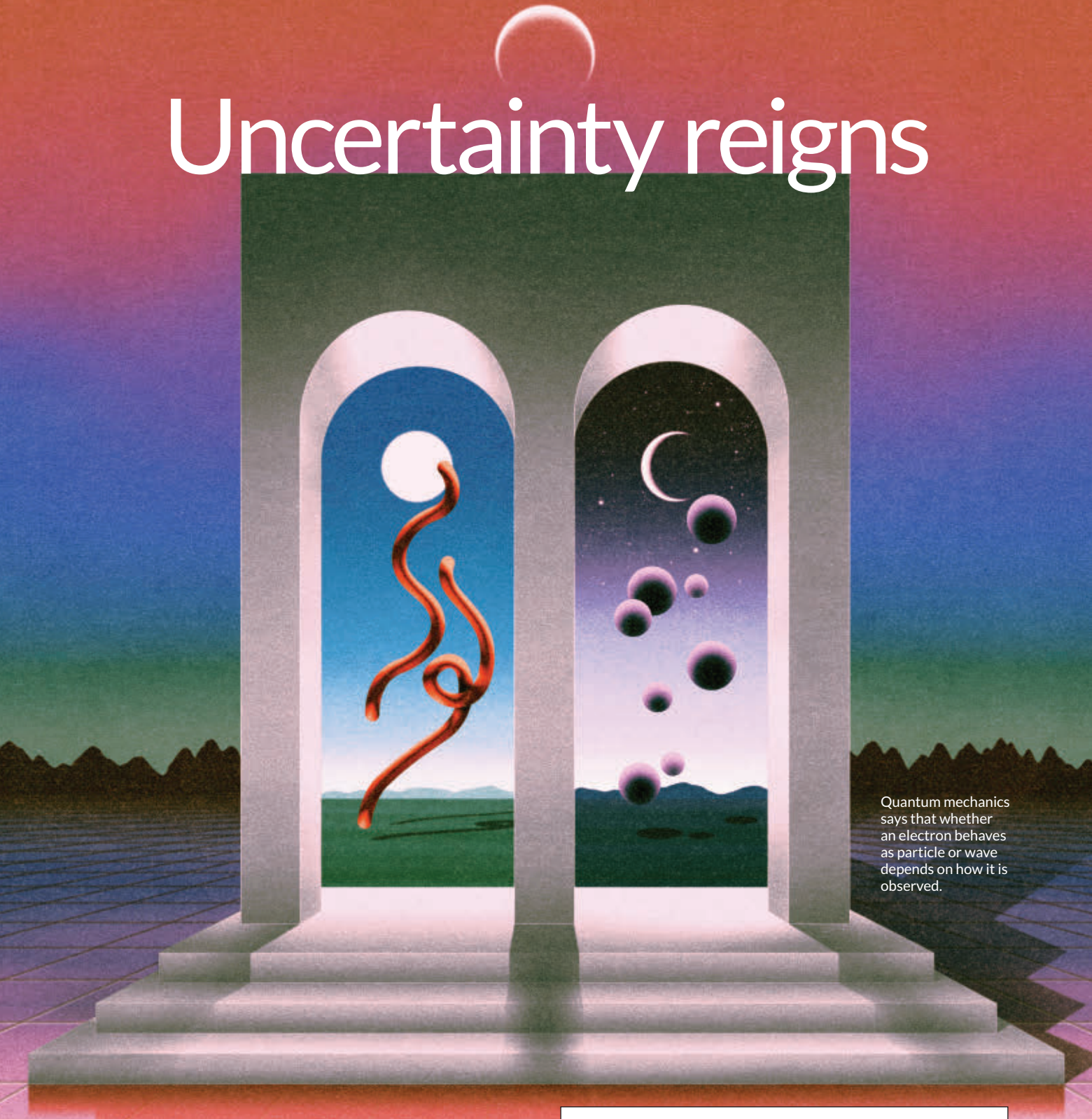
In the experiment, rather than the atoms' spins being in opposition, a different property created disagreement. The researchers used lasers to put the atoms into Rydberg states, meaning one of an atom's electrons is bumped to a very high energy level (*SN: 10/1/16, p. 7*). If one atom is in a Rydberg state, its neighbors prefer not to be. That setup begets a Rydberg-or-not discord, analogous to the spin-up and -down battle in a traditional quantum spin liquid.

The scientists confirmed the quantum spin liquid effect by studying the properties of atoms that fell along loops traced through the material. According to quantum math, those atoms should exhibit certain properties unique to quantum spin liquids. The results matched expectations for a quantum spin liquid and revealed that long-range entanglement was present.

Notably, the material's entanglement is topological. That means it is described by a branch of mathematics called topology, in which an object is defined by certain geometrical properties, for example, its number of holes (*SN: 10/29/16, p. 6*). Topology can protect information from being destroyed: A bagel that falls off the counter will still have exactly one hole, for example. This information-preserving feature could be a boon to quantum computers, which must grapple with fragile, easily destroyed quantum information that makes calculations subject to mistakes (*SN: 6/20/20, p. 18*).

Whether the material truly qualifies as a quantum spin liquid, despite not being based on spin, depends on your choice of language, says theoretical physicist Christopher Laumann of Boston University, who was not involved with the study. Some physicists use the term "spin" to describe other systems with two possible options, because they have the same mathematics as atomic spins that can point either up or down. "Words have meaning, until they don't," he quips. It all depends how you spin them. ■

Uncertainty reigns



Quantum mechanics says that whether an electron behaves as particle or wave depends on how it is observed.

ScienceNews 100

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A century after the quantum revolution, the nature of reality is still a mystery

By Tom Siegfried

Scientists are like prospectors, excavating the natural world seeking gems of knowledge about physical reality. And in the century just past, scientists have dug deep enough to discover that reality's foundations do not mirror the world of everyday appearances. At its roots, reality is described by the mysterious set of mathematical rules known as quantum mechanics.

Conceived at the turn of the 20th century and then emerging in its full form in the mid-1920s, quantum mechanics is the math that explains matter. It's the theory for describing the physics of the microworld, where atoms and molecules interact to generate the world of human experience. And it's at the heart of everything that made the century just past so dramatically unlike the century preceding it. From cell phones to supercomputers, DVDs to pdfs, quantum physics fueled the present-day electronics-based economy, transforming commerce, communication and entertainment.

But quantum theory taught scientists much more than how to make computer chips. It taught that reality isn't what it seems.

"The fundamental nature of reality could be radically different from our familiar world of objects moving around in space and interacting with each other," physicist Sean Carroll suggested in a recent tweet. "We shouldn't fool ourselves into mistaking the world as we experience it for the world as it really is."

In a technical paper backing up his tweet, Carroll notes that quantum theory consists of equations that describe mathematical entities roaming through an abstract realm of possible natural events. It's plausible, Carroll argues, that this quantum realm of mathematical possibilities represents the true, fundamental nature of reality. If so, all the physical phenomena we perceive are just a "higher-level emergent description" of what's really going on.

"Emergent" events in ordinary space are real in their own way, just not fundamental, Carroll allows. Belief that the "spatial arena" is fundamental "is more a matter of convenience and convention than one of principle," he says.

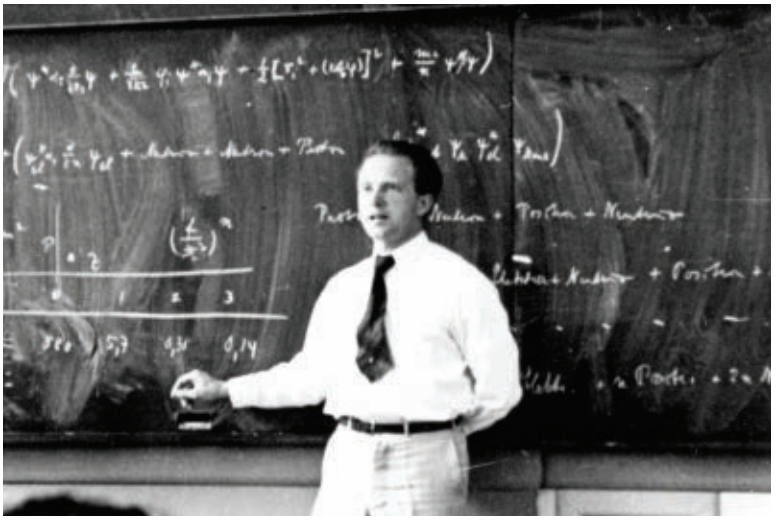
Carroll's perspective is not the only way of viewing the meaning of quantum math, he acknowledges, and it is not fully shared by most physicists. But everybody does agree that quantum physics has drastically remodeled humankind's understanding of nature. In fact, a fair reading of history suggests that quantum theory is the most dramatic shift in science's conception of reality since the ancient Greeks deposed mythological explanations of natural phenomena in favor of logic and reason. After all, quantum physics itself seems to defy logic and reason.

It doesn't, of course. Quantum theory represents the ultimate outcome of superior logical reasoning, arriving at truths that could never be discovered merely by observing the visible world.

