SN
SCIENCE NEWS MAGAZINE
SOCIETY FOR SCIENCE & THE PUBLIC
SEPTEMBER 16, 2017

Reading Dodos' Bones

Counting Up Black Holes

Southern Ocean Upwelling

Female Is Not Default Sex

Inner Potential

SPECIAL REPORT

Researchers seek ways to boost learning in people and machines

Kennesaw State University

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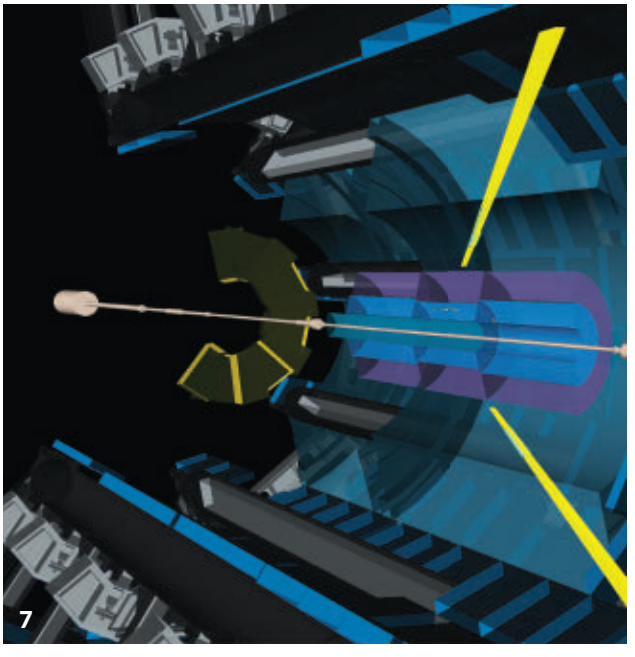

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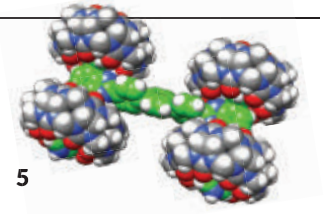
CLOCKWISE FROM TOP: ALEX NABAUM; E. MASSON; ATLAS EXPERIMENT © 2017 CERN



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Departments

SOCIETY UPDATE
Recent highlights from *Science News for Students*

COVER Researchers are applying cognitive science in the classroom. Others are finding surprises in how humans and machines learn. *Alex Nabaum*

Learning is a ubiquitous, mysterious phenomenon

I'll admit it. I'm addicted to learning. There's nothing quite like the thrill that comes with finding out something new.

It's no surprise I ended up this way. My parents were public school teachers. They instilled in me the belief that education not only opens up new opportunities but also is enjoyable in itself. My parents regularly took my siblings and me to museums, encouraged us to read widely and entertained our incessant "whys?" and "hows?" And though neither of my parents taught science, I remember studying constellations at night and experimenting with chemistry at the dining table. (My parents passed their passion for educating on to my younger brother and sister. One teaches math, the other biology and chemistry.)

Perhaps it's fitting, then, that as a new school year begins, I get to introduce *Science News*' special report on learning. Or maybe not. After all, learning is something we all do. I share a newsroom with reporters and editors who also get a big kick out of learning every day. In truth, a love of learning is probably quite common. From birth, we learn — to recognize faces, to talk, to walk. We take the clues thrown at our senses and piece together an understanding of our world. Yes, we learn the three R's in school, but we also learn (in and out of the classroom) how to build relationships, how to handle stress and what makes us happy. I'm currently learning how to prune my rosebush to get a great fall bloom, what makes an effective leader and the details of various cryptocurrencies. There's an adage, occasionally attributed to Albert Einstein, that says something like: The day you stop learning is the day you start dying. That seems about right to me.

And yet learning, such a natural and lifelong process, is a mystery. How does the brain — starting nearly from scratch, or at least seemingly so — synthesize inputs into new knowledge? How is that knowledge retained and called on? How does it drive behavior? What is the relationship between learning and memory, learning and intelligence, learning and consciousness? There are so many grand questions, and scientists are just scratching the surface.

Advances in neuroscience have allowed researchers to closely watch single nerve cells firing in learning brains, but a deeper understanding of the process might require zooming out to see what goes on between groups of brain cells, Laura Sanders reports on Page 22. People who learn with ease might be better at abandoning brain connections and forming new ones, she finds. On Page 30, Susan Gaidos investigates strategies to boost learning that have showed success in labs. Efforts are now under way to test some of these approaches in real-world classrooms.

Though we haven't cracked the secrets of superb learning yet, we are good — sometimes too good — at training machines to do something that looks like human learning. On Page 26, Maria Temming covers a recent problem in artificial intelligence: By training on sample data, machines can pick up human biases. Researchers are seeking ways to avoid the problem; the trouble is that these machines are largely black boxes.

The same might still be said about human brains, but I'm not discouraged. It just means there's plenty more to learn. — *Elizabeth Quill, Acting Editor in Chief*

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What Did You Do **Last Summer?**

The **Undergraduate Summer Research Stipend program** in Illinois Tech's College of Science provides $5,000 scholarships supporting talented students as they spend 10 weeks working alongside renowned faculty on high-impact research projects.

Undergraduate research stipend recipient Yonas Gebre conducts research in Assistant Professor Bryce Littlejohn's PROSPECT particle detector laboratory. By observing ghost-like antineutrino particles produced by nuclear reactors, this detector is probing the frontiers of physics while providing new information valuable to the nuclear power industry. Yonas and other students fabricated multiple PROSPECT detector sub-systems at Illinois Tech. Here, Yonas looks through one cell of the PROSPECT particle detector.

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ILLINOIS INSTITUTE OF TECHNOLOGY

Excerpt from the September 16, 1967 issue of *Science News*

50 YEARS AGO

Nuclear power go-ahead

West German power companies have decided to go ahead with two nuclear power station projects.... Compared with the U.S. and Britain, Germany has been relatively backward in the application of nuclear energy.... The slow German start is only partly the result of restrictions placed upon German nuclear research after the war.

UPDATE: Both East and West Germany embraced nuclear power until antinuclear protests in the 1970s gathered steam. In 1998, the unified German government began a nuclear phaseout, which Chancellor Angela Merkel halted in 2009. The 2011 Fukushima nuclear disaster in Japan caused a rapid reversal. Germany closed eight of its nuclear plants immediately, and announced that all nuclear power in the country would go dark by 2022 (*SN Online: 6/1/11*). A pivot to renewable energy — wind, solar, hydropower and biomass — produced 188 billion kilowatt-hours of electricity in 2016, nearly 32 percent of German electricity usage.

IT'S ALIVE

Aardvarks: a new face of climate change

Night is normal aardvark time to search for dinner.

When nocturnal aardvarks start sunbathing, something's wrong.

If the animals are desperate enough to bask like some cold, sluggish turtle, it's because they've got the chills. Robyn Hetem, an ecophysiologist, has the body temperature data to prove it — collected from late 2012 into 2013, the hottest summer the arid Kalahari region in South Africa had seen in more than 30 years.

Hotter, drier conditions are predicted to become the norm for southern Africa as the climate changes. Now Hetem and colleagues have used that foretaste of change to show that higher temperatures might hammer the normally heat-tolerant aardvarks by shrinking the animals' food supply.

Aardvarks live their burrow-digging lives just about anywhere in sub-Saharan Africa except the desert. The toothless night-foragers dine by slurping insect colonies. One of Hetem's students at the University of the Witwatersrand in Johannesburg spent two years collecting hundreds of aardvark droppings and can confirm that *Orycteropus afer* in the Kalahari eat only termites and ants. Yet the solitary, long-snouted, knee-high mammals are more closely related to elephants than to any pointy-nosed South American anteater.

An aardvark looks "very lethargic but is incredibly strong and fast," Hetem says.

When an aardvark warms itself in the Kalahari sun, it may be short on food and low on energy.

The researchers wanted to fit wild aardvarks with tracking devices and data loggers but first had to catch the animals. Nets failed. Traps failed. One cornered aardvark burst out of a burrow, knocked four men to the ground and then outran them.

Eventually, researchers placed instruments on six animals. When the Kalahari baked and good rains were months late, the aardvarks grew thin and bony. They started hunting during the day and sunbathing. The animals, once able to internally stabilize their body temperatures, started to have great plunging chills at night, according to data loggers. That's a sign of starvation, Hetem says, and occurs when the body no longer has energy to warm itself. Five of the six tracked animals died, along with at least 11 other aardvarks in the neighborhood.

Aardvark heat tolerance wasn't the problem. The animals were dying off because their food couldn't take the heat and drought, Hetem and colleagues argue in the July *Biology Letters*. Hot, dry spells can make ant and termite colonies shrink and retreat to hard-to-reach hideouts.

Other African wildlife might suffer from a shortage of aardvarks, which are prodigious burrow diggers. In a Kalahari study, one aardvark used more than 100 burrows in two years. So many hideaways are a boon for others. Bat-eared foxes, warthogs, birds called ant-eating chats and at least two dozen other species pop into aardvark architecture, sometimes outright moving in. If aardvarks dwindle, shelter might grow scarcer for other animals.

"We kind of think of climate change as: Things are going to get hotter and species might be sensitive to it," Hetem says. "There's so much more we need to understand." — *Susan Milius*

FROM TOP: BENJAMIN REY/UNIV. OF WITWATERSRAND; NORA WEYER/UNIV. OF WITWATERSRAND

THE -EST

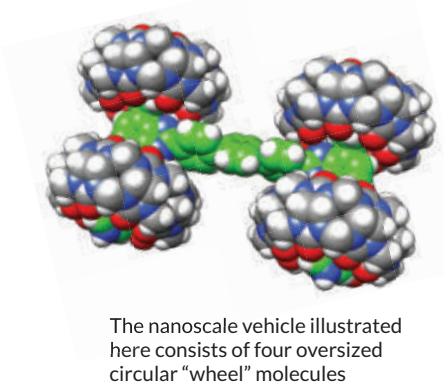
Nothing massive about this monster truck

The world's smallest monster truck has a chemical curiosity under its hood.

Made out of a mere five molecules, the Ohio Bobcat Nanowagon, big wheels and all, checks in at 3.5 nanometers long and 2.5 nanometers wide — about the width of a DNA strand. This pip-squeak vehicle took home the bronze in the first-ever nanocar race earlier this year, traveling farther down a track than three other contestants. But perhaps more important, researchers made a surprising observation while manufacturing this nanoracer.

Many of the Bobcat Nanowagons that the researchers produced broke apart when the team tried attaching them to a racetrack. Most of the broken bits looked like two-wheeled hoverboards.

"It's very surprising that it seems to be easier to break the chassis than to remove the wheel from the chassis," Eric Masson, one of the car's designers, said August 23 in Washington, D.C., at a news conference at an American Chemical Society meeting. The type of chemical bond linking atoms in the car frame is typically considered stronger than the kind of bond attaching its wheels.



The nanoscale vehicle illustrated here consists of four oversized circular "wheel" molecules fastened to an H-shaped frame.

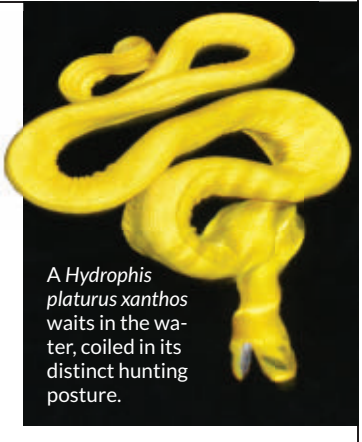
Masson, a chemist at Ohio University in Athens, and colleagues aren't sure why the Bobcat Nanowagon is more liable to snap in half than lose a wheel. Explaining this chemical quirk could help scientists better understand the operations of molecular machines, which may one day be useful for destroying tumors or delivering drugs to specific cells (*SN: 10/29/16, p. 6*). — *Maria Temming*

INTRODUCING

Yellow is the new sea snake

With its bright hue, this snake was bound to stand out sooner or later.

A newly discovered subspecies of sea snake, *Hydrophis platurus xanthos,* has a narrow geographic range and an unusual hunting trick. The canary-yellow reptile hunts at night in Golfo Dulce off Costa Rica's Pacific coast. With its body coiled up at the sea surface, the snake points its head under the water, mouth open. That folded posture "creates a buoy" that stabilizes the snake so it can nab prey in choppy water, says study coauthor Brooke Bessesen, a conservation biologist at Osa Conservation, a biodiversity-focused nonprofit in Washington, D.C. In contrast, typical *Hydrophis platurus*, with a black back and yellow underbelly, hunts during the day, floating straight on calm seas.



A *Hydrophis platurus xanthos* waits in the water, coiled in its distinct hunting posture.

The newly described venomous snake has been reported only in a small, 320-square-kilometer area of Golfo Dulce. After analyzing 154 living and preserved specimens, the researchers described the reptile's characteristics July 24 in *Zookeys*. The scientists hope that the subspecies designation will enable the Costa Rican government to protect the sunny serpent, which they worry is already at risk from overzealous animal collectors. — *Bethany Brookshire*

CLOCKWISE FROM TOP: LOVEGULI/ISTOCKPHOTO; B. BESSESEN; E. MASSON

SCIENCE STATS

Air pollution throws shade at solar power

Air pollution is a drag for renewable energy. Dust and other sky-darkening air pollutants slash solar energy production by 17 to 25 percent across parts of India, China and the Arabian Peninsula, a new study estimates. The haze can block sunlight from reaching solar panels. And if the particles land on a panel's flat surface, they cut down on the area exposed to the sun. Dust can come from natural sources, but the other pollutants have human-made origins, including cars, factories and coal-fired power plants.

Scientists collected and analyzed dust and pollution particles from solar panels in India, then extrapolated to quantify the impact on solar energy output in all three locations. China, which generates more solar energy than any other country, is losing up to 11 gigawatts of power capacity due to air pollution, the researchers report in the Aug. 8 *Environmental Science & Technology Letters*. That's a loss of about $10 billion per year in U.S. energy costs, says study coauthor Mike Bergin of Duke University. Regular cleaning of solar panels can help. Cleaning the air, however, is harder. — *Laurel Hamers*

17–25

percent

Reduction in solar energy output due to air pollution in parts of India, China and the Arabian Peninsula

LIFE & EVOLUTION

The life and times of dodos revealed

Bones help fill in extinct birds' annual calendar of events

BY SUSAN MILIUS

Dumb extinction jokes aside, dodos' life history is largely unknown.

Now the first closeup look inside the long-gone birds' bones is giving a glimpse into their lives, an international research team reports August 24 in *Scientific Reports*. Until now, almost nothing has been known about the basic biology of dodos, such as what time of year they mated or how quickly they grew.