It turns out that in the microworld — beyond the reach of the senses — phenomena play a game with fantastical rules. Matter's basic particles are not tiny rocks, but more like ghostly waves that maintain multiple possible futures until forced to assume the subatomic equivalent of substance. As a result, quantum math does not describe a relentless cause-and-effect sequence of events as Newtonian science had insisted. Instead science morphs from dictator to oddsmaker; quantum math tells only probabilities for different possible outcomes. Some uncertainty always remains.

The quantum revolution

The discovery of quantum uncertainty was what first impressed the world with the depth of the quantum revolution. German physicist Werner Heisenberg, in 1927, astounded the scientific community with the revelation that deterministic cause-and-effect physics failed when applied to atoms. It was impossible, Heisenberg deduced,



Werner Heisenberg, shown in 1936, declared with his uncertainty principle that a particle's position and velocity couldn't both be precisely measured at the same time.

OPPOSITE PAGE: MAX LÖFFLER; THIS PAGE: AIP EMILIO SEGRÈ VISUAL ARCHIVES

to measure both the location and velocity of a subatomic particle at the same time. If you measured one precisely, some uncertainty remained for the other.

"A particle may have an exact place or an exact speed, but it can not have both," as *Science News Letter*, the predecessor of *Science News*, reported in 1929. "Crudely stated, the new theory holds that chance rules the physical world." Heisenberg's uncertainty principle "is destined to revolutionize the ideas of the universe held by scientists and laymen to an even greater extent than Einstein's relativity."

Heisenberg's breakthrough was the culmination of a series of quantum surprises. First came German physicist Max Planck's discovery, in 1900, that light and other forms of radiation could be absorbed or emitted only in discrete packets, which Planck called quanta. A few years later Albert Einstein argued that light also traveled through space as packets, or particles, later called photons. Many physicists dismissed such early quantum clues as inconsequential. But in 1913, the Danish physicist Niels Bohr used quantum theory to explain the structure of the atom. Soon the world realized that reality needed reexamining.

By 1921, awareness of the quantum revolution had begun to expand beyond the confines of physics conferences. In that year, *Science News Bulletin*, the first iteration of *Science News*, distributed what was "believed to be the first popular explanation" of the quantum theory of radiation, provided by American physical chemist William D. Harkins. He proclaimed that the quantum theory "is of much more practical importance" than the theory of relativity.

"Since it concerns itself with the relations between matter and radiation," Harkins wrote, quantum theory "is of fundamental significance in connection with almost all processes which we know." Electricity, chemical reactions and how matter responds to heat all require quantum-theoretic explanations.

> Quantum theory "is of fundamental significance in connection with almost all processes which we know."
>
> **WILLIAM D. HARKINS**

As for atoms, traditional physics asserts that atoms and their parts can move about "in a large number of different ways," Harkins stated. But quantum theory maintains that "of all the states of motion (or ways of moving) prescribed by the older theory, only a certain number actually do occur." Therefore, events previously believed "to occur as continuous processes, actually do occur in steps."

But in 1921 quantum physics remained embryonic. Some of its implications had been discerned, but its full form remained undeveloped in detail. It was Heisenberg, in 1925, who first transformed the puzzling jumble of clues into a coherent mathematical picture. His decisive advance was developing a way to represent the energies of electrons in atoms using matrix algebra. With aid from German physicists Max Born and Pascual Jordan, Heisenberg's math became known as matrix mechanics. Shortly thereafter, Austrian physicist Erwin Schrödinger developed a competing equation for electron energies, viewing the supposed particles as waves described by a mathematical wave function. Schrödinger's "wave mechanics" turned out to be mathematically equivalent to Heisenberg's particle-based approach, and "quantum mechanics" became the general term for the math describing all subatomic systems.

Still, some confusion remained. It wasn't clear how an approach picturing electrons as particles could be equivalent to one supposing electrons to be waves. Bohr, by then regarded as the foremost of the world's atomic physicists, pondered the question deeply and by 1927 arrived at a novel viewpoint he called complementarity.

Bohr argued that the particle and wave views were complementary; both were necessary for a full description of subatomic phenomena. Whether a "particle" — say, an electron — exhibited its wave

Niels Bohr and Albert Einstein disagreed over the nature of reality.

PHOTOGRAPH BY PAUL EHRENFEST, COURTESY OF AIP EMILIO SEGRÈ VISUAL ARCHIVES, GAMOW COLLECTION

or particle nature depended on the experimental setup observing it. An apparatus designed to find a particle would find a particle; an apparatus geared to detect wave behavior would find a wave.

At about the same time, Heisenberg derived his uncertainty principle. Just as wave and particle could not be observed in the same experiment, position and velocity could not both be precisely measured at the same time. As physicist Wolfgang Pauli commented, "Now it becomes day in quantum theory."

But the quantum adventure was really just beginning.

A great debate

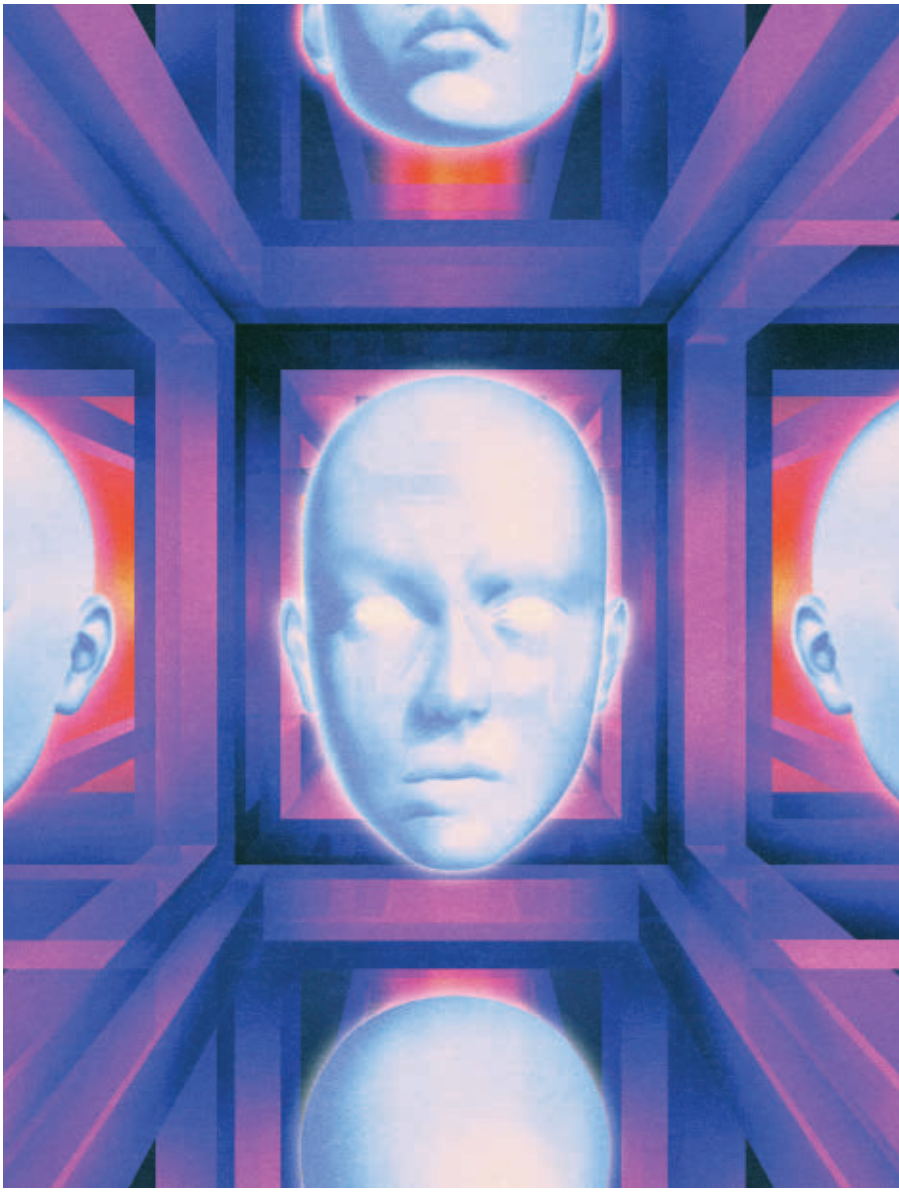
Many physicists, Einstein among them, deplored the implications of Heisenberg's uncertainty principle. Its introduction in 1927 eliminated the possibility of precisely predicting the outcomes of atomic observations. As Born had shown, you could merely predict the probabilities for the various possible outcomes, using calculations informed by the wave function that Schrödinger had introduced. Einstein famously retorted that he could not believe that God would play dice with the universe. Even worse, in Einstein's view, the wave-particle duality described by Bohr implied that a physicist could affect reality by deciding what kind of measurement to make. Surely, Einstein believed, reality existed independently of human observations.

On that point, Bohr engaged Einstein in a series of discussions that came to be known as the Bohr-Einstein debate, a continuing dialog that came to a head in 1935. In that year, Einstein, with collaborators Nathan Rosen and Boris Podolsky, described a thought experiment supposedly showing that quantum mechanics could not be a complete theory of reality.

In a brief summary in *Science News Letter* in May 1935, Podolsky explained that a complete theory must include a mathematical "counterpart for every element of the physical world." In other words, there should be a quantum wave function for the properties of every physical system. Yet if two physical systems, each described by a wave function, interact and then fly apart, "quantum mechanics ... does not enable us to calculate the wave function of each physical system after the separation." (In technical terms, the two systems become "entangled," a term coined by Schrödinger.) So quantum math cannot describe all elements of reality and is therefore incomplete.

Bohr soon responded, as reported in *Science News Letter* in August 1935. He declared that Einstein and colleagues' criterion for physical reality was ambiguous in quantum systems. Einstein, Podolsky and Rosen assumed that a system (say an electron) possessed definite values for certain properties (such as its momentum) before those values were measured. Quantum mechanics, Bohr explained, preserved different possible values for a particle's properties until one of them was measured. You could not assume the existence of an "element of reality" without specifying an experiment to measure it.

Einstein did not relent. He acknowledged that the uncertainty principle was correct with respect to what was observable in nature, but insisted that some invisible aspect of reality nevertheless



In the many worlds interpretation of quantum mechanics, all possible realities exist, but humans perceive just one.

MAX LÖFFLER

determined the course of physical events. In the early 1950s physicist David Bohm developed such a theory of "hidden variables" that restored determinism to quantum physics, but made no predictions that differed from the standard quantum mechanics math. Einstein was not impressed with Bohm's effort. "That way seems too cheap to me," Einstein wrote to Born, a lifelong friend.

Einstein died in 1955, Bohr in 1962, neither conceding to the other. In any case it seemed like an irresolvable dispute, since experiments would give the same results either way. But in 1964, physicist John Stewart Bell deduced a clever theorem about entangled particles, enabling experiments to probe the possibility of hidden variables. Beginning in the 1970s, and continuing to today, experiment after experiment confirmed the standard quantum mechanical predictions. Einstein's objection was overruled by the court of nature.

Still, many physicists expressed discomfort with Bohr's view (commonly referred to as the Copenhagen interpretation of quantum mechanics). One particularly dramatic challenge came from the physicist Hugh Everett III in 1957. He insisted that an experiment did not create one reality from the many quantum possibilities, but rather identified only one branch of reality. All the other experimental possibilities existed on other branches, all equally real. Humans perceive only their own particular branch, unaware of the others just as they are unaware of the rotation of the Earth. This "many worlds interpretation" was widely ignored at first but became popular decades later, with many adherents today.

Since Everett's work, numerous other interpretations of quantum theory have been offered. Some emphasize the "reality" of the wave function, the mathematical expression used for predicting the odds of different possibilities. Others emphasize the role of the math as describing the knowledge about reality accessible to experimenters.

Some interpretations attempt to reconcile the many worlds view with the fact that humans perceive only one reality. In the 1980s, physicists including H. Dieter Zeh and Wojciech Zurek identified the importance of a quantum system's interaction with its external environment, a process called quantum decoherence. Some of a particle's many possible realities rapidly evaporate as it encounters matter and radiation in its vicinity. Soon only one of the possible realities remains consistent with all the environmental interactions, explaining why on the human scale of time and size only one such reality is perceived.

This insight spawned the "consistent histories" interpretation, pioneered by Robert Griffiths and developed in more elaborate form by Murray Gell-Mann and James Hartle. It is widely known among physicists but has received little wider popularity and has not deterred the pursuit of other interpretations. Scientists continue to grapple with what quantum math means for the very nature of reality.

Using principles of quantum information theory, a particle's quantum state can be replicated at a distant location, a feat known as quantum teleportation.

MAX LÖFFLER

It from quantum bit

In the 1990s, the quest for quantum clarity took a new turn with the rise of quantum information theory. Physicist John Archibald Wheeler, a disciple of Bohr, had long emphasized that specific realities emerged from the fog of quantum possibilities by irreversible amplifications — such as an electron definitely establishing its location by leaving a mark after hitting a detector. Wheeler

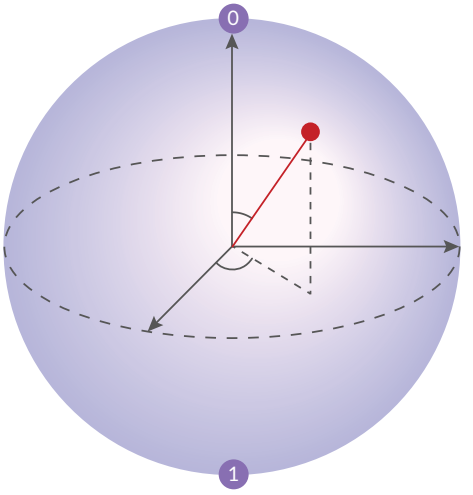
suggested that reality as a whole could be built up from such processes, which he compared to yes or no questions — is the electron here? Answers corresponded to bits of information, the 1s and 0s used by computers. Wheeler coined the slogan "it from bit" to describe the link between existence and information.

Taking the analogy further, one of Wheeler's former students, Benjamin Schumacher, devised the notion of a quantum version of the classical bit of information. He introduced the quantum bit, or qubit, at a conference in Dallas in 1992.

Schumacher's qubit provided a basis for building computers that could process quantum information. Such "quantum computers" had previously been envisioned, in different ways, by physicists Paul Benioff, Richard Feynman and David Deutsch. In 1994, mathematician Peter Shor showed how a quantum computer manipulating qubits could crack the toughest secret codes, launching a quest to design and build quantum computers capable of that and other clever computing feats. By the early 21st century, rudimentary quantum computers had been built; the latest versions can perform some computing tasks but are not powerful enough yet to make current cryptography methods obsolete. For certain types of problems, though, quantum computing may soon achieve superiority over standard computers.

Quantum computing's realization has not resolved the debate over quantum interpretations. Deutsch believed that quantum computers would support the many worlds view. Hardly anyone else agrees, though. And decades of quantum experiments have not provided any support for novel interpretations — all the results comply with the traditional quantum mechanics expectations. Quantum systems preserve different values for certain properties until one is measured, just as Bohr insisted. But nobody is completely satisfied, perhaps because the 20th century's other pillar of fundamental physics, Einstein's theory of gravity (general relativity), does not fit in quantum theory's framework.

For decades now, the quest for a quantum theory of gravity has fallen short of success, despite many promising ideas. Most recently a new approach suggests that the geometry of spacetime, the source of gravity in Einstein's theory, may in some way be built from the entanglement of quantum entities. If so, the mysterious behavior of the quantum world defies understanding in terms of ordinary events in space and time because quantum reality creates spacetime, rather than occupying it. If so, human observers witness an artificial, emergent reality that gives the impression of events happening in space and time while the true, inaccessible reality doesn't have to play by the spacetime rules.



A new unit of info
Benjamin Schumacher introduced the quantum bit, or qubit, in 1992, which offers a foundation for quantum computing. The qubit can exist as both a 0 and 1. When the qubit is represented on a sphere, the angles formed by the radius to the point on the sphere determine the odds of measuring a 0 or 1.

In a crude way this view echoes that of Parmenides, the ancient Greek philosopher who taught that all change is an illusion. Our senses show us the "way of seeming," Parmenides declared; only logic and reason can reveal "the way of truth." Parmenides didn't reach that insight by doing the math, of course (he said it was explained to him by a goddess). But he was a crucial figure in the history of science, initiating the use of rigorous deductive reasoning and relying on it even when it led to conclusions that defied sensory experience.