Based on 22 bones from different birds and weather patterns on the island Mauritius where the birds lived, scientists worked out how bones changed as birds grew up. With this information, the team proposes a month-by-month dodo to-do list. For August: Start breeding. That's the end of winter in the Southern Hemisphere, where Mauritius lies. Chicks would hatch in spring and grow in a rapid spurt before summer, proposes study coauthor Delphine Angst, a paleontologist at the University of Cape Town in South Africa.

Summer would have been the toughest season for dodos, the team says. Between about November and March, cyclones can rip across the island, uprooting plants, stripping leaves and fruit and disrupting food sources. During that time, the birds probably just about stopped growing, a lag that could explain periodic lines in bones where birds had deposited little new material.

On top of those lag lines, some bones also showed relatively little new growth before signs of molting. This pattern suggests that as summer was winding down in March, adults that had survived cyclone season started renewing their feathers. The new plumage would thus be ready in time for August mating flirtations.

The dodo (*Raphus cucullatus*) lived only on Mauritius. The bird slid from a marvel first described to Westerners in 1598 to extinction in less than a century, Angst says. Sailors delirious for fresh meat slaughtered flocks, but more destructive, she thinks, were the rats, pigs, monkeys and other invaders that sailors brought with them.

Museums have few dodo bones, and the new study was only possible because of recent discoveries that let scientists feel more comfortable about actually cutting sections out of some of the precious collections: The Dodo Research Program turned up more bones in Mauritius. And Angst herself got a startling message from people selling a house near Paris that was once owned by a 19th century naturalist born on Mauritius. "We have a lot of dirty old stuff in the corner of the house — are you interested?" she remembers being told. "It was literally the morning before Christmas," she says, when she discovered a treasure trove of dodo bones.

By scrutinizing microscope images, the researchers identified an almost grown-up youngster. It had built bone with collagen fibers and other materials in disorderly patterns typical of fast chick growth among many modern birds.

In bones identified as coming from mature dodos, that disorder had turned into more orderly layers. Though dodos were flightless, they grew like most modern birds, researchers concluded. Some other flightless birds, such as ostriches, grow their skeletons fast but then stop abruptly with no restructuring, Angst says.

The dodo bones also revealed markers of other life events. Some had inner gaps like those created when modern birds pull calcium out of their bones to make new feathers in a hurry during the annual molt. Two of the bones showed an extra calcium buildup on the inner hollow core. That suggests that these bones belonged to ovulating females storing calcium to form eggshells.

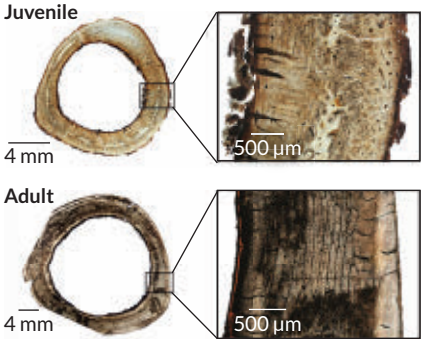
While the proposed dodo calendar is speculative, the assumptions "are not unreasonable," says paleontologist William Sellers of the University of Manchester in England, who was not part of the new study. The proposal could explain records from sailors who noted different looks for dodo plumage at different times of year.

The proposed timing of life events also makes sense based on what's known about birds now living on Mauritius, says paleontologist Antoine Louchart of CNRS at École Normale Supérieure de Lyon. Modern birds, however, can provide only some hints of the life and times of dodos, he says, "because the dodo was so modified and so unique in its proportions, size and flightlessness." So the bones do help flesh out the dodos' tale, Louchart says. ■

Mother and chick dodos (illustrated) needed to eat well and get healthy before the stressful cyclone season, according to a new reconstruction of the flightless birds' life history.

FROM TOP: JULIAN HUME; D. ANGST *ET AL*/*SCIENTIFIC REPORTS* 2017

These leg-bone cross sections helped scientists distinguish between young and mature dodos. The juvenile had a thick zone of irregularly patterned bone on the outside wall, plus a more slowly deposited, orderly layer next to the inside wall. In contrast, the adult had a slowly deposited, orderly zone on the outside wall.



ATOM & COSMOS

Black hole census results in big tally

High count of cosmic chasms clarifies gravitational wave data

BY EMILY CONOVER

The Milky Way teems with black holes — about 100 million of them.

But there's no reason to fear. "By astronomical standards, it's a pretty small number," says physicist Daniel Holz of the University of Chicago. The number of stars in the Milky Way, for example, is about a thousand times larger.

A team at the University of California, Irvine calculated the galaxy's black hole population as part of a new census that estimates the numbers of cosmic chasms in galaxies big and small. The analysis, in press in *Monthly Notices of the Royal Astronomical Society*, quantified stellar-mass black holes, which form when a star collapses. Such objects can have masses tens of times that of the sun.

To draw up the celestial inventory, the scientists combined a variety of information about stars and galaxies. A star's size and composition determine whether it can form a black hole and how big it will be. And given a galaxy's size, scientists can estimate the number and properties of stars within, allowing researchers to deduce the number of black holes and their sizes.

Such stellar-mass black holes are a target of the Advanced Laser Interferometer Gravitational-Wave Observatory, LIGO, which has detected three sets of gravitational waves from colliding black holes (*SN: 6/24/17, p. 6*). When LIGO made its first detection, some physicists thought the coalescing black holes were surprisingly large; each was about 30 times the mass of the sun. This puzzle led scientists to propose exotic origins for LIGO's black holes — for example, that they formed during the universe's infancy, instead of from collapsing stars (*SN: 9/3/16, p. 8*).

But the new result indicates that, in the Milky Way alone, there are about 10 million black holes at least that hefty. So "you don't have to do anything particularly odd or unusual in order to explain the LIGO signal," says physicist and study coauthor James Bullock.

Astrophysicist Richard O'Shaughnessy of the Rochester Institute of Technology in New York says the work may placate researchers who thought LIGO's large black holes were an oddity. ■

ATOM & COSMOS

Aloof light particles nudged to interact

Photon-photon scattering detected at the Large Hadron Collider

BY EMILY CONOVER

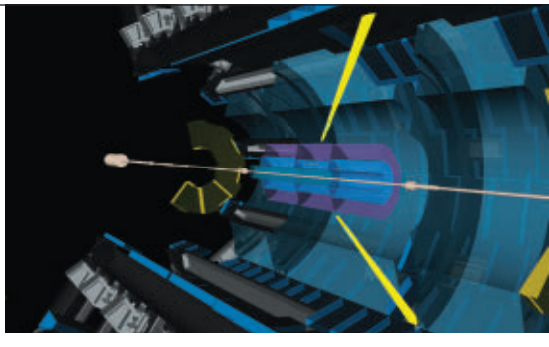
Cross two flashlight beams and they pass right through one another. That's because particles of light, or photons, are mostly antisocial — they don't interact with each other. But now scientists have spotted evidence of photons bouncing off other photons at the Large Hadron Collider at CERN, the European particle physics lab in Geneva.

"This is a very basic process. It's never been observed before, and here it is finally emerging from the data," says theoretical physicist John Ellis of King's College London, who was not involved with the study. Researchers with the ATLAS experiment at the LHC report the result August 14 in *Nature Physics*.

Photons have no electric charge, so they shouldn't notice one another. But there's an exception to that rule. According to quantum mechanics, photons can briefly transform into transient pairs of electrically charged particles and antiparticles — such as an electron and a positron — before reverting to photons. Predictions made over 80 years ago suggest that this phenomenon allows photons to ricochet away from one another.

This light-by-light scattering is rare, making it difficult to measure. But photons with more energy interact more often, providing additional chances to spot the scattering. To produce such energetic photons, scientists slammed beams of lead nuclei together in the LHC. Photons flit in and out of existence in the lead nuclei's strong electromagnetic fields. When two nuclei got close enough that their electromagnetic fields overlapped, two photons could interact with one another and be scattered away.

To detect the interaction, ATLAS scientists sifted through their data to find collisions in which only two photons — the two that scattered away from the collision — appeared in the aftermath. "That's the trickiest part of the whole thing," says Peter Steinberg, a physicist at Brookhaven National Laboratory in Upton, N.Y., and a member of the ATLAS collaboration. The scientists had to ensure that, in their enormous, highly sensitive particle detector, only two photons appeared, and convince themselves that no other particles had gone unaccounted for. The researchers found 13 such events over 19 days of data collection. Although other processes can mimic light-by-light scattering, the researchers predict that only a few such events were included in the sample.



Photons (yellow beams) bounce off each other in collisions of lead nuclei in the ATLAS detector (illustrated) at the Large Hadron Collider.

The number of observed scattering events agrees with the predictions of the standard model, physicists' theory of particle physics. But a more precise measurement of the rate of interaction might differ from expectations. If it does, that could hint at the existence of new, undiscovered particles. ■

BODY & BRAIN

Lyme diagnostics could get an upgrade

New test distinguishes between two similar tickborne diseases

BY AIMEE CUNNINGHAM

A new testing method can distinguish between early Lyme disease and a similar tickborne illness, researchers report. The approach may one day lead to a reliable diagnostic test for Lyme, an illness that can be challenging to identify.

Using patient blood serum samples, the test accurately discerned early Lyme disease from the southern tick–associated rash illness, or STARI, up to 98 times out of 100. When the comparison also included samples from healthy people, the method accurately identified early Lyme disease up to 85 times out of 100, beating a commonly used Lyme test's rate of 44 of 100, researchers report in the Aug. 16 *Science Translational Medicine*. The test relies on clues found in the rise and fall of the abundance of molecules that play a role in the body's inflammatory response.

"From a diagnostic perspective, this may be very helpful, eventually," says Mark Soloski, an immunologist at Johns Hopkins Medicine who was not involved with the study. "That's a really big deal," he says, especially in areas such as the U.S. mid-Atlantic region where Lyme and STARI overlap.

In the United States, Lyme disease is primarily caused by an infection with *Borrelia burgdorferi* bacteria, which are spread by the bites of black-legged ticks. An estimated 300,000 cases of Lyme disease occur nationally each year. Patients usually develop a rash and fever, chills, fatigue and aches. Black-legged ticks live in the northeastern, mid-Atlantic and north-central United States; western black-legged ticks reside along the Pacific coast and also transmit *B. burgdorferi*.

An accurate diagnosis can be difficult early in the disease, says Paul Arnaboldi, an immunologist at New York Medical College in Valhalla who was not involved in the study. Lyme disease is diagnosed based on the rash, symptoms and tick exposure. But other illnesses have similar symptoms, and the rash can be missed. A test for antibodies to the Lyme pathogen can aid diagnosis, but it works only after a patient has developed them, which can take a few weeks.

STARI, spread by the lone star tick, which lives in the eastern and southeastern United States, can begin with a rash and similar, though typically milder, symptoms. The pathogen responsible for STARI is unknown, but *B. burgdorferi* has been ruled out. So far STARI has not been tied to arthritis or other chronic symptoms linked to Lyme, though the lone star tick has been connected to a serious allergy to red meat (*SN: 8/19/17, p. 16*). Parts of both ticks' ranges overlap, adding to diagnosis difficulties.

Microbiologist John Belisle and his colleagues had previously shown that a testing method based on small molecules related to metabolism could distinguish between early Lyme disease and healthy serum samples. "Think of it as a fingerprint," says Belisle, of Colorado State University in Fort Collins. The technique takes note of differences in the abundance of metabolites, such as sugars, lipids and amino acids, involved in inflammation.

In the new work, Belisle and colleagues measured differences in the levels of metabolites in serum samples from Lyme and STARI patients. The researchers then developed a "fingerprint" based on 261 small molecules to differentiate between the two illnesses. To determine the accuracy, the team tested another set of samples from patients with Lyme and STARI as well as those from healthy people. "We were able to distinguish all three groups," Belisle says.

As a diagnostic test, "the approach has promise," Arnaboldi says. But additional research will be necessary to see if the technique can sort out early Lyme disease, STARI and other tickborne diseases in patients with unknown illnesses. ■

S. TERRYN *ET AL*/*SCIENCE ROBOTICS* 2017

MATH & TECHNOLOGY

Robot, heal thyself

A new type of soft robot can go under the knife and make a full recovery in about a day.

Researchers fashioned a robotic hand, a gripper (shown above) and muscle from self-healing rubbery material. To test the robots' resilience, the engineers sliced each with a scalpel, then put the robots in an oven. After cranking up the heat to 80° Celsius, baking the bots for 40 minutes, then cooling them to about room temperature, the researchers found that all the cuts had closed up. A day later, the machines had regained almost all of their original strength and flexibility, the researchers report online August 16 in *Science Robotics*.

Incisions broke bonds between two chemical ingredients in the material, furan and maleimide. At higher temperatures, these compounds naturally split up and move around more easily. So as the researchers cooled the material, the compounds rebonded with those on the other side of an incision.

"This material could heal, in theory, an infinite number of times," says study coauthor Bram Vanderborght, an engineer at Vrije Universiteit Brussels.

The work helps address a major limitation of squishy, flexible robots. Though well-suited to navigating rough terrain and handling fragile objects, the robots are vulnerable to punctures and tears. — *Maria Temming*

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ScienceNews

GENES & CELLS

Female embryos dismantle male tissue

Protein crucial to developing as female identified in mouse study

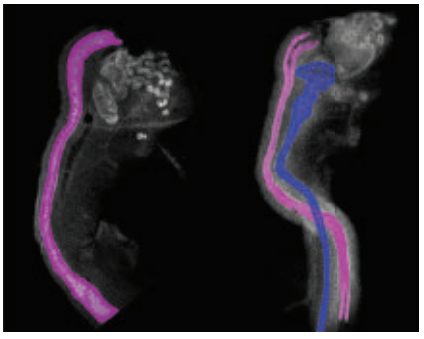
BY TINA HESMAN SAEY

Add a new ingredient to the sugar, spice and everything nice needed to make girls.

A protein called COUP-TFII is necessary to eliminate male reproductive tissue from female mouse embryos, researchers report in the Aug. 18 *Science*. For decades, females have been considered the "default" sex in mammals. The new work overturns that idea, showing that making female reproductive organs is an active process.

In males, Wolffian duct tissue develops into parts needed to ejaculate sperm, including the epididymis, vas deferens and seminal vesicles. In females, a similar tissue, the Müllerian duct, becomes the fallopian tubes, uterus and vagina. Both duct tissues are present in early embryos.

A study 70 years ago indicated that the testes make testosterone and an anti-Müllerian hormone to maintain the Wolffian duct and suppress female tissue development. If those hormones are missing, the study concluded, the Wolffian duct degrades and an embryo by default develops as female.



A normal female mouse embryo (left) has only female reproductive tissue (pink). Removing a certain protein causes a female embryo to develop male reproductive tissue (blue) too.

That's the story written in textbooks, says Amanda Swain, a developmental biologist at the Institute of Cancer Research in London. But the new study "demonstrates that females also have a pathway to make sure you don't get the wrong ducts," says Swain, who wrote a commentary in the same issue of *Science*.

Testing the textbook explanation wasn't what Humphrey Yao, a reproductive biologist, and colleagues set out to do. Instead, the researchers wanted to learn how tissues on the outside of the early ducts communicate with the tubes' lining, says Yao, of the National Institute of Environmental Health Sciences in Research Triangle Park, N.C.

COUP-TFII is produced in that outer layer. Yao suspected it was involved in talking with the lining. The researchers blocked the communication in early female mouse embryos' reproductive tissue by removing the gene for COUP-TFII.

To the team's surprise, the Wolffian duct remained in the female mice along with the female Müllerian duct. Searching for an explanation, Yao and colleagues tested whether removing COUP-TFII changed the ovaries to produce testosterone like testes do. Testosterone could feed the male tissue and allow it to persist, the scientists thought.

ATOM & COSMOS

Moon's magnetism was long-lasting

Lunar dynamo persisted until at least 2.5 billon years ago

BY ASHLEY YEAGER

The moon had a magnetic field for at least 2 billion years, or maybe longer.

Analysis of a rock collected by Apollo astronauts reveals the moon had a weak magnetic field until 1 billion to 2.5 billion years ago, at least a billion years later than previous data showed. Extending this lifetime offers insights into how small bodies generate magnetic fields, researchers report August 9 in *Science Advances*. The result also suggests that life could survive on tiny planets or moons.

"A magnetic field protects the atmosphere of a planet or moon, and the atmosphere protects the surface," says study coauthor Sonia Tikoo, a planetary scientist at Rutgers University in New Brunswick, N.J. Together, the two protect a planetary body's potential habitability.

The roughly 4.5-billion-year-old moon does not currently have a global magnetic field. On Earth, molten rock sloshes around the outer core of the planet over time, causing electrically conductive fluid moving inside to form a magnetic field, in a setup known as a dynamo. At 1 percent of Earth's mass, the moon would have cooled too quickly to generate a long-lived roiling interior.

Magnetized rocks brought back by Apollo astronauts, however, have revealed that the moon must have had some magnetizing force. Previous studies have found that the magnetic field was strong at least 4.25 billion years ago but then dwindled and maybe even got cut off about 3.2 billion years ago.

Tikoo and colleagues reanalyzed a rock collected during the Apollo 15 mission in 1971. The team determined the 1-billion- to 2.5-billion-year-old rock was magnetized. The finding indicates the moon had a magnetic field, albeit a weak one, when the rock formed.

A drop in the magnetic field strength over time suggests that the dynamo driving the field was generated in two distinct ways, Tikoo says. Early on, Earth and the moon would have sat much closer together, allowing Earth's gravity to tug on and spin the moon's rocky exterior. That outer layer would have dragged against the liquid interior, generating friction and a very strong magnetic field.

Then slowly, starting about 3.5 billion years ago, the moon moved away from Earth, weakening the dynamo. But by

Researchers analyzing samples of this moon rock expanded the known history of how long the moon's magnetic field lasted.

FROM TOP: YAO LAB/NIEHS; NASA

"No, the ovary is just like an ovary. There's nothing wrong with it," Yao says. Further work demonstrated that no stray testosterone was responsible for the male tissue sticking around.

Instead, COUP-TFII appears to be the foreman of a biochemical wrecking crew that demolishes the Wolffian duct in females. Without the protein barking orders, the demolition crew is idle and the male duct isn't torn down. Signals that trigger COUP-TFII production and activity aren't yet understood.

"This study fills a void in our understanding of the mechanism of regression of the Wolffian duct," reproductive biologists Patricia Donahoe and David Pépin of Harvard Medical School said in an e-mail.

While the study was in mice, COUP-TFII probably works similarly in other mammals, including humans, Donahoe says. On occasion, females carry Wolffian duct remnants, which can lead to tumors. And sometimes males carry female reproductive organs, which can cause infertility and other problems. Researchers should look for defects in COUP-TFII in these patients, Donahoe says. ■

that point, the moon would have started to cool, causing less dense, hotter material in the core to rise and denser, cooler material to sink, as in Earth's core. This roiling of material would have sustained a weak field that lasted for at least a billion years, until the moon's interior cooled, causing the dynamo to die completely, the team suggests.

The two-pronged explanation for the moon's dynamo is "an entirely plausible idea," says Ian Garrick-Bethell, a planetary scientist at the University of California, Santa Cruz. But researchers are just starting to create computer simulations of the strength of magnetic fields to understand how such weaker fields might arise. So it is hard to know what generated the lunar dynamo, he says.

If the new idea is correct, other small planets and moons may also have weak, long-lived magnetic fields. Such an enduring shield could protect life from radiation, boosting its chances for survival. ■

B. SAVAGE/*SCIENCE* 2017

EARTH & ENVIRONMENT

Continents' bottoms found

Earthquake waves reveal thickness of landmasses

BY MARIA TEMMING

Earthquakes are revealing just how deep the continents beneath our feet go.

Scientists analyzed seismic waves from quakes that have rocked various regions of the world, including Antarctica, the Americas and Africa. Almost everywhere, patterns in these waves indicated a layer of partially melted material between 130 and 190 kilometers underground.

That boundary marks the bottom of continental plates, argue seismologist Saikiran Tharimena of the University of Southampton in England and colleagues. That finding, described in the Aug. 11 *Science*, may help resolve a debate over the thickness of Earth's landmasses.

Tectonic plates consist of the Earth's crust and the uppermost, rigid part of the mantle. Rock fragments belched up by volcanic eruptions suggest that the rigid rock of the continents extends about 175 kilometers underground, where it sits atop slightly runnier material in the mantle. But some analyses of earthquake vibrations have suggested that continents could run 200 or 300 kilometers deep, very gradually transitioning from cold, hard rock to hotter, gooier material.

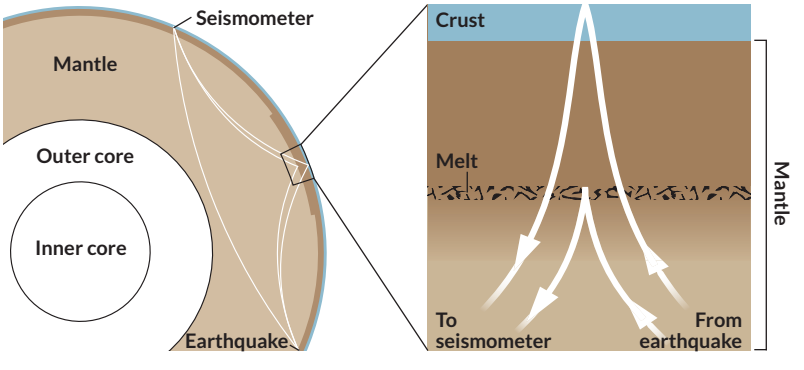
That disagreement may exist, says Tharimena, because seismologists had previously analyzed fairly shallow earthquake vibrations that couldn't show Earth's structure in fine detail at depths greater than about 150 kilometers.

Tharimena's team looked at waves that bounced off boundaries between different layers in Earth's upper mantle and other waves that ricocheted off the underside of the planet's surface before ultimately reaching the same seismometer. By measuring how long it took for each kind of wave to reach the seismometer, the researchers could map the depths and consistencies of different layers of materials in the continental plates.

The data reveal a sharp transition from rigid rock to slightly mushier material at a fairly similar depth for all continents. For instance, the melt starts about 182 kilometers under South Africa and about 163 kilometers under Antarctica. This is about as deep as diamonds are known to exist. Because diamonds are thought to reside only within continents, the team concluded that this partially melted layer marks the continents' bottom.

Getting this global estimate is "a big deal," says Brian Savage, a geophysicist at the University of Rhode Island in Kingston who wrote a commentary in the same issue of *Science*. The finding could lead to better simulations of plate tectonics, which could provide insights into what Earth looked like in the past and what it might look like in the future. ■

Bounce back Seismic waves take different routes from an earthquake to a seismometer (left). Some travel deep through Earth's mantle. Others reflect off a layer of melt in the upper mantle or bounce off the Earth's crust (right). By clocking the time it takes these reflected waves to reach the same seismometer, scientists say they have discovered a melt layer 130 to 190 kilometers deep that marks the bottom of continental plates.



HUMANS & SOCIETY

Chipped teeth hint at *Homo naledi* diet

Ancient hominid probably ate gritty or hard foods, study finds

BY BRUCE BOWER

Give *Homo naledi* credit for originality. The fossils of this humanlike species previously revealed a peculiar body plan. Now its pockmarked teeth speak to an unusually hard-edged diet.

H. naledi had a much higher rate of chipped teeth than other members of the human evolutionary family that once occupied the same region of South Africa, say biological anthropologist Ian Towle and colleagues. This kind of dental damage results from frequent biting and chewing on hard or gritty objects, such as tubers dug out of the ground, the researchers report in the September *American Journal of Physical Anthropology*.

"A diet containing hard and resistant foods like nuts and seeds, or contaminants such as grit, is most likely for *H. naledi*," says Towle, of Liverpool John Moores University in England.

> Extensive tooth chipping shows that "something unusual is going on" with *H. naledi*'s diet.
>
> PETER UNGAR

Extensive tooth chipping shows that "something unusual is going on" with *H. naledi*'s diet, says Peter Ungar, a paleoanthropologist at the University of Arkansas in Fayetteville. He directs ongoing microscopic studies of *H. naledi* teeth that may provide additional clues to what this species ate.

Grit from surrounding soil can coat nutrient-rich, underground plant parts, including tubers and roots. Regularly eating those things can cause the type of chipping found on *H. naledi* teeth, says paleobiologist Paul Constantino of Saint Michael's College in Colchester, Vt. "Many animals cannot access these underground plants, but primates can, especially if they use digging sticks."

Tooth damage sustained by *Homo naledi*, an ancient South African hominid, resulted from a diet heavy in hard or gritty objects, researchers say. One likely chip culprit: dirt-covered tubers pulled up from underground.

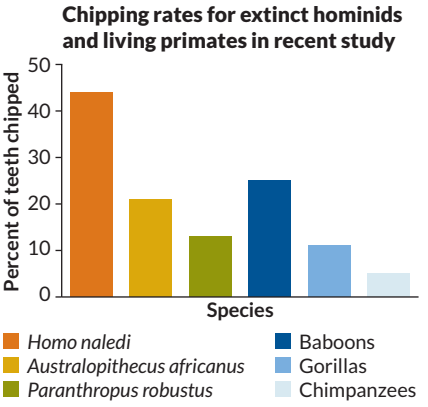
H. naledi fossils, first found in South Africa's Dinaledi Chamber and later in a second nearby cave (*SN: 6/10/17, p. 6*), date to 236,000 to 335,000 years ago. The species had a largely humanlike lower body, a relatively small brain and curved fingers suited for climbing trees.

Towle's group studied 126 of 156 permanent *H. naledi* teeth found in Dinaledi Chamber. Those finds come from a minimum of 12 individuals, nine of whom had at least one chipped chopper. Two of the remaining three individuals were represented by only one tooth. Excluded teeth were too damaged to study, had not erupted above the gum surface or showed signs of having rarely been used for chewing food.

Chips appear on 56, or about 44 percent, of the examined *H. naledi* teeth, Towle's team says. Half of those specimens sustained two or more chips. About 54 percent of molars and 44 percent of premolars, both found toward the back of the mouth, display at least one chip. For teeth at the front of the mouth, those figures fell to 25 percent for canines and 33 percent for incisors.

Chewing on small, hard objects must have caused all those chips, Towle says. Using teeth as tools, say to grasp animal hides, mainly damages front teeth, not cheek teeth as in *H. naledi*. Homemade toothpicks produce marks between teeth unlike those on the *H. naledi* finds.

Two South African hominids from between roughly 1 million and 3 million years ago, *Australopithecus africanus* and *Paranthropus robustus*, show lower rates of tooth chipping than *H. naledi*, at about 21 percent and 13 percent, respectively, the investigators find. Researchers have suspected that those species ate hard or gritty foods, though ancient menus are difficult to reconstruct (*SN: 6/4/11, p. 8*). Little evidence exists on the extent of tooth chipping in ancient *Homo* species. But if *H. naledi* consumed underground plants, Stone Age *Homo sapiens* in Africa likely did as well, Constantino says.



Dental dents *Homo naledi* had high rates of chipped teeth compared with other fossil hominids from South Africa. Among living primates, baboons, which eat gritty and hard foods, come closest to *H. naledi*'s chip rate. SOURCE: I. TOWLE, J.D. IRISH AND I. DE GROOTE/*AM. J. OF PHYS. ANTHROPOL.* 2017

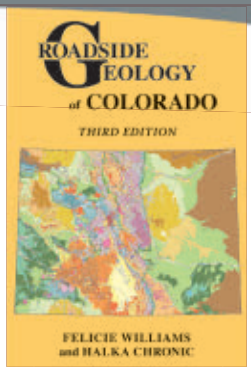
In further tooth comparisons with living primates, baboons — consumers of underground plants and hard-shelled fruits — showed the greatest similarity to *H. naledi*, with fractures on 25 percent of their teeth. That figure reached only about 11 percent in gorillas and 5 percent in chimpanzees.

Human teeth found at sites in Italy, Morocco and the United States show rates and patterns of tooth fractures similar to *H. naledi*. Two of those sites date to between 1,000 and 1,700 years ago. The third site, in Morocco, dates to between 11,000 and 12,000 years ago. People at all three sites are suspected to have had diets unusually heavy on gritty or hard-shelled foods, the scientists say.

Chips mar 50 percent of *H. naledi* right teeth, versus 38 percent of left teeth. That right-side tilt might signify that the Dinaledi crowd were mostly right-handers who typically placed food on the right side of their mouths. But more fossil teeth are needed to evaluate that possibility, Towle cautions. ■

FROM TOP: T. TIBBITTS; I. TOWLE

GEOLOGIC ROAD TRIP OF THE MONTH



MESA VERDE NATIONAL PARK

Mesa Verde National Park was established to preserve and display unusual archeological remains—clustered dwellings on the mesa surface and cave-sheltered apartment houses of people who inhabited this area from A.D. 900 to 1250. But the dramatic mesa with its high shale slopes and nearly impregnable sandstone cliffs is as distinctive geologically as the archeological sites it preserves.

Forming the lower slopes of Mesa Verde, the Mancos Shale is well exposed along the entrance road. This brownish gray shale accumulated as mud in the shallow sea that spread across the center of the continent in Cretaceous time. Many small faults offset its thin sandstone layers. It slides extremely easily, necessitating never-ending road repairs. In addition to removing landslide debris from the highway, repairs involve stabilizing slides by unloading their tops, buttressing their lower ends, and adding drainage pipes to lessen wetting of the shale. The ditch on the inner edge of the road catches small slides and rockfalls and helps drain rainwater and snowmelt from slide areas.