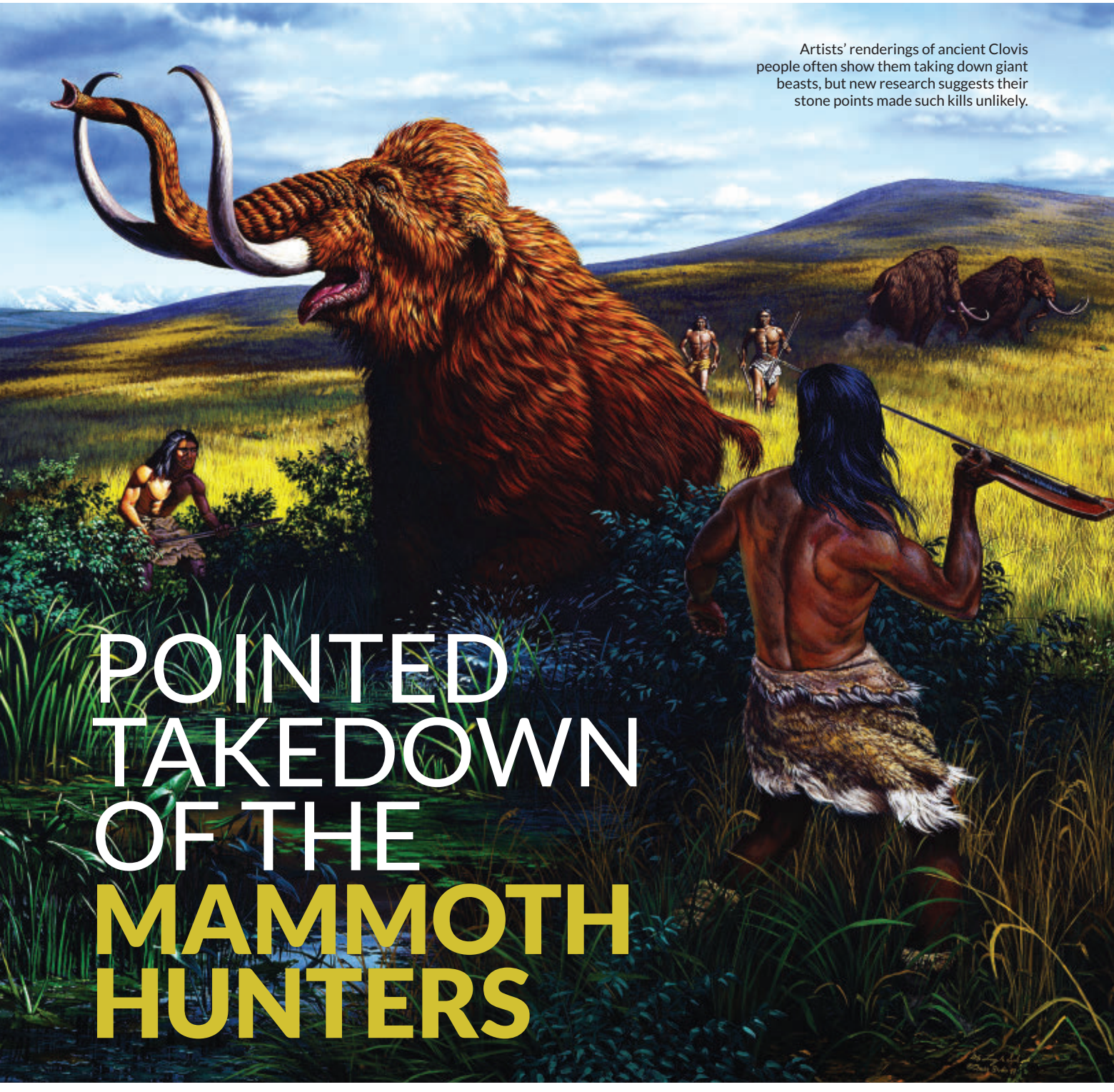
Yet as some of the other ancient Greeks realized, the world of the senses does offer clues about the reality we can't see. "Phenomena are a sight of the unseen," Anaxagoras said. As Carroll puts it, in modern terms, "the world as we experience it" is certainly related to "the world as it really is."

"But the relationship is complicated," he says, "and it's real work to figure it out."

In fact, it took two millennia of hard work for the Greek revolution in explaining nature to mature into Newtonian science's mechanistic understanding of reality. Three centuries later quantum physics revolutionized science's grasp of reality to a comparable extent. Yet the lack of agreement on what it all means suggests that perhaps science needs to dig a little deeper still. ■

Explore more

- Tom Siegfried. "Clash of the quantum titans." *Science News*. November 20, 2010. Read it at bit.ly/SN_quantumtitans



Artists' renderings of ancient Clovis people often show them taking down giant beasts, but new research suggests their stone points made such kills unlikely.

CHASE STUDIO/ SCIENCE SOURCE

POINTED TAKEDOWN OF THE MAMMOTH HUNTERS

Ancient people in the Americas may not have had weapons suited to big-game hunting

By Bruce Bower

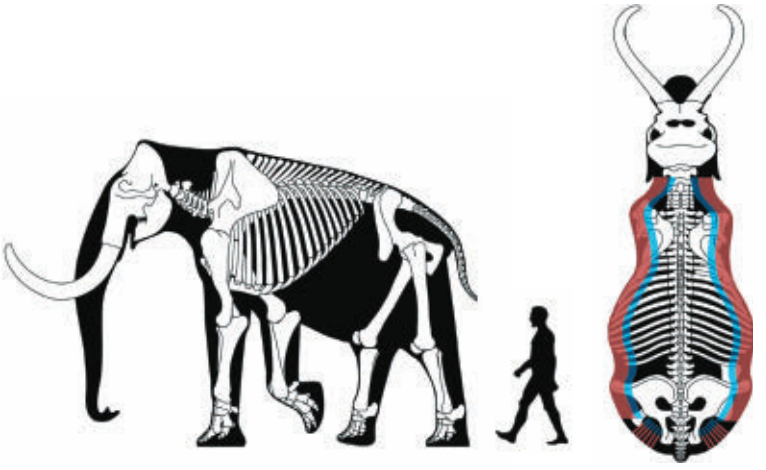
An amateur archaeologist exploring a dried-out, ancient stream channel called Blackwater Draw near Clovis, New Mexico, made a startling discovery in 1929. He came across chiseled stone points strewn among mammoth fossils. Razor-sharp edges bordering each artifact gracefully curved up to a pointed tip. Thin grooves chipped into the bases of these stone points suggested that they were spearpoints that people had once attached to handles or poles.

Researchers who examined the Blackwater Draw finds saw them as clear evidence of mammoths having been killed by human hunters sometime in the past. Ensuing generations of archaeologists filled out the picture of an intrepid mammoth-killing bunch, dubbed the Clovis people, who spread across North America between around 13,500 and 12,500 years ago. Clovis points or skeletal damage presumably caused by them have been found among mammoth bones at 11 North American sites, including Blackwater Draw. Two other North American sites containing mastodon bones, one featuring remains of extinct elephant-like creatures called gomphotheres, plus a site that yielded camel and horse fossils also include Clovis points or evidence of injuries from sharp, pointed stones (*SN: 8/9/14, p. 7*).

Archaeologists typically refer to these places as kill sites. It's long been assumed that Clovis hunters must have left spearpoints lying among the bones of mammoths and other massive creatures after killing and butchering them. If so, Clovis big-game hunters possibly contributed to the extinction of their enormous prey (*SN: 11/24/18, p. 22*).

But the Clovis people's status as adept killers of tusked beasts weighing up to about 9 metric tons has come under fire. New experimental and archaeological studies suggest an entirely different scenario, says archaeologist Metin Eren of Kent State University in Ohio. Clovis points had many uses, like a Swiss Army knife, Eren contends. Spear-throwing hunters might have occasionally killed a mammoth, especially one separated from its group or slowed due to injury. More often, these tools served as knives to cut meat off carcasses of already dead mammoths or as dart tips hurled to scare away other scavenging animals drawn to mammoth remains, Eren and his colleagues conclude in the October *Journal of Archaeological Science: Reports*.

"It's not clear that Clovis points attached to spears could even have penetrated a mammoth's hide," Eren says. "We need to stop assuming that Clovis people and earlier Stone Age groups [in Asia and Europe] must have been mammoth hunters."



Big protection
A mammoth's skeleton shows ribs and other bones that sheltered internal organs. A view from the top, right, shows presumed average (red) and maximum (blue) penetration depths of Clovis points hurled at high speeds at a mammoth, based on experimental evidence, assuming the weapons passed through dense hair and a thick hide, and avoided bones.

His argument has been greeted with interested skepticism by some Clovis investigators. "We have an instrument, the Clovis point, that keeps showing up in direct association with dead [mammoth] bodies," says archaeologist David Kilby of Texas State University in San Marcos. "I remain convinced that Clovis points were designed to serve as reliable hunting weapons."

Mammoth challenges

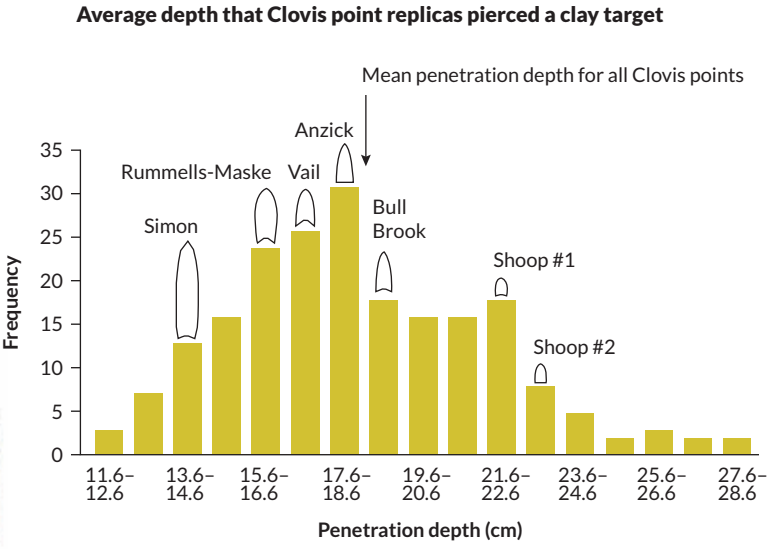
Eren made the same argument not too long ago. A spear tipped with a Clovis point and hurled from a spear thrower "could have easily taken down the largest Stone Age beasts," he said on camera in an episode of the 2015 PBS documentary series *First Peoples*.

Since then, several lines of evidence have led Eren to retract that claim. Crucial clues came from reconstructions of mammoths' skeletal and internal anatomy — both from earlier studies by other researchers, as well as new evidence gathered by Eren's group. The reconstructions show how well-protected these creatures were from spears heaved or thrust at them.