Above the Mancos Shale are shoreline sandstones of the Mesaverde Group, deposited as the Cretaceous sea retreated eastward. Originally defined as a single formation, the Mesaverde is now given group status and subdivided into three formations. The lowest of these, the Point Lookout Sandstone, forms the cliffs that top the northern end of Mesa Verde. Farther south it is overlain by the shale-coal sequence of the Menefee Formation, deposited in marshes and swamps close to the sea's edge. Above the Menefee Formation is the Cliffhouse Sandstone. The strata dip southward here; the Cliffhouse Sandstone and Menefee Formation have eroded off the high northern prow of Mesa Verde.

Slope-forming Mancos Shale and cliff-forming sandstones of the Mesaverde Group characterize Mesa Verde National Park. Erosion of the soft shale undermines resistant, blocky sandstone layers that form the upper cliffs. —Lucy Chronic photo

The cliff dwellings of Mesa Verde were built in sheltering recesses in the Cliffhouse Sandstone. Springs emerging at the bottom of the porous sandstone supplied water to the villages. The springs also promoted cave formation, weakening and undermining the rock. —Felicie Williams photo

The Menefee Formation erodes easily, undermining the massive, light-colored Cliffhouse Sandstone. Rainwater percolating through the porous sandstone reaches the less permeable shales of the Menefee Formation and flows sideways along the layers. Weakened by seepage from small springs where this flow emerges from the cliffs, the sandstone falls away or spalls off in great arcs to create the arched caves that sheltered early inhabitants. What could be more convenient than a weatherproof shelter furnished by nature, complete with a supply of running—or at least seeping—water? The cliffs of the Point Lookout Sandstone below sufficed to keep out enemies and provided a ready disposal system: refuse was just tossed over the edge. Archeologists searching for clues to the daily life of early inhabitants often look along the base of the cliffs.

Streams that drain Mesa Verde are typical of plateau areas. Upstream, each major stream branches again and again to form a treelike or dendritic pattern. Stream erosion is not severe here now, but during times of more intense rainfall, as in the rainy cycles that accompanied Ice Age glaciation, each small stream worked its way headward into the plateau, branching and rebranching, following joints in the rock to carve the narrow, steep ravines. As a result, the mesa is shaped something like a human hand, with deep canyons draining southward between its long fingers.

The first inhabitants of Mesa Verde lived on the surface of the plateau, where they built pit houses, farmed, and hunted. Farming was facilitated by a thin coating of fine, even-grained soil, wind-deposited silt dating back to Pleistocene times. Later, cave dwellings gave protection from both weather and enemies; farming still continued on the top of the mesa. Cave dwellings were occupied for less than one hundred years before their abandonment, which may have been caused by a twenty-four-year drought dated by tree-ring studies. Many other ruins in the Southwest were abandoned at about the same time.

LIFE & EVOLUTION

Polluted reefs may favor dark snakes

Skin pigment could help the reptiles get rid of toxic metals

BY SUSAN MILIUS

Maybe it's more than reptile fashion. The high percentage of citified sea snakes wearing black might be a sign that pollution is an evolutionary force.

Off the coasts of Australia and New Caledonia, some turtle-headed sea snakes (*Emydocephalus annulatus*) sport pale bands on their dark skins. Others go all black. In 15 places surveyed, the all-black form was more likely to predominate in waters near cities, a military site or industrial zones than along more pristine reefs, says Rick Shine, an evolutionary ecologist at the University of Sydney.

That trend, plus some analysis of trace elements in snakes' skin, suggests that the abundant dark forms could turn out to be an example of industrial melanism, or darkening due to pollution, Shine and his colleagues propose in the Aug. 21 *Current Biology*.

The most famous example of this evolutionary phenomenon comes from a dark form of peppered moth that overtook pale populations in 19th century England (*SN: 6/25/16, p. 6*). Darker wings created better camouflage from hungry birds in the grimy industrializing landscape.

Turtle-headed sea snakes can be fully dark (left) or sport pale bands (right). Dark coloring may be more advantageous in polluted waters, researchers propose, because the dark skin pigment binds to toxic metals that get sloughed off when a snake sheds its skin (as the snake at left is doing).

Shine doesn't think the sea snakes are going for camouflage, though. Instead, the snakes could be more like the dark-feathered pigeons of Paris. The melanin that gives that city's feral birds their urban chic also does a great job of binding traces of toxic metals such as zinc, explains evolutionary ecologist Marion Chatelain of the University of Warsaw. When birds molt, getting rid of darker feathers lets them unload more of the unhealthful urban pollutants, she and colleagues have reported.

This process could explain why marine biologist and study coauthor Claire Goiran has so many dark turtle-headed sea snakes in the lagoon not far from her University of New Caledonia in Nouméa campus. Earlier studies had found only downsides to dark coloration: More seaweed spores colonize dark snakes, and the fuzz can cut swimming speed by 20 percent and cause a snake to shed its skin more often than normal.

To test a scenario of industrial melanism, the researchers collected data on skin colors for a total of about 1,450 snakes, both live and museum specimens, from 15 sites in New Caledonia and Australia. Higher percentages of all-dark snakes wriggled around the nine polluted sites surveyed. At one, a remote Australian reef that the military had long used as a bombing range, all 13 specimens were dark.

To test shed skins for trace metals, Goiran and Shine enlisted the help of Paco Bustamante of the University of La Rochelle in France, who studies trace metal contamination in marine life.

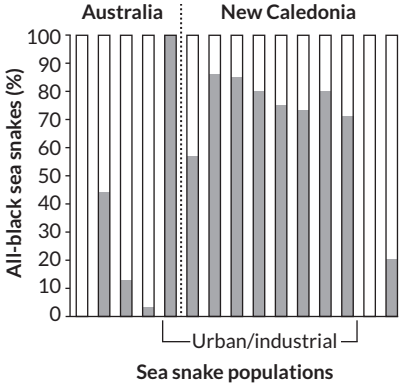
The researchers managed to collect sloughed skins from 17 turtle-headed snakes, which inconveniently shed their skin underwater. For a larger sample to compare light and dark patches, the scientists turned to two local species of sea kraits, which have banded skin and visit land to shed it.

Overall, sea snake skins held concentrations of trace elements higher than those that can cause health problems in birds and mammals, the researchers report. In the krait skins, dark zones had slightly more of some contaminants, such as zinc and arsenic, than pale bands did.

The idea that polluted water favors melanized sea snakes "is a reasonable hypothesis," Chatelain says. Definitive tests will require more data and different approaches. Genetic testing, for example, would clarify whether dark populations arose instead from small groups of pioneers that happened to have a lot of black snakes.

That testing could be a long way off. Sea snakes are evolutionary cousins of cobras and mambas, and some of the species swimming around Australia and New Caledonia are "bowel-loosenings large," Shine says. At least the little turtle-headed ones, which eat eggs of small reef fish, have venom glands that have atrophied and "probably couldn't fit a human finger in their mouths." But until someone figures out how to keep the snakes alive in captivity for more than a few days, Shine isn't expecting definitive genetics. ■

Where dark snakes live Across 15 sites in Australia and New Caledonia, turtle-headed sea snake populations in urban or industrial areas had higher percentages of black snakes than populations in more pristine waters. The pattern supports the idea that darkening might help snakes cope with pollution.



SNAKES: C. GOIRAN; GRAPH: C. GOIRAN, P. BUSTAMANTE AND R. SHINE/*CURRENT BIOLOGY* 2017

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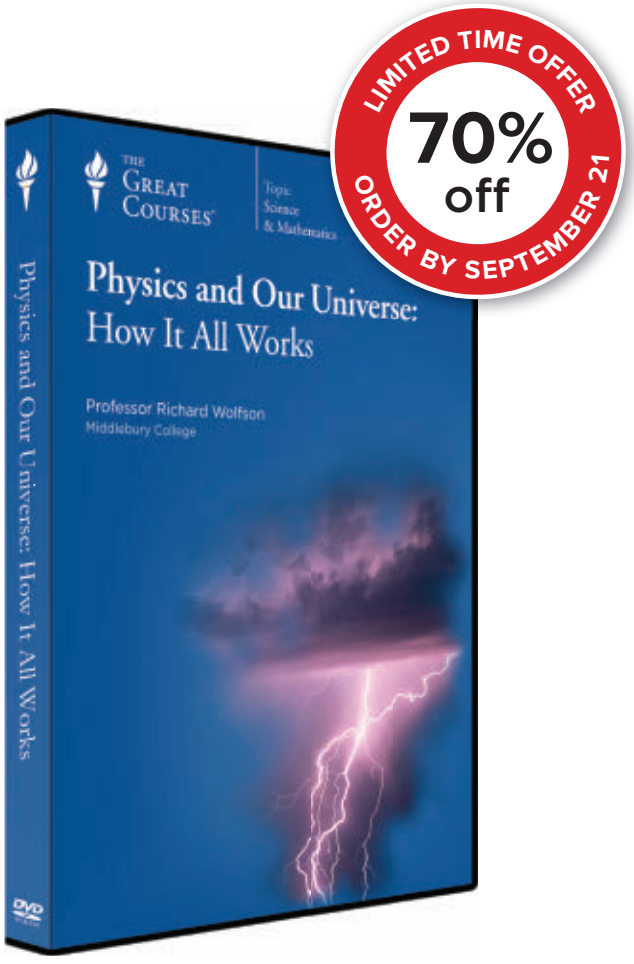

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ATOM & COSMOS

Cosmic lens sees black hole's burps

Observations could someday help explain origins of hot jets

BY LISA GROSSMAN

Astronomers have caught their best look yet at blobs of hot gas fleeing a supermassive black hole, thanks to a new kind of cosmic magnifying glass.

Anthony Readhead of the Owens Valley Radio Observatory at Caltech and colleagues caught two small, hot bursts traveling away from a bright galaxy called J1415+1320 at near the speed of light. Although the galaxy is billions of light-years away and the blobs are tiny compared with the galaxy, a lucky alignment may have created what's called a gravitational lens that magnified the galaxy and its environs.

"We're peering right down into the core of the nucleus of this active galaxy," Readhead says. "We think this is potentially a very powerful new window." The researchers report the findings in two papers in the Aug. 20 *Astrophysical Journal*.

Supermassive black holes shoot hot jets thousands of light-years into space (like this one emerging from galaxy M87). For the first time, scientists think they've detected the start of such a jet.

J1415+1320 is a blazar, a bright galaxy with a supermassive black hole at its center that's emitting a plasma jet pointed toward Earth. The black hole is feeding on a disk of white-hot gas that swirls around it, making the host galaxy glow brightly in gamma and radio waves. Readhead and his team have observed the galaxy twice a week since 2008.

In 2009, J1415+1320 started doing something strange. Over the course of about a year, the blazar grew brighter, then dimmer, then brighter again. Plotting the brightness over time revealed a symmetrical U shape in the data.

At first, the team thought the change was caused by a cloud of plasma within the Milky Way that happened to pass between Earth and the blazar, scattering its light. But then the same thing happened again in 2014.

Conversations with colleagues at other observatories revealed that the galaxy behaved the same way when observed in many electromagnetic wavelengths, not just with a radio telescope. That wouldn't happen if a stray cloud of plasma were to blame.

Now, Readhead and colleagues argue that what they've seen is the blazar's black hole emitting burps of plasma, magnified 100 times by a new kind of gravitational lens. These cosmic lenses are massive objects that can bend the path of light passing by, making objects in the background look distorted from the point of view of telescopes on Earth. Astronomers can use this distortion to learn about the background objects and their lenses.

All known lenses so far have either been enormous — millions of times the mass of the sun, like an entire galaxy — or relatively tiny, like a single planet.

The lens that magnified J1415+1320 seems to be something in between. It's about 2.7 billion light-years away and associated with a spiral galaxy, but is less massive than the entire galaxy. The lens could lie within or near the galaxy and could be a collection of thousands of stars. Or it could be something more exotic, like difficult-to-spot midsize black holes.

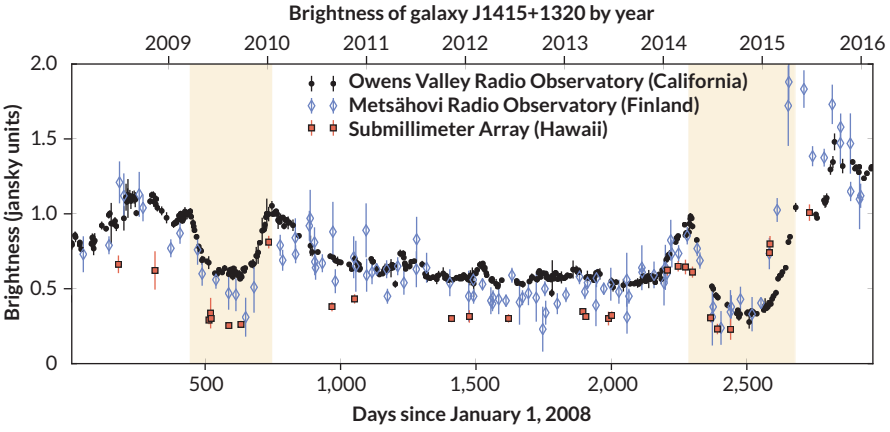
The data's U-shaped features appeared when the background black hole emitted matter that sped away at nearly the speed of light and passed behind this lens from the perspective of Earth, the team says.

"As far as I know, there's nothing like that that has been observed before," says astrophysicist Eileen Meyer of the University of Maryland, Baltimore County.

If the lens is indeed real, the finding could help solve the mystery of how black holes shoot out hot charged particles. "We actually don't know how these jets are launched," says Harish Vedantham, also of the Owens Valley Radio Observatory and a coauthor of the new papers. "We don't have definitive answers because we can't make an image on the [size] scales of where this emission is happening."

The new observations suggest a way to produce such an image. The lens magnified the black hole 100 times as much as is possible with current telescopes, so more observations could help reveal more about its nature.

If more observations rule out the lens, things could get even stranger. "If it's not a gravitational lens, then it's an intrinsic property of the jets themselves," says Readhead. "Then it will have interesting implications for the physics of the actual jet. I think it's a win-win situation." ■



Now 'U' see it Galaxy J1415+1320 dimmed and brightened over the course of a year in 2009 and in 2014 (shaded regions), causing U-shaped dips in data tracking the galaxy's brightness. The dimming may have been caused by the galaxy's black hole emitting blobs of hot plasma, which were magnified by a cluster of stars acting as a cosmic lens, researchers report.