Eren's team combined measurements from Asian woolly mammoths and Columbian mammoths of North America, the presumed prey of Clovis people. Several frozen carcasses recovered in Asia indicate that woolly mammoth skin was 2 to 3 centimeters thick on average, the group estimates. Beneath the skin lay 8 to 9 centimeters of fat. And above that skin, woolly mammoth hides were covered by 5 to 15 centimeters of dense underfur topped by a layer of outer hairs 10 to 60 centimeters long.

Using measurements of ribs from two Columbian mammoths, whose remains are mounted at a Texas museum, Eren's team then estimated how far a Clovis spearpoint had to travel to reach vulnerable internal organs.

M.I. EREN *ET AL/J. ARCHAEOL. SCI. REP.* 2021



Try, try again
Clovis points found at sites across North America come in a range of sizes and shapes (several shown above, left). Replicas of seven points were tested for their ability to penetrate clay blocks used as stand-ins for tougher animal tissue. The bars on the chart (right) denote the number of times the replicas reached various depths in the clay. Outlines of seven Clovis point forms used in the experiment appear above their average penetration depths. Few of the stone projectiles traveled far enough into the targets to have had a chance to cause lethal injury to an actual mammoth.
SOURCE: M.I. EREN *ET AL/ J. ARCHAEOL. SCI. REP.* 2021

A Clovis point had to plunge 17 to 30 centimeters deep to kill an Asian woolly mammoth, the team calculated. The distance would be close, but not quite as deep, for Columbian mammoths, which may have lacked underfur.

Even after slicing through hair, hide, fat and tissue on the way into a mammoth's chest, a Clovis point had to dodge a picket fence of thick ribs to reach the beast's internal organs. A spear-point that entered through the stomach and into an opening at the back of the rib cage would have had to travel farther than one aimed at the chest, although it's unclear how much farther.

With those estimates in mind — and inspired by earlier experiments in which researchers thrust or hurled spears tipped with Clovis points into dead elephants — Eren put the points to the test.

In those earlier elephant experiments, spear-points often pierced the animals' hides. But for a variety of reasons that likely included the condition of carcasses and the speeds at which spears were launched, only some points penetrated deep enough to have reached the vital organs of a mammoth or mastodon. Eren used a lab setup that offered a better chance of shooting Clovis points deep into a hunting target than would have been possible in an actual encounter with a mammoth-sized creature. Yet even with this advantage, Eren's results suggest that Clovis points generally did not penetrate deep enough to have been effective mammoth killers.

In one study published in the July 2020 *Lithic Technology*, replicas of seven types of Clovis points covering the sizes and shapes that have been found at archaeological sites were fastened to wooden shafts. The sizes ranged from a bullet-shaped point about two-thirds as long as an adult's thumb to a missile-shaped point nearly as long as a pencil. A bow mounted on a shooting device fired each type of Clovis point 30 times into blocks of moist clay from a distance of about 1.8 meters. Spears traveled at a speed in the upper range of shots that have been propelled by people using spear-throwing tools. The clay blocks, fortified with crystalline silica dust, provided slightly less resistance than the tissue of an elephant or other large animal.

Over 210 shots, Clovis points penetrated clay blocks — which lacked the thick skins of mammoths that would have slowed or blocked spears thrown during actual hunts — to an average depth of 18.6 centimeters, Eren says. Penetration depths of four types of points equaled or fell short of the overall average. Only a couple of shots using the most successful point penetrated as deep as 28.6 centimeters. Smaller points tended to pierce deeper into targets than larger points. But the relatively broad, thick tips on all the Clovis points limited their ability to penetrate clay and enter animal tissue, even assuming one of these weapons managed to breech a mammoth's tough skin without breaking, Eren says.

Ancient mammoth hunters may have hurled slightly larger Clovis points than the experimental replicas and perhaps launched shots with somewhat greater momentum. Still, sending a spear through an animal's hide, fat and tissue at an angle that avoided ribs on the way to a fatal rendezvous with internal organs was highly unlikely, Eren says. Unlike the lab setup, presumed mammoth

FROM LEFT: M.I. EREN *ET AL/LITHIC TECHNOLOGY* 2020; C. CHANG

hunters would have taken aim at animals on the move. Spears that lodged in a mammoth's hide probably felt like a series of stinging pinpricks that could easily have angered the creature and caused it to charge at or stomp on human pursuers.

Lack of impact

If Clovis people effectively hunted mammoths, their spears would have often hit ribs or other bones, Eren says. Those impacts should have left behind many broken Clovis points at presumed kill sites.

Another experiment supported that expectation. Eren shot 203 replicas of the seven Clovis point types at oak boards, which are not as hard or dense as human or cow ribs. All but three points broke on the first shot. The rest broke on the second shot.

Yet of 93 Clovis points previously found at 15 presumed kill sites, only 12 of 74 discovered among mammoth, mastodon or gomphothere bones had broken, probably after hitting bone, Eren and his colleagues found. In contrast, 10 of 19 Clovis points associated with bison bones — smaller prey with thinner hides likely hunted by Clovis people (*SN: 5/13/17, p. 8*) — had fragmented due to hard impacts.

Mammoths and their supersized brethren may have fallen prey to Clovis hunters on rare occasions, but the huge beasts would have typically withstood a hail of spears tipped with Clovis points, Eren contends. Even attempts to disable a mammoth by severing tendons in its legs with bladelike Clovis chopping tools attached to handles would probably have failed. In another experiment, Eren swung replicas of such implements at a simulated mammoth foot consisting of a hoof-shaped slab of 5-centimeter-thick clay surrounding beef tendons. Again, in this best-case scenario, chops with Clovis blades sometimes partially cut a tendon but never sliced entirely through one. Often, blades left tendons untouched.

Hunting need not have occurred for Clovis points to have been left among mammoth bones. Microscopic damage that has been observed on Clovis points indicates that they could have served as knives to butcher huge beasts that had already died, Eren says. These knives could have been used to cut all sorts of material, from animal hides to edible plants.

Mixed reviews

Eren's group raises valid doubts about how well Clovis points worked as mammoth killers, says archaeologist Vance Haynes of the University of Arizona at Tucson. Clovis points discovered at alleged kill sites "could have just as well been used for butchering and then left behind." Scavenged animals could have died of natural causes, accidental injuries or lethal wounds inflicted by nonhuman predators.

No clear evidence of hunting exists at the few sites containing both Clovis points and bones of mammoth or other large animals, Haynes says. For instance, although more than 10,000 Clovis points have been recovered in North America, mostly at campsites and in storage spots called caches, none have been found embedded in bones of big game.

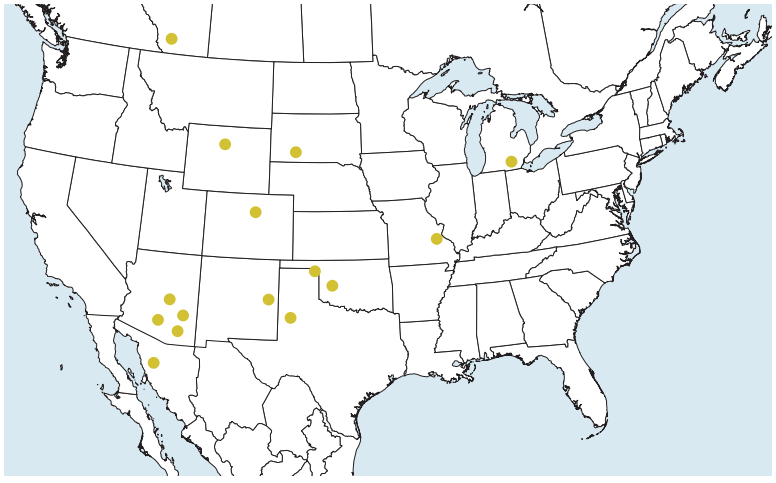
Spears tipped with Clovis points, as well as long segments of bone and ivory shaped into rods with pointed tips found at a few Clovis sites, might have occasionally been thrust by hand at massive prey in order to wound or kill, Haynes speculates.

Other archaeologists see no reason to recant traditional views of Clovis points as lethal big-game hunting weapons. Precisely because mammoths were so difficult to kill, Clovis hunters would have thrown or thrust spears at torso areas unprotected

M.I. EREN *ET AL/J. ARCHAEOL. SCI. REP.* 2021




To test whether Clovis tools could disable mammoths, Metin Eren and colleagues, including Kent State archaeologist Michelle Bebber (shown, center left), placed beef tendons against a wooden dowel and then encased them in 5 centimeters of clay to re-create a mammoth foot. Here, Eren (shown, center right) swings a replica Clovis blade tool at the clay foot. Damage inflicted on internal tendons was minimal, sometimes producing partial cuts (far right).



Human-beast interactions On this partial map of North America, gold dots designate sites regarded by some researchers as displaying clear evidence of human hunting or scavenging of mammoths and other big game, mostly mastodons. SOURCE: D.K. GRAYSON AND D.J. MELTZER/ *J. ARCHAEOL. SCI.* 2015

by ribs, says Texas State's Kilby. Such wounds wouldn't kill right away, but hunters could follow massive prey until bleeding or injuries led to death. That tactic would have resulted in few Clovis points striking ribs and then breaking, consistent with what Eren's group found.

Such a scenario might have led to the death of a mammoth at a 12,900-year-old site in eastern Wyoming called La Prele. Excavations at La Prele since 1986 have uncovered bones from a mammoth and remnants of a temporary settlement where families gathered to feed off the carcass. Finds include a Clovis point that displays damage from a high-speed impact, says Todd Surovell of the University of Wyoming in Laramie, who directs work at La Prele.

"Clovis points were clearly intended to be hunting weapons," Surovell says. "I don't believe for a second that they were primarily used as knives."

Surprising survival

Determining whether Clovis people scavenged mammoths more often than they hunted them will help to clarify a long-standing debate about whether Stone Age groups drove those creatures to extinction, says archaeologist Ashley Smallwood of the University of Louisville in Kentucky.

Advocates of proficient big-game hunting by Clovis people and by even earlier groups in northern Asia suspect that humans killed off mammoths within a few hundred years of first encountering them.

Eren and other researchers think it more likely that those animals died out as ancient shifts to a warmer, wetter climate shrank the grasslands on which the animals lived. Ancient DNA has already supported a similar scenario of extinction by climate change for Siberian woolly rhinos around 14,000 years ago (*SN: 9/12/20, p. 9*). A recent study, also based on ancient DNA, suggests the same for mammoths.

Evolutionary geneticist Yucheng Wang of the University of Cambridge and his colleagues analyzed plant and animal DNA extracted from 535 sediment samples from the Arctic spanning roughly the last 50,000 years.

Based on that genetic evidence, mammoths survived in Arctic parts of North America until about 8,600 years ago, in northeast Siberia until around 7,300 years ago and in north-central Siberia until as late as about 3,900 years ago, the researchers reported October 20 in *Nature*. Thus, mammoths coexisted with people for several thousand years or more in those regions. That means in North America, mammoths outlasted the Clovis culture by nearly 5,000 years. An unexpectedly late survival of plants suited to grassland and tundra areas appears to have enabled mammoths to persist longer than previously estimated, the researchers say.

Woolly mammoths died out in various parts of Eurasia over many thousands of years before meeting their final end in the Arctic locales studied by Wang's group, say ecologist Damien Fordham of the University of Adelaide in Australia and his colleagues. Computer simulations based on ancient DNA, fossil and climate data suggest that rising temperatures and growing human populations led to mammoth die-offs in Europe and Asia starting around 19,000 years ago and in much of Asia starting roughly 15,000 years ago, Fordham's team reported November 5 in *Ecology Letters*.

Similar to Wang's ancient DNA findings, Fordham's computer simulations suggest that woolly mammoths survived in still-frigid Siberia until roughly 3,000 years ago.

Rapid movements of ancient human groups across Eurasia disrupted woolly mammoths' ability to move among areas once plentiful with food and water, Fordham's group suggests. That, more than hunting, hastened the huge beasts' demise, the researchers suspect.

Perhaps North American mammoth extinction similarly played out in stages. Maybe human hunters played only a minor role in that process. Whatever the case, mammoths, it seems, are as capable of throwing curves at scientists as Clovis people and their stone points. ■

Explore more

■ Metin I. Eren *et al*. "On the efficacy of Clovis fluted points for hunting proboscideans." *Journal of Archaeological Science: Reports*. October 2021.

C. CHANG

3,000-Year-Old Beauty Secret Revealed

Turquoise — the original fashion icon — comes full circle for an amazing price.

She's been around for thousands of years, but she's never gone out of fashion. We're talking turquoise, one of the world's most ancient gems. Egyptian queens adorned themselves with turquoise jewelry more than 3,000 years ago. And the blue beauty is even more coveted now than she was a millennia ago.

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CONVERSATIONS WITH MAYA

GEORGE YANCOPOULOS
Regeneron Scientific Founder,
President and Chief Scientific Officer

Maya Ajmera, President & CEO of the Society for Science and Publisher of *Science News*, chatted with George Yancopoulos, an alumnus and one of the top winners of the 1976 Science Talent Search. Yancopoulos is Regeneron's Scientific Founder, President and Chief Scientific Officer. Regeneron is the title sponsor for two of the Society's science competitions: the Regeneron Science Talent Search and the Regeneron International Science and Engineering Fair. The biotechnology company also supports the Society's suite of outreach and equity programs.

You're an alum of the 1976 Science Talent Search. How did the competition impact your life?

I can honestly say the competition changed my life. I was lucky enough to attend the esteemed Bronx High School of Science in New York City. Up until that point, my heroes were the typical sports heroes that many kids look up to. But at Bronx Science, people looked up to the winners of the Science Talent Search (STS), which was sponsored by Westinghouse at the time. I remember when I first went to the school, people would point to a student and say, "Hey, look, there goes a winner of the Westinghouse," in a hushed, respectful way, similar to the way someone might point to a top football player at another high school.

And so I changed my goals and decided that I wanted to be a Westinghouse winner. When I was named an STS finalist, I met all these other amazing kids who were operating at a whole different level than I had ever seen. I didn't think I belonged. When I was named one of the winners, it gave me confidence that maybe I could devote my life to doing science and using science to try to better the world.

Like me, you are a first-generation American. What effect did being the child of immigrants have on your education and early career?

I have many complex, layered views on what leads to success. I grew up in a poor, first-generation immigrant family. My parents never finished high school because of a war taking place in their home country of Greece. Many would view this as a great handicap. I saw the hunger of poverty and the challenge of being an immigrant. But I believe those experiences can be a great driver of success—especially if your parents, like mine, came to America specifically to give their children a better chance. I owe everything to my parents because they sacrificed everything to give me that chance. That experience gave me the drive and the discipline to succeed. I talk about this constantly with my own children: Affluence, which many consider privilege, can breed complacency.

History tells us that I'm just one of so many examples. Some of the greatest innovators and success stories in America started in poor immigrant homes.

Regeneron has taken on a wide array of diseases from eczema to Ebola to cancer to COVID-19. How does the company decide what challenges to focus on?

Regeneron is very different from almost every other biotech and pharmaceutical company in that we don't start by trying to cure any specific disease. It always starts with us trying to take advantage of a new scientific or technological advancement—or applying our own expertise or new tech—which we can then imagine being used to cure disease. For example, when I was a graduate student I had an idea

about making a mouse with a human immune system, which would enable us to challenge the mouse with diseases like Ebola or COVID-19. If the mouse survived, it survived because its immune system beat the disease. So we could use a platform like that—a genetically humanized immune system in a mouse—and then repeatedly challenge it with diseases like Ebola or COVID, and let the animal come up with the cure. Because it's using genetically humanized components, we can clone the cure and give it to humans. That's where a lot of our treatments come from.

Every single one of our approved medicines has been discovered in-house by our scientists using our own technologies. And those technologies are amenable to addressing multiple diseases. So whether it be eczema or COVID-19, we have technology in place that we have been building for decades that could allow us to quickly go in there and develop a treatment.

Regeneron has nine treatments approved by the U.S. Food and Drug Administration, and one FDA-authorized treatment, which is an unusually high number for a biotech company. What has contributed to Regeneron's success?

It starts with the people. Regeneron is a very unusual company in many ways. We're a company that was launched by physician scientists and is run primarily by scientists, which contributes to our culture. I think there should be more companies that are started and run by scientists. When a company is founded by physician scientists, it's being led by people who have taken an oath. Regeneron's motto comes from my partner Len Schleifer's father: Do well by doing good.

We don't go after diseases by how much money can be made. Regeneron considers whether we can make an impact on a disease and help change people's lives.

A lot of science around COVID-19 has become highly politicized. How has Regeneron worked within that politicized climate?

Our way of life—our lives themselves—are threatened by this pandemic, and the biopharmaceutical industry has responded by creating two very complementary classes of medicines: one, the vaccines, and two, therapeutics like our monoclonal antibody cocktail, REGEN-COV. What a great success story in record time.

I'm not sure exactly how this happened, but it seems to me like one political group is much more focused on widespread vaccination and not talking so much about monoclonal antibody treatments, and the other political side became more focused on treatments, even perhaps ignoring vaccines.

But really society now has two complementary, synergistic—and equally necessary—approaches to COVID-19, and we should be valuing them both. We shouldn't be breaking them down by political affiliations. We should be saying, this is an amazing toolkit of approaches that science has brought us, and they are all saving lives.

George Yancopoulos addresses the audience at the Regeneron Science Talent Search 2018 Awards Gala.

You, Len and Regeneron have made a significant investment in young people through your support of the Regeneron Science Talent Search, the Regeneron International Science and Engineering Fair, as well as multiple outreach and equity initiatives. Why is this a priority for Regeneron?

Frankly, I think there's nothing more important for humanity. We believe students are our most valuable resource. We have to find the best and the brightest, who are often ignored in today's society.

Out of our more than $100 million commitment to STS, more than a third of it is going to increase the opportunities and the outreach for schools in underserved communities. This is about finding the next Albert Einstein. Our future existence depends on it. We have true existential threats. We saw how devastating a pandemic can be, and we have new epidemics that are coming down the pike.