FROM TOP: H.K. VEDANTHAM *ET AL/ASTROPHYS. J.* 2017; HUBBLE HERITAGE TEAM/STSCI/AURA, NASA, ESA

MATH & TECHNOLOGY

Tiny antennas read signals in new way

Technology could be useful for wearable, injectable electronics

BY MARIA TEMMING

Antennas just got a whole lot smaller.

Tiny chips that communicate via radio waves are a tenth to a hundredth the length of current state-of-the-art compact antennas. At only a couple hundred micrometers across — comparable to the thickness of a piece of paper — these next-gen antennas can relay the same types of signals as those used by TVs, cell phones and radios, researchers report August 22 in *Nature Communications*. The advance could pave the way for wearable, or even injectable, electronics, says Nian Sun, a study coauthor and an electrical and computer engineer at Northeastern University in Boston.

Antenna miniaturization has stalled for decades, so these minuscule devices are "a huge deal," says biomedical engineer John Domann of Virginia Tech.

A traditional antenna picks up signals when electromagnetic waves moving through the air wash over it, causing the antenna's electrons to flow through it in a current. That current creates an electric voltage, essentially a readout of the message the electromagnetic waves carried.

But the longer the wavelength, the longer an antenna must be to generate a voltage big enough to convey that message clearly, Domann says. An antenna typically needs to be at least one-tenth the length of the electromagnetic waves it's picking up. For instance, cell phones tuned in to 11- to 15-centimeter-long radio waves need antennas at least a few centimeters long to get good reception.

In the new study, the researchers overcame that size limit by fashioning antennas that use a different method to translate signals. When electromagnetic waves pass over one of these chip antennas, the waves activate atoms in a layer of magnetic material. Similar to the way sport spectators stand and sit to create waves that ripple across a stadium, the atoms switch their magnetic alignments back and forth creating a magnetic current that runs through the chip.

That magnetic current vibrates an underlying layer of piezoelectric material — a material that generates voltage when bent or squeezed. Since the vibrations create much shorter waves than those from incoming airborne electromagnetic signals, an antenna can be much smaller and still work.

The researchers built tiny antennas whose communications fell within the range of radio frequencies used by GPS, Wi-Fi, FM radio and broadcast TV.

Teeny antennas could have many practical applications. Domann says he is most excited about potential biomedical uses, such as implantable devices that could monitor patients and then transmit information to doctors in real time. ■

MATTER & ENERGY

Molecules face the biggest chill

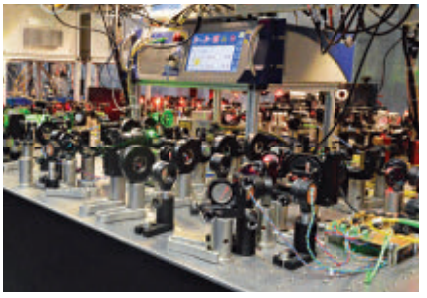
Lasers push temperatures lower than previous limit

BY EMILY CONOVER

Molecules are seriously chilling out. Scientists report the first cooling of molecules below a previously impassable milestone. The result, in which scientists cooled molecules down to tens of millionths of a degree, is a step toward reaching the ultracold temperatures already achievable with atoms, researchers report August 28 in *Nature Physics*.

Scientists regularly chill atoms to less than a millionth of a degree above absolute zero (–273.15° Celsius), even reaching temperatures as low as 50 trillionths of a degree (*SN: 5/16/15, p. 4*). But molecules are more difficult to cool, as they can spin and vibrate in a variety of ways and that motion is a form of heat.

Previously, physicists have made ultracold molecules by convincing pre-chilled atoms to link up (*SN: 12/20/08, p. 22*), but the technique works for only a few kinds of molecules. Putting the freeze on already assembled molecules has allowed scientists to chill additional types but, until now, down to only a few hundreds of millionths of degrees.



Using this complex setup of lasers, physicists cooled molecules to a frosty 50 millionths of a degree above absolute zero.

Using lasers and magnetic fields, the scientists corralled and cooled molecules inside a magneto-optical trap. In the trap, molecules of calcium monofluoride are slowed — and therefore cooled — when they absorb photons from a laser. But only so much cooling is possible. So to go beyond what's called the Doppler limit, the team then adapted a method used for cooling atoms, known as Sisyphus cooling. Two lasers pointed at one another create an electromagnetic field that acts like an endless hill the molecule must climb, thereby sapping its energy and heat. With these two techniques, the molecules reached about 50 millionths of a degree above absolute zero.

As the art of laser cooling advanced in recent decades, ultracold atoms became a popular research topic. Study coauthor Michael Tarbutt, a physicist at Imperial College London, predicts cold-molecule research is "going to explode in exactly the same way that it did for cold atoms."

Cold molecules could be useful for a variety of scientific purposes: studying how chemical reactions occur, looking for hints of new fundamental particles or simulating complex quantum materials in which many particles interact at once.

"It's a really exciting result," says physicist David DeMille of Yale University. "It turns out it's harder in almost every way to apply laser cooling and trapping to molecules, but there are many, many motivations for doing that." ■

BODY & BRAIN

How an itch hitches a ride to the brain

Spinal cord sends signals to a region involved in other sensations

BY LAUREL HAMERS

Scientists have traced the sensation of itch to a place you can't scratch.

The discomfort of a mosquito bite or an allergic reaction activates itch-sensitive nerve cells in the spinal cord. Those neurons talk to the parabrachial nucleus, researchers report in the Aug. 18 *Science*. It's a brain region that's known to receive information about other sensations, such as pain and taste.

The discovery gets researchers one step closer to finding out where itch signals ultimately end up. "The parabrachial nucleus is just the first relay center for [itch signals] going into the brain," says study coauthor Yan-Gang Sun.

Understanding the way the brain handles these signals could someday provide relief for people with chronic itch, says Sun, a neuroscientist at the Chinese Academy of Sciences in Shanghai. While the itchiness of a bug bite is annoying, longer-term, "uncontrollable scratching behavior can cause serious skin damage."

Previous studies have looked at the way an itch registers on the skin or how neurons convey those sensations to the spinal cord. But how those signals travel to the brain has been a trickier question, and this research is a "major step" toward answering it, says Zhou-Feng Chen, director of the Center for the Study of Itch at Washington University School of Medicine in St. Louis.

A network of neurons in the spinal cord wrangles itch signals, previous research suggests. Spinal neurons that make a protein called gastrin-releasing peptide receptor have been shown to be important in itch signaling. But those neurons didn't link up directly to the parabrachial nucleus, or PBN, Sun's team found; instead, they talked to other neurons that send messages to the PBN.

When given a drug that induces allergic itching, mice showed greater activity in the neurons connecting the spinal cord to the PBN, Sun and colleagues found. In another experiment, the researchers silenced the activity of neurons that send messages to the PBN, and mice given either a drug that induces an allergic itch or one that causes chronic itchiness scratched less often.

It's too soon to say whether itch signals in humans follow the same route — or whether all itches take the same path. A drug-induced itch is different from one that comes from a light touch, and the brain might handle them differently. ■

MEILIN SANCHO/IMPERIAL COLLEGE LONDON

ROLF_52/ISTOCKPHOTO

Terra-cotta warriors, made over 2,200 years ago, stand in the tomb of China's first emperor. Distributing different clay pastes to specialized workshops enabled the production of so many finely crafted statues, scientists propose.

HUMANS & SOCIETY

Clay army made from custom pastes

Specialized workshops shaped China's terra-cotta figures

BY BRUCE BOWER

China's first emperor broke the mold when he had himself buried with a terra-cotta army. Now insight into the careful crafting of those soldiers is coming from the clays used to build them. Custom clay pastes were mixed at a clay-making center and then distributed to specialized workshops that cranked out thousands of the life-size figures, new research suggests.

Roughly 700,000 craftsmen and laborers built Emperor Qin Shihuang's palatial mausoleum in east-central China between 247 B.C. and 210 B.C. A portion of those workers gathered clay from nearby deposits and prepared it in at least three forms, researchers propose in the August *Antiquity*. On-site or nearby workshops used different signature clay recipes for terra-cotta warriors, bronze waterfowl with clay cores and paving bricks for pits in which the soldiers stood.

Around 7,000 ceramic foot soldiers, generals and horses — equipped with a variety of bronze weapons — make up the army, which was accidentally discovered in 1974 by farmers digging a well. The emperor regarded the ceramic statues as a magic army that would protect him as he ruled in the afterlife, many researchers suspect.

Building and assembling the multitude was an enormous task. Workers poured clay mixtures into casts of torsos, limbs and other body parts, and then assembled the bodies, taking care to create different facial features for each soldier. Finished statues, now mostly gray, were covered in colored lacquers and probably fired in kilns. Most figures were placed inside one giant pit. Earthen walls formed 11 parallel corridors where statues stood in battle-ready rows.

> Workshops used different signature clay recipes for terra-cotta warriors, waterfowl figures and paving bricks.

Still, no workshops or debris firmly linked to the statue-making process have been found. So, the number, size, location and organization of workshops involved in producing the emperor's ceramic troops remain uncertain.

Patrick Quinn, an archaeologist at University College London, and three Chinese colleagues studied the composition of clay samples from the site. The pieces were taken from 12 terra-cotta warriors and five clay bricks from the largest pit, two acrobat statues and an earthen wall found in a second pit, and clay fragments from inside three bronze waterfowl statues in a third pit.

Microscopic analysis of the samples revealed that the clay came from deposits near the tomb's location, the scientists say. But the recipes for different parts varied. Paving bricks contained a mixture of only dark and light clays, while the clay used for warriors and acrobats had sand worked in. Sand and plant fragments were folded into a clay mixture that formed the core of the bronze waterfowl.

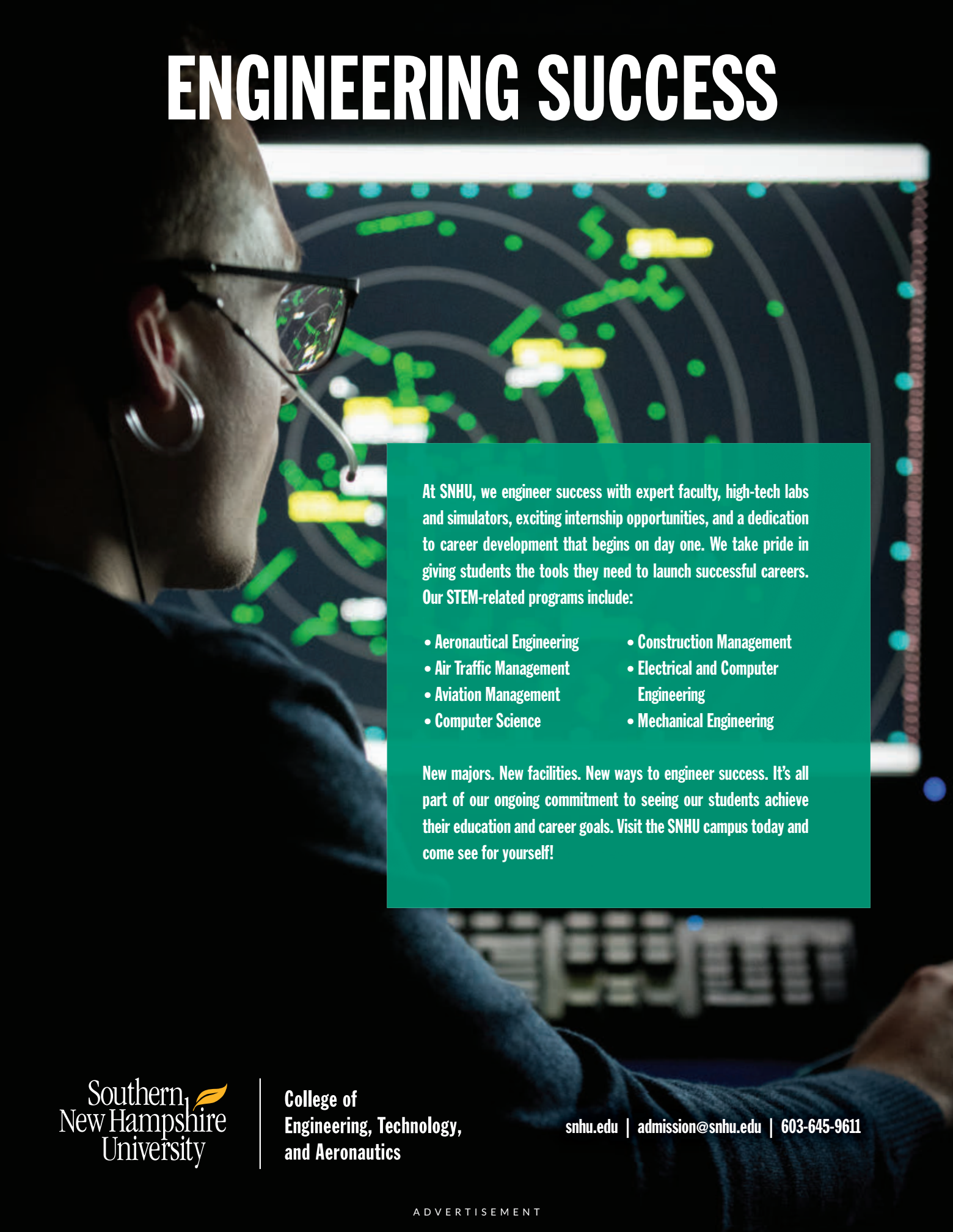
Sand may have made the clay more malleable for shaping into ornate figures and increased statues' durability, the researchers speculate. Plant pieces may have helped reduce the weight of birds' clay cores. A clay-processing site at or just outside the emperor's mausoleum must have doled out the appropriate clay pastes to an array of workshops where potters made statues, bricks or other objects, the scientists propose.

What's more, many statue and waterfowl samples show signs of having been slowly heated in kilns at temperatures of no more than 750° Celsius. That's at least 150 degrees lower than some previous estimates, the investigators say. Fires set during an attack on the tomb after the emperor's death may have refired some of the clay, accounting for the temperature discrepancy, the researchers say.

"I'm not at all surprised by the new findings," says East Asian art historian Robin D.S. Yates of McGill University in Montreal. Legal and administrative documents previously found at two other Qin Empire sites describe workshops that specialized in various types of craft production, Yates says.

In some cases, artisans' stamps and inscriptions on terra-cotta warriors match those on excavated roof tiles from Emperor Qin's mausoleum. The markings suggest that some workshops made several types of ceramic objects, says East Asian art historian Lothar Ledderose of Heidelberg University in Germany. Inscriptions on statues also indicate that artisans working at off-site factories collaborated with potters at local workshops to produce the terra-cotta army, Ledderose says. ■

ENGINEERING SUCCESS



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One such challenge has been the growing demand for engineering and other STEM-related programs. As more and more students enter college with the goal of earning high-paying jobs after graduation, the ability to offer a first-rate education responsive to the needs of a wide range of scientific industries is more important than ever.

Southern New Hampshire University has risen to meet this challenge by launching our brand new College of Engineering, Technology, and Aeronautics (CETA). At SNHU, we have always measured our success by our students' success, and this new college allows us to better serve our students' needs both now and into the future.

"They have an idea of what they want to be, and they want a university that's going to provide them with a learning environment to be able to succeed in that," says James Smith, CETA's executive vice president. "And clearly, they want a pathway to a job."

Guiding students along the path to their career goals has long been a strength at SNHU. The results speak for themselves—we've placed graduates at world-class companies and organizations ranging from Disney World to the Boston Celtics to the Department of Homeland Security—but we believe it's the way we go about it that makes us truly special.

We empower our students at SNHU. We empower them to shape their own education, but, more than that, we empower them to seek out the experience they need to find success in their field of study. Our Career and Professional Development Center posts over 1,000 internship and job listings each year, a number that is sure to grow as we develop new partnerships with engineering and aeronautical organizations for our CETA students. With career development opportunities built directly into our curriculum, our goal is to ensure that every student who leaves SNHU does so fully prepared to enter the workforce.

Improving access to education is one of SNHU's guiding principles, but we want to do more. CETA gives us the opportunity to serve yet another growing subset of students entering the world of higher education, and it also gives us the chance to put cutting-edge resources in the hands of those students.

Over the next three years, SNHU will invest $40 million in CETA, an investment that includes the construction of a new, state-of-the-art academic building that will house the college and its engineering and aeronautics labs. SNHU's College of Online and Continuing Education has given us access to resources that outpace many similarly sized institutions, and we will continue to use those resources to make improvements to our campus, expand our academic offerings, and make a high-quality private education accessible to as many students as possible.

If you'd like to learn more about Southern New Hampshire University, feel free to get in touch! You can email us at **admission@snhu.edu** or call us at **603-645-9611**.

Flex Time

The brain's ability to shift connections might ease learning

By Laura Sanders

ALEX NABAUM

Peer inside the brain of someone learning. You might be lucky enough to spy a synapse pop into existence. That physical bridge between two nerve cells seals new knowledge into the brain. As new information arrives, synapses form and strengthen, while others weaken, making way for new connections.

You might see more subtle changes, too, like fluctuations in the levels of signaling molecules, or even slight boosts in nerve cell activity. Over the last few decades, scientists have zoomed in on these microscopic changes that happen as the brain learns. And while that detailed scrutiny has revealed a lot about the synapses that wire our brains, it isn't enough. Neuroscientists still lack a complete picture of how the brain learns.

They may have been looking too closely. When it comes to the neuroscience of learning, zeroing in on synapse action misses the forest for the trees.

A new, zoomed-out approach attempts to make sense of the large-scale changes that enable learning. By studying the shifting interactions between many different brain regions over time, scientists are beginning to grasp how the brain takes in new information and holds onto it.

These kinds of studies rely on powerful math. Brain scientists are co-opting approaches developed in other network-based sciences, borrowing tools that reveal in precise, numerical terms the shape and function of the neural pathways that shift as human brains learn.

"When you're learning, it doesn't just require a change in activity in a single region," says Danielle Bassett, a network neuroscientist at the University of Pennsylvania. "It really requires many different regions to be involved." Her holistic approach asks, "what's actually happening in your brain while you're learning?" Bassett is charging ahead to both define this new field of "network neuroscience" and push its boundaries.

"This line of work is very promising," says neuroscientist Olaf Sporns of Indiana University Bloomington. Bassett's research, he says, has great potential to bridge gaps between brain-imaging studies and scientists' understanding of how learning happens. "I think she's very much on the right track."

Already, Bassett and others have found tantalizing hints that the brains that learn best have networks that are flexible, able to rejigger connections on the fly to allow new knowledge in. Some brain regions always communicate with the same neural partners, rarely switching to others. But brain regions that exhibit the most flexibility quickly swap who they're talking with, like a parent who sends a birthday party invite to the preschool e-mail list, then moments later, shoots off a work memo to colleagues.

In a few studies, researchers have witnessed this flexibility in action, watching networks reconfigure as people learn something while inside a brain scanner. Network flexibility may help several types of learning, though too much flexibility may be linked to disorders such as schizophrenia, studies suggest.

Not surprisingly, some researchers are rushing to apply this new information, testing ways to boost brain flexibility for those of us who may be too rigid in our neural connections.

"These are pretty new ideas," says cognitive neuroscientist Raphael Gerraty of Columbia University. The mathematical and computational tools required for this type of research didn't exist until recently, he says. So people just weren't thinking about learning from a large-scale network perspective. "In some ways, it was a pretty boring mathematical, computational roadblock," Gerraty says. But now the road is clear, opening "this conceptual avenue ... that people can now explore."

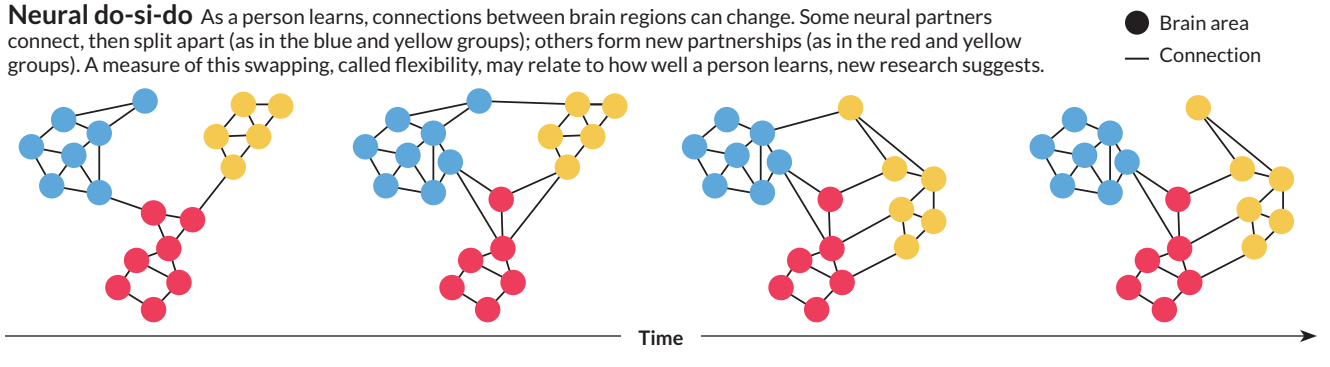
Special Report: Inner Potential

Every day we encounter new opportunities to learn. How do we best take advantage? *Science News* writers explore the come-and-go connections in the human brain, how machines that mimic learning can pick up biases and efforts to boost classroom learning.

It takes a neural village

That conceptual avenue is more of a map, made of countless neural roads. Even when a person learns something very simple, large swaths of the brain jump in to help. Learning an easy sequence of movements, like tapping out a brief tune on a keyboard, prompts activity in the part of the brain that directs finger movements. The action also calls in brain areas involved in

Neural do-si-do As a person learns, connections between brain regions can change. Some neural partners connect, then split apart (as in the blue and yellow groups); others form new partnerships (as in the red and yellow groups). A measure of this swapping, called flexibility, may relate to how well a person learns, new research suggests.



ADAPTED FROM D. BASSETT AND M. MATTAR/*TRENDS IN COGNITIVE SCIENCES* 2017

vision, decision making, memory and planning. And finger taps are a pretty basic type of learning. In many situations, learning calls up even more brain areas, integrating information from multiple sources, Gerraty says.

He and colleagues caught glimpses of some of these interactions by scanning the brains of people who had learned associations between two faces. Only one of the faces was then paired with a reward. In later experiments, the researchers tested whether people could figure out that the halo of good fortune associated with the one face also extended to the face it had been partnered with earlier. This process, called "transfer of learning," is something that people do all the time in daily life, such as when you're wary of the salad at a restaurant that recently served tainted cheese.

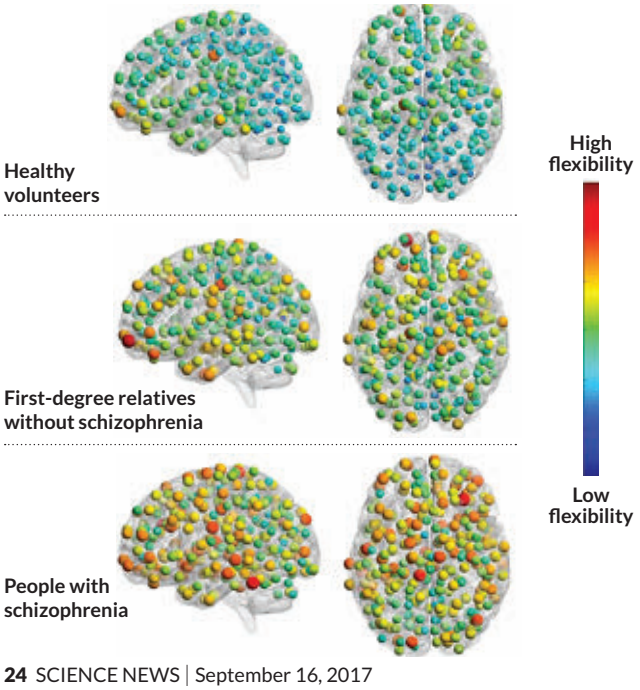
Study participants who were good at applying knowledge about one thing — in this case, a face — to a separate thing showed particular brain signatures, Gerraty and colleagues reported in 2014 in the *Journal of Neuroscience*. Connections between the hippocampus, a brain structure important for memory, and the ventromedial prefrontal cortex, involved in self-control and decision making, were weaker in good learners than in people who struggled to learn. The scans, performed several days after the learning task, revealed inherent differences between brains, the researchers say. The experiment also turned up other neural network differences among these regions and larger-scale networks that span the brain.

Children who have difficulty learning math, when scanned, also show unexpected brain connectivity, according to research by neuroscientist Vinod Menon of Stanford University and colleagues. Compared with kids without disabilities, children with developmental dyscalculia who were scanned while doing math problems had more connections, particularly among regions involved in solving math problems. That overconnectivity, described in 2015 in *Developmental Science*, was a surprise, Menon says, since earlier work had suggested that these math-related networks were too weak. But it may be that too many links create a system that can't accommodate new information. "The idea is that if you have a hyperconnected system, it's not going to be as responsive," he says.

There's a balance to be struck, Menon says. Neural pathways that are too weak can't carry necessary information, and pathways that are too connected won't allow new information to move in. But the problem isn't as simple as that. "It's not that everything is changing everywhere," he says. "There is a specificity to it." Some connections are more important than others, depending on the task.

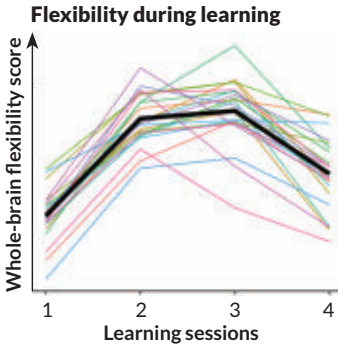
Neural networks need to shuttle information around quickly and fluidly. To really get a sense of this movement as opposed to snapshots frozen in time, scientists need to watch the brain as it learns. "The next stage is to figure out how the networks actually shift," Menon says. "That's where the studies from Dani Bassett and others will be very useful."

Too much of a good thing Compared with healthy people (top row), people with schizophrenia (bottom) and their close relatives (middle) showed signs of more flexibility across their brains. The greater the flexibility, the larger the spheres and redder the color.



Flex when needed

As people learned a new task — pairing a butterfly with a particular flower — brain flexibility changed in a recent study. Flexibility across the whole brain rose then dropped as training continued. Reasons for the decline are unclear, but information flow in the brain may change as people master a task. Each colored line represents one person's flexibility score over time (the black line is an average).



Flexing in real time

Bassett and colleagues have captured these changing networks as people learn. Volunteers were given simple sequences to tap out on a keyboard while undergoing a functional MRI scan. During six weeks of scanning as people learned the task, neural networks in their brains shifted around. Some connections grew stronger and some grew weaker, Bassett and her team reported in *Nature Neuroscience* in 2015.

People who quickly learned to tap the correct sequence of keys showed an interesting neural trait: As they learned, they shed certain connections between their frontal cortex, the outermost layer of the brain toward the front of the head, and the cingulate, which sits toward the middle of the brain. This connection has been implicated in directing attention, setting goals and making plans, skills that may be important for the early stages of learning but not for later stages, Bassett and colleagues suspect. Compared with slow learners, fast learners were more likely to have shunted these connections, a

FROM TOP: R. GERRATY *ET AL*/BIORXIV.ORG 2017; U. BRAUN *ET AL*/*PNAS* 2016

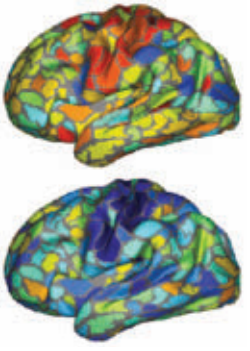
process that may have made their brains more efficient.

Flexibility seems to be important for other kinds of learning too. Reinforcement learning, in which right answers get a thumbs up and wrong answers are called out, also taps into brain flexibility, Gerraty, Bassett and others reported online May 30 at bioRxiv.org. This network comprises many points on the cortex, the brain's outer layer, and a deeper structure known as the striatum. Other work on language comprehension, published by Bassett and colleagues last year in *Cerebral Cortex*, found some brain regions that were able to quickly form and break connections.

These studies captured brains in the process of learning, revealing "a much more interesting network structure than what we previously thought when we were only looking at static snapshots," Gerraty says. The learning brain is incredibly dynamic, he says, with modules breaking off from partners and finding new ones.

While the details of those dynamics differ from study to study, there is an underlying commonality: "It seems that part of learning about the world is having parts of your brain become more flexible, and more able to communicate with different areas," Gerraty says. In other words, the act of learning takes flexibility.

But too much of a good thing may be bad. While performing a recall task in a scanner, people with schizophrenia had higher flexibility among neural networks across the brain than did healthy people, Bassett and colleagues reported last year in the *Proceedings of the National Academy of Sciences*. "That suggests to me that while flexibility is good for healthy people, there is perhaps such a thing as too much flexibility," Bassett says.



When you're happy and you know it

A team tracked one researcher's mood and brain flexibility for a year. When he was happiest, his brain was most flexible. Regions in which high flexibility was most closely linked with positive mood are red (top). When he was surprised, flexibility was low overall. Regions with the strongest link between surprise and low flexibility are dark blue (bottom).

Just how this flexibility arises, and what controls it, is unknown. Andrea Stocco, a cognitive neuroscientist at the University of Washington in Seattle, suspects that a group of brain structures called the basal ganglia, deep within the brain, has an important role in controlling flexibility. He compares this region, which includes the striatum, to an air traffic controller who shunts information to where it's most needed. One of the basal ganglia's jobs seems to be shutting things down. "Most of the time, the basal ganglia is blocking something," he says. Other researchers have found evidence that crucial "hubs" in the cortex help control flexibility.