What advice do you give to young people?

Don't take your life for granted. You have to do something with your life to make it all worthwhile, to pay back everyone who came before you. That's your duty. I think that young people have to understand that we have a duty and obligation to pay back all of humanity that got us here, and we have an obligation to pay it forward. To do that, there needs to be an incredible emphasis on education, drive and trying to do your best.

There are many challenges in the world today. What is keeping you up at night right now?

I worry about the climate, the environment and food supply. I'm not happy with the current approaches and technologies, and don't believe the green energy sources that we have in place are going to be sufficient. I've encouraged my kids to go into these areas, and I actually am thinking that if I'm going to add another thing to my life, it is going to be to figure out a way to really help and jump-start new research in these areas because I think our world is being destroyed and we have to do better.

EXHIBIT

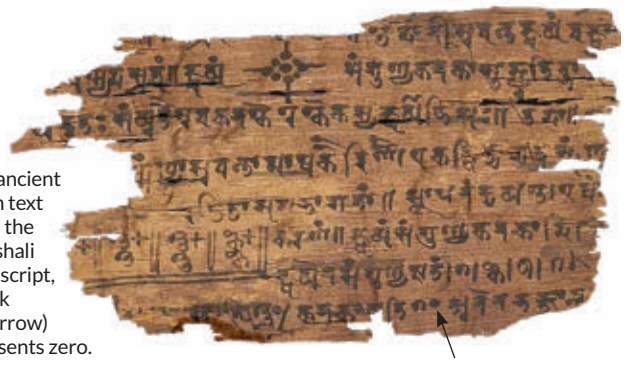
Journey through the history of math

Around 1900 B.C., a student in the Sumerian city of Nippur, in what's now Iraq, copied a multiplication table onto a clay tablet. Some 4,000 years later, that schoolwork survives, as do the student's errors (10 times 45, for example, is definitely not 270). The work is a reminder that no matter how elegant or infallible mathematics may seem, it's still a human endeavor.

That's one lesson I took from "History of Mathematics," an online exhibit developed by the National Museum of Mathematics in New York City and Wolfram Research, a computational technology company. Bringing together the Sumerian tablet and more than 70 other artifacts, the exhibit demonstrates how math has been a universal language across cultures and throughout time.

Divided into nine "galleries," the exhibit sums up the development of key topics related to mathematics, including counting, arithmetic, algebra, geometry and prime numbers. Each gallery has a short timeline and features a handful of artifacts that serve as entry points to explore some milestones in more depth.

Among the highlights: The oldest known surviving calculating device, the Salamis Tablet, is a marble counting board from the Greek island of Salamis dating to 300 B.C. It's a precursor to the abacus. By moving pebbles across the board, a person could perform calculations. An early documented instance of using a symbol for "zero" as a placeholder (to, say, distinguish 1 from 10, 100 or 1,000) appears in the Bakhshali Manuscript, an Indian text dating to perhaps as early as A.D. 300. The manuscript's black dots eventually morphed into the open circles we know today as zeros. Also on display is *Al-Jabr*. Written in around 820 by Persian polymath Muḥammad ibn Mūsā al-Khwārizmī, the book established the field of algebra and gave the discipline its name. In 1557, the *Whetstone of Witte*, an English algebra text, introduced the modern equal symbol.



In an ancient Indian text called the Bakhshali Manuscript, a black dot (arrow) represents zero.

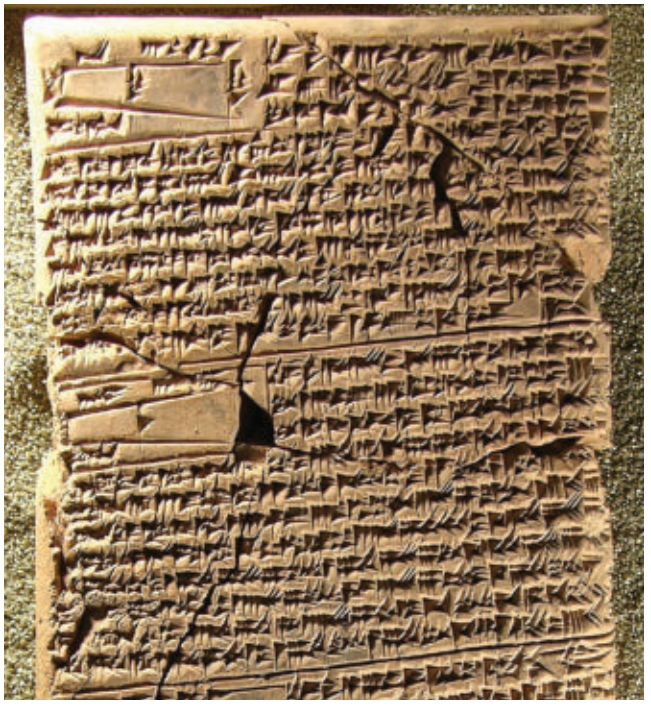
But the exhibit is more than just a collection of fun facts. As the galleries explain, humans' relationship with numbers goes back deep into prehistory. Modern math, however, stems from the rise of cities, with the need to keep track of people and supplies, and to undertake ever more complex construction projects.

Some mathematical principles must have been so vital to civilization's success that they appeared in many ancient cultures. Take the Pythagorean theorem. The Greek philosopher Pythagoras, who lived in the sixth century B.C., famously related the side lengths of a right triangle in the equation $a^2 + b^2 = c^2$. But a clay tablet reveals that people in Mesopotamia had worked out the relationship more than 1,000 years earlier. Ancient Chinese and Indian scholars were also familiar with the relationship.

Other math problems have had multiple solutions. The history of counting is littered with an array of methods for keeping track of numbers, from various forms of finger counting to the stringed recording devices called quipus, or khipus, used in the Inca Empire in the 1400s and 1500s. The placement and types of knots along a quipu's strings indicate different numerical values, though researchers today are still trying to understand exactly how to interpret the data recorded on these devices (*SN: 7/6/19 & 7/20/19, p. 12*).

Parts of the exhibit assume a high level of mathematical knowledge, such as some of the interactive features that give technical explanations behind some artifacts' mathematical principles. But a section of "learning journeys" aimed at "kids and others" provides materials that fill in some of the missing details from the main galleries and will appeal to adults whose memories of high school or college math are fuzzy.

"History of Mathematics" is a fascinating starting point for anyone interested in learning about the origins of the mathematical concepts that so many of us use every day but often take for granted. — *Erin Wayman*



This tablet, dated to as early as 2000 B.C., shows several math problems and drawings of trapezoids and triangles. The text suggests that people in Mesopotamia grasped the Pythagorean theorem long before the Greek philosopher Pythagoras, for whom the theorem is now named, lived.

FROM TOP: NATIONAL GEOGRAPHIC/WIKIMEDIA COMMONS; SCHOYEN COLLECTION

See the "History of Mathematics" at **history-of-mathematics.org**

NOVEMBER 6, 2021

Twinspired poetry

Identical twins may have a set of unique chemical signatures on their DNA that could be used to identify people conceived as identical twins, even if they lost their sibling in the womb or were separated at birth, **Jonathan Lambert** reported in "Identical twins share DNA tags" (*SN: 11/6/21, p. 8*). The story inspired reader **Boghos L. Artinian** to share a poem:

Identical twins Bob and Bill /
Decades-old, yet identical still; /
Afraid to date and separate, / That
each may have a different fate!

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Feel the burn

*The discovery of a protein receptor in nerve cells that detects heat and capsaicin — the compound that makes chili peppers spicy — was one of the 2021 Nobel Prize winners in physiology or medicine, **Tina Hesman Saey** and **Freda Kreier** reported in "This year's Nobel Prizes awarded"* (SN: 11/6/21, p. 14). Reader **Joe Gadway** wondered how people can tell the difference between high temperatures and spiciness if the same protein detects both.

"A lot of people ask me this question," says Nobel laureate **David Julius**, the molecular physiologist at the University of California, San Francisco who discovered the receptor, called TRPV1. "Sometimes it is difficult to discriminate between [whether] your mouth is on fire because of capsaicin or because something's hot-hot."

Other receptors in nerve cells that can sense thermal heat but not capsaicin may help distinguish spiciness from temperature, **Julius** says. But these receptors' contributions to heat sensation haven't been worked out as thoroughly as TRPV1's role has.

Thermal heat suppresses cold-sensing nerve fibers whereas capsaicin does not, he says. Quieting signals from the cold-sensing nerves may be another clue to help the brain figure out the source of the heat.

Speed could play a role in telling the two sensations apart as well, **Julius** says. Nerve cells register thermal signals faster than they do chemical signals. While a "hot" signal goes away once you stop touching a hot object, the burn of chili peppers endures. So those temporal clues may also help people tell thermal heat from chemical heat.

Great escape

*Moon rock samples retrieved by China's Chang'e-5 mission reveal that lava oozed on the lunar surface just 2 billion years ago, **Freda Kreier** reported in "Moon rocks record young lava flows"* (SN: 11/6/21, p. 6). **Kreier** reported that the moon was a lot closer to Earth 2 billion years ago and has been slowly inching away from the planet. Reader **Rick Mott** wanted to know how the moon manages to move away from Earth.