Push for more

Researchers don't yet know how measures of flexibility in brain regions relate to the microscopic changes that accompany learning. For now, the macro and the micro views of learning are separate worlds. Despite that missing middle ground, researchers are charging ahead, looking for signs that neural flexibility might offer a way to boost learning aptitude.

It's possible that external brain stimulation may enhance flexibility. After receiving brain stimulation carefully aimed at a known memory circuit, people were better able to recall lists of words, scientists reported May 8 in *Current Biology*. If stimulation can boost memory, some argue, the technique could enhance flexibility and perhaps learning too.

Certain drugs show promise. DXM, found in some cough medicines, blocks proteins that help regulate nerve cell chatter. Compared with a placebo, the compound made some brain regions more flexible and able to rapidly switch partners in healthy people, Bassett and colleagues reported last year in the *Proceedings of the National Academy of Sciences*. She is also studying whether neurofeedback — a process in which people try to change their brain patterns to become more flexible with real-time monitoring — can help.

Something even simpler might work for boosting flexibility. On March 31 in *Scientific Reports*, Bassett and colleagues described their network analyses of an unusual subject. For a project called MyConnectome, neuroscientist Russ Poldrack, then at the University of Texas at Austin, had three brain scans a week for a year while assiduously tracking measures that included mood. Bassett and her team applied their mathematical tools to Poldrack's data to get measurements of his neural flexibility on any given scan day. The team then looked for associations with mood. The standout result: When Poldrack was happiest, his brain was most flexible, for reasons that aren't yet clear. (Flexibility was lowest when he was surprised.)

Those results are from a single person, so it's unknown how well they would generalize to others. What's more, the study identifies only a link, not that happiness causes more flexibility or vice versa. But the idea is intriguing, if not obvious, Bassett says. "Of course, no teacher is really going to say we're doing rocket science if we tell them we should make the kids happier and then they'll learn better." But finding out exactly how happiness relates to learning is important, she says.

The research is just getting started. But already, insights on learning are coming quickly from the small group of researchers viewing the brain as a matrix of nodes and links that deftly shift, swap and rearrange themselves. Zoomed out, network science brings to the brain "a whole new set of hypotheses and new ways of testing them," Bassett says. ■

Explore more

- Danielle Bassett and Marcelo G. Mattar. "A network neuroscience of human learning: Potential to inform quantitative theories of brain and behavior." *Trends in Cognitive Sciences*. April 2017.

Laura Sanders is a freelance writer based in Corvallis, Ore.

R.F. BETZEL ET AL/SCIENTIFIC REPORTS 2017

FAIR-MINDED MACHINES

A new drive to revamp artificial intelligence may cut down bias

By Maria Temming

ALEX NABAUM

You've probably encountered at least one machine-learning algorithm today. These clever computer codes sort search engine results, weed spam e-mails from inboxes and optimize navigation routes in real time. People entrust these programs with increasingly complex — and sometimes life-changing — decisions, such as diagnosing diseases and predicting criminal activity.

Machine-learning algorithms can make these sophisticated calls because they don't simply follow a series of programmed instructions the way traditional algorithms do. Instead, these souped-up programs study past examples of how to complete a task, discern patterns from the examples and use that information to make decisions on a case-by-case basis.

Unfortunately, letting machines with this artificial intelligence, or AI, figure things out for themselves doesn't just make them good critical "thinkers," it also gives them a chance to pick up biases.

Investigations in recent years have uncovered several ways algorithms exhibit discrimination. In 2015, researchers reported that Google's ad service preferentially displayed postings related to high-paying jobs to men. A 2016 ProPublica investigation found that COMPAS, a tool used by many courtrooms to predict whether a criminal will break the law again, wrongly predicted that black defendants would reoffend nearly twice as often as it made that wrong prediction for whites. The Human Rights Data Analysis Group also showed that the crime prediction tool PredPol could lead police to unfairly target low-income, minority neighborhoods (*SN Online: 3/8/17*). Clearly, algorithms' seemingly humanlike intelligence can come with humanlike prejudices.

"This is a very common issue with machine learning," says computer scientist Moritz Hardt of the University of California, Berkeley. Even if a programmer designs an algorithm without prejudicial intent, "you're very likely to end up in a situation that will have fairness issues," Hardt says. "This is more the default than the exception."

Developers may not even realize a program has taught itself certain prejudices. This problem gets down to what is known as a black box issue: How exactly is an algorithm reaching its conclusions? Since no one tells a machine-learning algorithm exactly how to do its job, it's often unclear — even to the algorithm's creator — how or why it ends up using data the way it does to make decisions.

Several socially conscious computer and data scientists have recently started wrestling with the problem of machine bias. Some have come up with ways to add fairness requirements into machine-learning systems. Others have found ways to illuminate the sources of algorithms' biased behavior. But the very nature of machine-learning algorithms as self-taught systems means there's no easy fix to make them play fair.

Learning by example

In most cases, machine learning is a game of algorithm see, algorithm do. The programmer assigns an algorithm a goal — say, predicting whether people will default on loans. But the machine gets no explicit instructions on how to achieve that goal. Instead, the programmer gives the algorithm a dataset to learn from, such as a cache of past loan applications labeled with whether the applicant defaulted.

The algorithm then tests various ways to combine loan application attributes to predict who will default. The program works through all of the applications in the dataset, fine-tuning its decision-making procedure along the way. Once fully trained, the algorithm should ideally be able to take any new loan application and accurately determine whether that person will default.

The trouble arises when training data are riddled with biases that an algorithm may incorporate into its decisions. For instance, if a human resources department's hiring algorithm is trained on historical employment data from a time when men were favored over women, it may recommend hiring men more often than women. Or, if there were fewer female applicants in the past, then the algorithm has fewer examples of those applications to learn from, and it may not be as accurate at judging women's applications.

At first glance, the answer seems obvious: Remove any sensitive features, such as race or sex, from the training data. The problem is, there are many ostensibly nonsensitive aspects of a dataset that could play proxy for some sensitive feature. Zip code may be strongly related to race, college major to sex, health to socioeconomic status.

And it may be impossible to tell how different pieces of data — sensitive or otherwise — factor into an algorithm's verdicts. Many machine-learning algorithms develop deliberative processes that involve so many thousands of complex steps that they're impossible for people to review.

Creators of machine-learning systems "used to be able to look at the source code of our programs and understand how they work, but that era is long gone," says Simon DeDeo, a cognitive scientist at Carnegie Mellon University in Pittsburgh. In many cases, neither an algorithm's authors nor its users care how it works, as long as it works, he adds. "It's like, 'I don't care how you made the food; it tastes good.'"

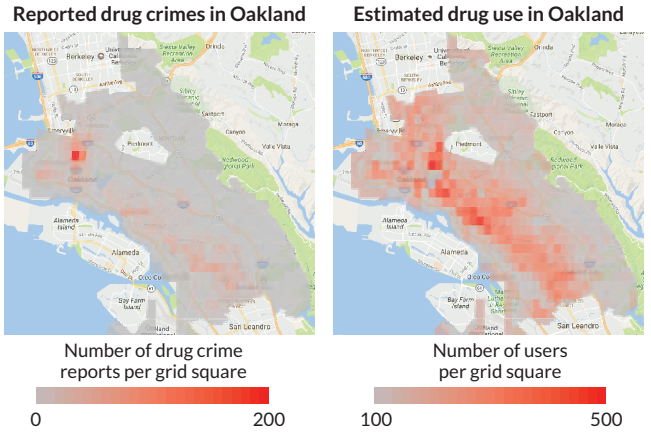
But in other cases, the inner workings of an algorithm could make the difference between someone getting parole, an executive position, a mortgage or even a scholarship. So computer

Pervasive tech

Machine learning has a growing list of jobs:

- Siri, Alexa and other virtual assistants
- Online vendors that serve up "you may also like" lists
- Image-recognition programs that tag photos on social media or identify weeds in crop fields
- Credit card fraud detection that alerts customers of unusual card activity
- Criminal prediction systems that weigh in on bond amount, sentence length and parole
- Systems that suggest medical treatments, such as IBM's Watson
- Gradescope and other apps that help teachers mark papers
- Language translator apps

Prediction prejudice A machine-learning program trained on drug crime data from Oakland, Calif., would offer a skewed perspective on where to send police officers. Reported drug crimes came mainly from nonwhite and low-income neighborhoods in 2010 (left). But 2011 public health data suggest drug use was much more widespread (right).



and data scientists are coming up with creative ways to work around the black box status of machine-learning algorithms.

Setting algorithms straight

Some researchers have suggested that training data could be edited before given to machine-learning programs so that the data are less likely to imbue algorithms with bias. In 2015, one group proposed testing data for potential bias by building a computer program that uses people's nonsensitive features to predict their sensitive ones, like race or sex. If the program could do this with reasonable accuracy, the dataset's sensitive and nonsensitive attributes were tightly connected, the researchers concluded. That tight connection was liable to train discriminatory machine-learning algorithms.

To fix bias-prone datasets, the scientists proposed altering the values of whatever nonsensitive elements their computer program had used to predict sensitive features. For instance, if their program had relied heavily on zip code to predict race, the researchers could assign fake values to more and more digits of people's zip codes until they were no longer a useful predictor for race. The data could be used to train an algorithm clear of that bias — though there might be a tradeoff with accuracy.

On the flip side, other research groups have proposed de-biasing the outputs of already-trained machine-learning algorithms. In 2016 at the Conference on Neural Information Processing Systems in Barcelona, Hardt and colleagues recommended comparing a machine-learning algorithm's past predictions with real-world outcomes to see if the algorithm was making mistakes equally for different demographics. This was meant to prevent situations like the one created by COMPAS, which made wrong predictions about black and white defendants at different rates. Among defendants who didn't go on to commit more crimes, blacks were flagged by COMPAS as future criminals more often than whites. Among those who did break the law again, whites were more often mislabeled as low-risk for future criminal activity.

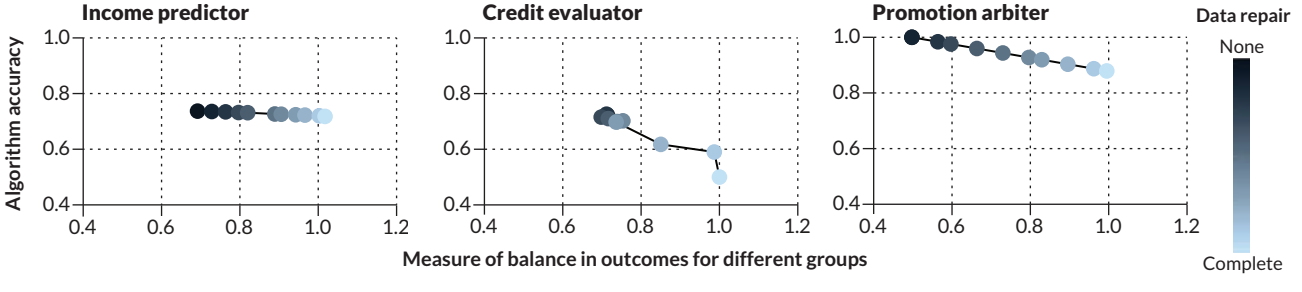
For a machine-learning algorithm that exhibits this kind of discrimination, Hardt's team suggested switching some of the program's past decisions until each demographic gets erroneous outputs at the same rate. Then, that amount of output muddling, a sort of correction, could be applied to future verdicts to ensure continued even-handedness. One limitation, Hardt points out, is that it may take a while to collect a sufficient stockpile of actual outcomes to compare with the algorithm's predictions.

A third camp of researchers has written fairness guidelines into the machine-learning algorithms themselves. The idea is that when people let an algorithm loose on a training dataset, they don't just give the software the goal of making accurate decisions. The programmers also tell the algorithm that its outputs must meet some certain standard of fairness, so it should design its decision-making procedure accordingly.

In April, computer scientist Bilal Zafar of the Max Planck Institute for Software Systems in Kaiserslautern, Germany, and colleagues proposed that developers add instructions to machine-learning algorithms to ensure they dole out errors to different demographics at equal rates — the same type of requirement Hardt's team set. This technique, presented in Perth, Australia, at the International World Wide Web Conference, requires that the training data have information about whether the examples in the dataset were actually good or bad decisions. For something like stop-and-frisk data, where it's known whether a frisked person actually had a weapon, the approach works. Developers could add code to their program that tells it to account for past wrongful stops.

Zafar and colleagues tested their technique by designing a

Fix it To try to remove bias, researchers altered the training data used to teach three algorithms: an income predictor, a credit scorer and a judge of promotion-worthiness. For all three, the change could bring the ratio of outputs for different demographics up to 1 (the mark of complete balance between groups). However, the data-fixing decreased accuracy for credit scores and promotion decisions. SOURCE: M. FELDMAN *ET AL*/ARXIV.ORG 2015



FROM TOP: K. LUM/HRDAG; E. OTWELL

crime-predicting machine-learning algorithm with specific nondiscrimination instructions. The researchers trained their algorithm on a dataset containing criminal profiles and whether those people actually reoffended. By forcing their algorithm to be a more equal opportunity error-maker, the researchers were able to reduce the difference between how often blacks and whites who didn't recommit were wrongly classified as being likely to do so: The fraction of people that COMPAS mislabeled as future criminals was about 45 percent for blacks and 23 percent for whites. In the researchers' new algorithm, misclassification of blacks dropped to 26 percent and held at 23 percent for whites.

These are just a few recent additions to a small, but expanding, toolbox of techniques for forcing fairness on machine-learning systems. But how these algorithmic fix-its stack up against one another is an open question since many of them use different standards of fairness. Some require algorithms to give members of different populations certain results at about the same rate. Others tell an algorithm to accurately classify or misclassify different groups at the same rate. Still others work with definitions of individual fairness that require algorithms to treat people who are similar barring one sensitive feature similarly. To complicate matters, recent research has shown that, in some cases, meeting more than one fairness criterion at once can be impossible.

"We have to think about forms of unfairness that we may want to eliminate, rather than hoping for a system that is absolutely fair in every possible dimension," says Anupam Datta, a computer scientist at Carnegie Mellon.