"The moon and Earth are caught in a constant gravitational tug-of-war," **Kreier** says. Earth's gravity keeps the moon orbiting Earth while the moon's gravity tugs on the planet. The force of this tugging allows the moon to steal some rotational energy from Earth, making the natural satellite's orbit bigger. "This is pushing the moon away at a rate of about 3.78 centimeters per year, roughly the same rate our fingernails grow," she says.

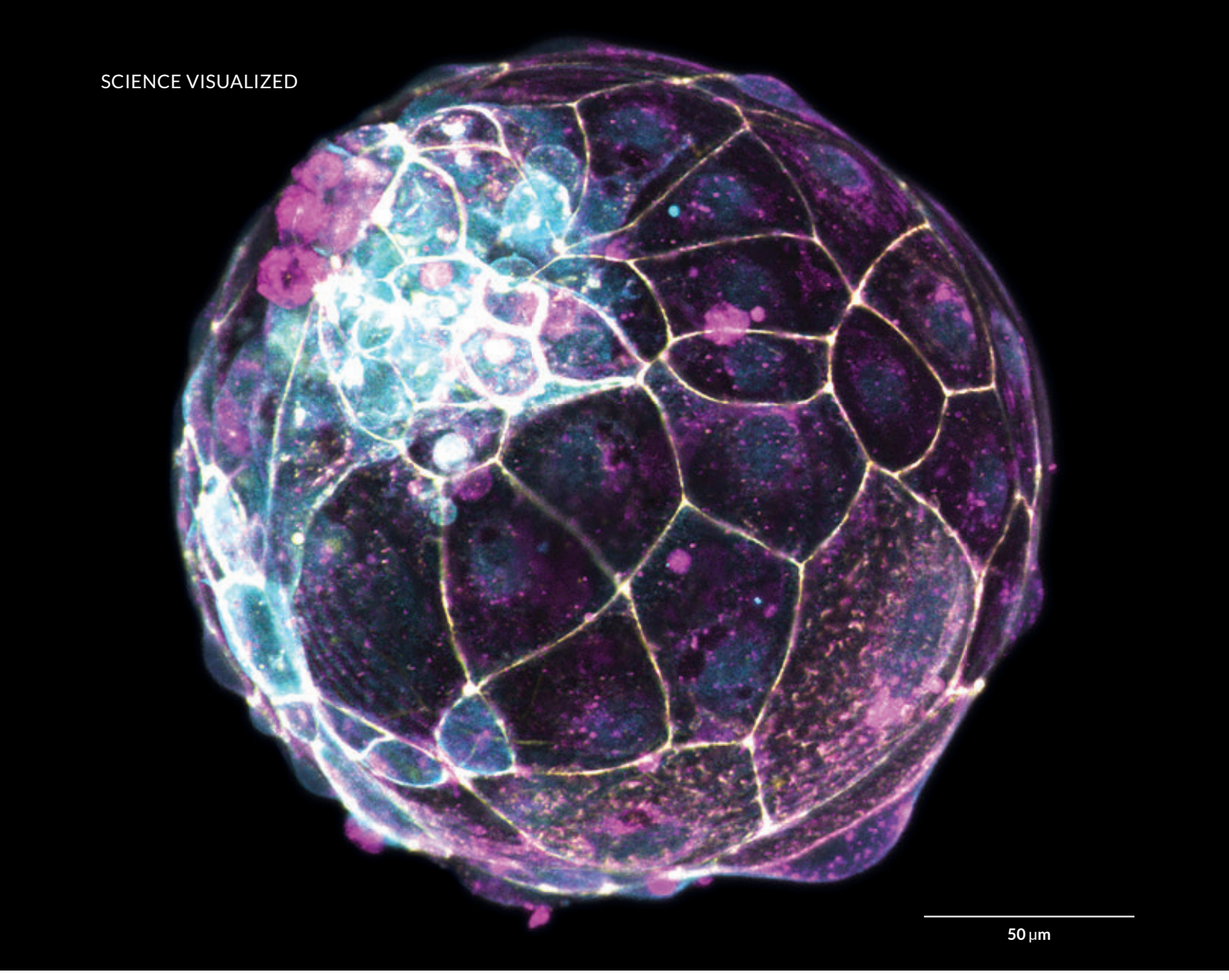
This tug-of-war is also slowing down Earth's spin, gradually making our days longer, **Kreier** says. In 100 years, a day on Earth will be about two milliseconds longer than it is today.

Clarification

In the November 6 issue's Feedback, a reader asked how scientists contained fusion reactions in a recent experiment (*SN: 9/11/21, p. 11*). Our response noted that fusion reactions don't need containment because they fizzle out on their own. This also means that, in the future, generating energy using fusion would have no risk of a runaway reaction, which could cause an explosion. While fission reactions don't stop on their own as fusion reactions do, we neglected to make clear that modern fission reactors are designed to prevent runaway reactions. Meltdowns in fission reactors are still possible if heat can't be removed from the reactor.

Correction

"A serious look at psychedelics" (*SN: 12/4/21, p. 20*) incorrectly identified the drug that Aldous Huxley popularized in his book *The Doors of Perception*. Rather than LSD, the drug was mescaline, a psychedelic compound made by certain cacti. And the book was published in 1954, not 1953.



‘Blastoids’ offer a new way to study fertility

Newly created “blastoids” could give scientists a faster and simpler way to research embryonic development than using fertilized human eggs.

Made of human stem cells, these blastoids are the most developmentally accurate model yet for studying how the blastocyst — a structure present at an early stage of embryonic development — grows and implants into the lining of the uterus, researchers report December 2 in *Nature*.

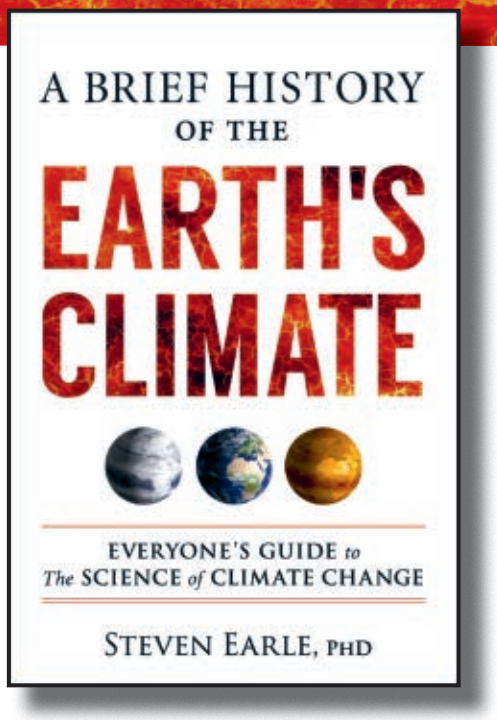
Conducting research on human embryos is highly regulated and controversial. But lab-made blastoids can help researchers avoid some of those hurdles. While blastoids have been created before, the team argues those models don’t replicate blastocyst cells as well as the new blastoids do. (The blastoid shown above has been chemically altered to fluoresce.)

A week after fertilization, developing human embryos implant into the uterus using a blastocyst, a spherical envelope of cells surrounding the cells that will become the embryo. To replicate this process, the team led by stem cell biologist Nicolas Rivron at the Institute of Molecular Biotechnology of the Austrian Academy of Sciences in Vienna looked to lab-grown human stem cells.

The researchers chemically inhibited molecular pathways involved in the cells’ growth and the timing of life cycle events. As a result, the cells formed blastoids that had the same three cell types found in blastocysts.

When the team put blastoids on lab-grown cells from the lining of the uterus, the spheres adhered to the surface, recreating a crucial step in early pregnancy. And the scientists identified a compound that prevents blastoid attachment as well as one that encourages it, revealing their potential as nonhormonal contraceptives or fertility treatments.

These blastoids aren’t thought capable of developing into humans. Still, the team did not let the models develop past 13 days, in accordance with guidelines for human embryos that cap research on their development at two weeks of existence. — *Jake Buehler*



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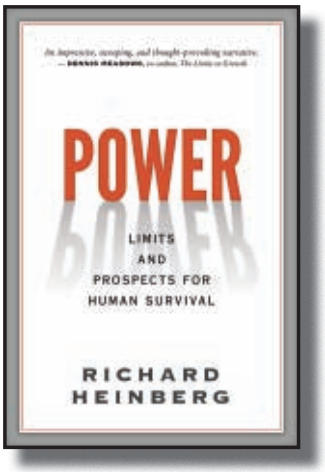

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Jon Graff was a lifelong *Science News* reader who greatly admired the communications skills of its writers and editors. During his life, Jon helped devise the secure methods we use every day to make online credit card transactions. He also loved taking long trips in the Southwest on his beloved green bike.

When Jon looked back over his life as he grew older, he thought about the things that mattered to him most—his biking friends, his seminal work as a cryptographic architect and decades of reading *Science News*.

Sadly, Jon died in January 2021 at the age of 77. Before he died, Jon made a bequest intention to create an endowment—The Jon C. Graff Fund for *Science News*—whose income will benefit both the Society for Science and *Science News* journalism in perpetuity.

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