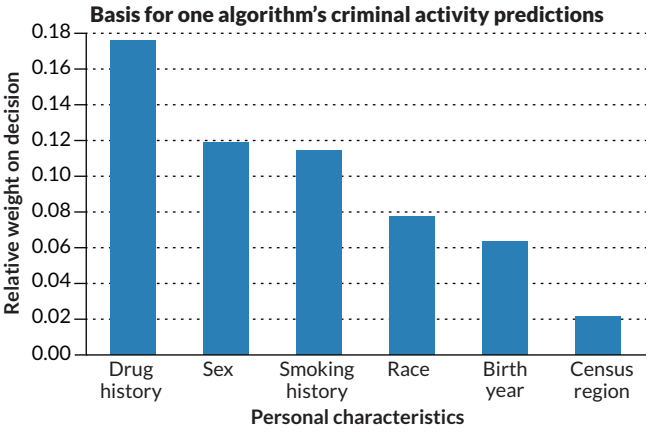
Still, those who don't want to commit to one standard of fairness can perform de-biasing procedures after the fact to see whether outputs change, Hardt says, which could be a warning sign of algorithmic bias.

Show your work

But even if someone discovered that an algorithm fell short of some fairness standard, that wouldn't necessarily mean the program needed to be changed, Datta says. He imagines a scenario in which a credit-classifying algorithm might give favorable results to some races more than others. If the algorithm based its decisions on race or some race-related variable like zip code that shouldn't affect credit scoring, that would be a problem. But what if the algorithm's scores relied heavily on debt-to-income ratio, which may also be associated with race? "We may want to allow that," Datta says, since debt-to-income ratio is a feature directly relevant to credit.

Of course, users can't easily judge an algorithm's fairness on these finer points when its reasoning is a total black box. So computer scientists have to find indirect ways to discern what machine-learning systems are up to.

One technique for interrogating algorithms, proposed by Datta and colleagues in 2016 in San Jose, Calif., at the IEEE Symposium on Security and Privacy, involves altering the inputs of an algorithm and observing how that affects the outputs. "Let's say I'm interested in understanding the influence of my age on this decision, or my gender on this decision," Datta says. "Then I might be interested in asking, 'What if I had a clone that was identical to me, but the gender was flipped? Would the outcome be different or not?' " In this way, the researchers could determine how much individual features or groups of features affect an algorithm's judgments. Users performing this kind of auditing could decide for themselves whether the algorithm's use of data was cause for concern. Of course, if the code's behavior is deemed unacceptable, there's still the question of what to do about it. There's no "So your algorithm is biased, now what?" instruction manual.



Inside AI Computer scientist Anupam Datta and colleagues devised a way to show how various dataset features influence an algorithm's output. In an algorithm that predicts a person's likelihood of committing crimes, race had a role but carried less weight than drug history.
SOURCE: A. DATTA, S. SEN AND Y. ZICK/IEEE SYMPOSIUM ON SECURITY AND PRIVACY 2016

The effort to curb machine bias is still in its nascent stages. "I'm not aware of any system either identifying or resolving discrimination that's actively deployed in any application," says Nathan Srebro, a computer scientist at the University of Chicago. "Right now, it's mostly trying to figure things out."

Computer scientist Suresh Venkatasubramanian agrees. "Every research area has to go through this exploration phase," he says, "where we may have only very preliminary and half-baked answers, but the questions are interesting."

Still, Venkatasubramanian, of the University of Utah in Salt Lake City, is optimistic about the future of this important corner of computer and data science. "For a couple of years now ... the cadence of the debate has gone something like this: 'Algorithms are awesome, we should use them everywhere. Oh no, algorithms are not awesome, here are their problems,' " he says. But now, at least, people have started proposing solutions, and weighing the various benefits and limitations of those ideas. So, he says, "we're not freaking out as much." ■

Explore more

- "Machine learning: the power and promise of computers that learn by example." The Royal Society, 2017. royalsociety.org/machine-learning

E. OTWELL

Make it stick

Teaching methods from lab studies move into classrooms

By Susan Gaidos

Sure, students in the classroom have to remember facts, but they also have to apply them. Some research efforts to enhance learning zero in on methods to strengthen memory and recall, while others bolster students' abilities to stay on task, think more fluidly and mentally track and juggle information.

But there's a catch. The science behind student learning is so far based on carefully controlled studies, primarily with college students. Do the same approaches work with younger students? Will they work in a classroom of 25 or 30 kids of varying abilities?

These are questions researchers are asking now, says Erin Higgins of the U.S. Department of Education's National Center for Education Research. Moving from the lab to a classroom, with all its disruptions and distractions, is key for pinning down what works, under what conditions and for whom. In the process of tweaking some of the most promising tools and strategies for classroom use, educators hope to find ways to help low-performing students gain skills that already pay off for their more successful peers. The efforts described here draw on new, innovative training methods to boost learning in K-12 classrooms. Higgins calls them "great examples" of the work under way.

Recall with cues

For college students, "free recall" is one of the most effective ways to make new knowledge stick, says psychologist Jeffrey Karpicke of Purdue University in West Lafayette, Ind. Students who read a passage and then jotted down details they remembered from the material recalled about 50 percent more information a week later than did students who just reviewed the material.

The trick for younger learners, Karpicke found, is to provide cues to help recall, without making the task too easy. After studying lists of unrelated words (banana and football), fourth-graders either restudied the words or practiced retrieving them from memory before taking a free recall test. Findings, published last year in *Frontiers in Psychology*, show that children at all reading levels remembered at least 25 percent more words when they practiced retrieving with the help of some cues compared with just rereading the lists.

With psychologist Michael Jones of Indiana University Bloomington, Karpicke is creating a computer-based self-test to help kids hone their retrieval skills. Students might have to answer fill-in-the-blank questions or rearrange scrambled words. Teachers will be able to tailor the tests to the curriculum. Parts of the program are being tested in schools in West Lafayette this year. The program gets harder as children succeed but easier if they struggle. "It's important that students experience success," Karpicke says, while keeping the task challenging.

Hold that thought

Working memory, which allows a person to hold on to information long enough to use it, is often a weakness in children who struggle with math, says educational psychologist Lynn Fuchs of Vanderbilt University in Nashville.

Handy for remembering a phone number long enough to find a pen to write it down or for multiplying numbers in our heads, working memory can be strengthened through exercises that put progressively tougher demands on it. But general training may not be enough to help struggling math learners, according to a 2015 review of school-based programs, published in the *Journal of Educational Psychology*.

Fuchs has developed a routine that embeds working memory exercises within math lessons. Designed for second-graders at risk for math difficulties, the program has students focus on key words in a word problem and hold the words in mind while breaking the problem into smaller segments and choosing the right math tools to solve the problem.

Aiming to catch young learners before they fall behind, researchers are testing the program in Nashville classrooms this school year.

ALL: ALEX NABAUM

Sum of the parts

Researchers typically test one new strategy in isolation, but in real classrooms, educators may try more than one approach at once. Jodi Davenport of WestEd, a San Francisco–based education research and development group, codirected a multi-institutional effort to revise a seventh-grade math curriculum using a handful of promising strategies.

Lessons were spaced out to expose students to key concepts or procedures multiple times and were combined with frequent quizzes. Graphics accompanied examples of how to work a problem, to strengthen the connection between the visual and verbal material. Researchers trained 181 teachers at 114 schools and then tracked 2,465 students in 22 states over a full school year.

Strategies such as showing incorrect examples along with correct ones (to point out common errors) and removing distracting information were especially helpful to underperforming students, Davenport says. Students with lower pretest scores scored higher on posttests in six of eight math units when using the new curriculum versus the traditional materials, the researchers reported in March in Washington, D.C., at the Society for Research on Educational Effectiveness meeting.

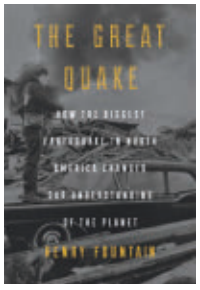
Testing the program in so many schools amid teacher turnover and other real-life challenges made controlling for variance hard, so the data weren't as robust as researchers had hoped. But there appeared to be improvements, particularly in girls, underrepresented minorities, English-language learners and special education students. The methods work by helping students focus and link related info, Davenport speculates. "Successful students have these skills," she says. "They've developed strategies ... to focus their attention and employ problem-solving skills as they work through a problem." She hopes to help teachers give struggling kids those same skills.

Granting executive powers

Students must learn to stay focused in the face of distraction, to direct actions toward a goal and to hold what they have just seen or heard in mind while they work with it. These abilities are part of a set of cognitive skills called executive function.

There's strong evidence that well-designed video games can improve executive function among teens and adults, says psychologist Bruce Homer of the City University of New York. "But we need more research to determine if — and how well — these skills transfer to the classroom to ... improve academic performance," he says. With psychologist Richard Mayer of the University of California, Santa Barbara, Homer is developing a series of video games for students from middle school to college. Each game targets a specific area of executive function, such as shifting attention or avoiding distractions.

The first of three games is in testing, assigned as homework for 300 kids in Santa Barbara and New York City schools. In the game, students must quickly adapt to rule changes as aliens land on Earth and request help gathering supplies. Preliminary findings show that after eight 30-minute sessions, players of the alien game showed substantially greater improvements in ability to shift strategies in standard cognitive tests compared with students who played a different game. This fall, researchers plan to study whether gains in executive function from game play can improve actual performance in specific academic areas. ■



The Great Quake
Henry Fountain
CROWN, $28

BOOKSHELF

Disaster fuels geologic detective story

In the early evening of March 27, 1964, a magnitude 9.2 earthquake roiled Alaska. For nearly five minutes, the ground shuddered violently in what was, and still is, the second biggest temblor in recorded history.

Across the southern part of the state, land cracked and split, lifting some areas nearly 12 meters — about as high as a telephone pole — in an instant. Deep, house-swallowing maws opened up. Near the coast, ground turned jellylike and slid into bays, dooming almost everyone standing on it. Local tsunamis swamped towns and villages.

Not many people lived in the newly formed state at the time. If the quake had struck in a more developed place, the damage and death toll would have been far greater. As it was, more than 130 people were killed.

In *The Great Quake*, Henry Fountain, a science journalist at the *New York Times*, tells a vivid tale of this natural drama through the eyes of the people who experienced the earthquake and the scientist who unearthed its secrets. The result is an engrossing story of ruin and revelation — one that ultimately shows how the 1964 quake provided some of the earliest supporting evidence for the theory of plate tectonics, then a disputed idea.

Using details from his own interviews with survivors — along with newspaper articles, diaries and other published accounts — Fountain focuses his story on two places near Prince William Sound. More people died in the port of Valdez (a familiar name because of the 1989 Exxon Valdez oil spill) than in any other Alaskan community, while the small village of Chenega suffered the highest proportional loss of life. Fountain's tracking of the myriad small decisions people made that fateful day — that either put them in harm's way or kept them safe — is meticulous. The experiences of the survivors and the lost are haunting.

Interwoven with stories of the human tragedy is Fountain's account of the painstaking scientific gumshoe work necessary to piece together how such a monster earthquake had occurred. That's where George Plafker, a geologist with the U.S. Geological Survey, comes in. In surveying the quake's aftermath, Plafker, along with others, noticed something strange: There was no surface evidence of a fault large enough to explain the colossal shaking or the widespread uplift and sinking of land over hundreds of thousands of square kilometers.

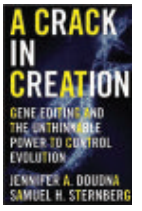
Today, scientists know that Earth's outer layer is divided into giant pieces and that the motion of tectonic plates — as they bump together or slide past each other — helps explain how some earthquakes occur. But in the mid-1960s, plate tectonics was just a hypothesis in need of real-world validation.

Plafker's crucial contribution was to realize that the powerful Alaskan quake had no surface fault because it took place at what is now known as a subduction zone, where dense oceanic crust sinks under lighter continental crust. The insight into the quake's origin provided some of the first real proof of tectonic plate movements.

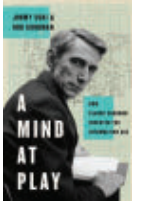
Throughout the book, Fountain weaves in brief histories of key people and ideas in the development of the theory of plate tectonics. For those familiar with the history, Fountain doesn't offer much new. People less familiar may find it a little difficult to keep one geologist straight from another geophysicist.

But *The Great Quake* is an elegant showcase of how the progressive work of numerous scientists over time — all the while questioning, debating, changing their minds — can be pieced together into an idea that reshapes how we see and understand the planet. — *Emily DeMarco*

BOOKSHELF



A Crack in Creation
Jennifer A. Doudna and Samuel H. Sternberg
Two experts in CRISPR/Cas9 gene editing recount the technology's development and various applications, and consider the ethical implications of tinkering with human embryos. *Houghton Mifflin Harcourt, $28*



A Mind at Play
Jimmy Soni and Rob Goodman
A thorough biography explores both the quirky personal life and the intellectual genius of Claude Shannon, the man whose math established modern information theory and made the computer revolution possible. *Simon & Schuster, $27*

Fishing
Brian Fagan
In tracing the history of fishing — from our ancient ancestors' opportunistic catches to today's commercial fleets — an archaeologist makes the case that this underappreciated form of subsistence played a crucial role in shaping civilization. *Yale Univ., $30*

Arithmetic
Paul Lockhart
More than just an informative survey of the fundamentals of basic arithmetic, this fun book offers a philosophical take on number systems and revels in the beauty of math. *Belknap Press, $22.95*

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Are fidget spinners tools or toys?

A fidget spinner craze is sweeping the United States. People of all ages are flicking the devices, which come in all manner of shapes, colors and materials. The gadgets follow a long line of toy fads, from Hula-Hoops and Pokémon cards to Silly Bandz. Some people argue that spinners relieve stress, anxiety and even symptoms of attention-deficit/hyperactivity disorder (ADHD). However, some schools have banned the mesmerizing devices for being too distracting. So, are fidget spinners annoying toys or therapeutic tools? Science suggests that they can be both.
— Kathryn Hulick

Read more: **sciencenewsforstudents.org/fidget-spinners**

Tongues 'taste' water by sensing sour

Many people would say pure water tastes like nothing. But then how would mammals know that what we're drinking is water? Tongues do detect water, a new study shows — and they do so by sensing acid. Bicarbonate-rich saliva is slightly basic. Drinking water washes the saliva away. An enzyme instantly kicks in to replace the bicarbonate ions. As a side effect, it produces protons, making local saliva more acidic. The tongue's sour-sensing cells detect that acid. So our tongues detect water by sensing sour. But detection and flavor aren't the same, so water still "tastes" like nothing.
— Bethany Brookshire

Read more: **sciencenewsforstudents.org/water-taste**

How the Arctic Ocean became salty

Long ago, the Arctic Ocean was a huge freshwater lake. Precisely how and when this lake became the world's northernmost ocean hadn't been clear. A new analysis describes what allowed the Atlantic's water to overwhelm that massive lake. Some 35 million years ago, a land bridge separating it from the salty Atlantic Ocean began sinking. Eventually, the bridge sank far enough that the Atlantic's seawater started overrunning into the lake. But even that wasn't enough, by itself, to tip the scales right away and transform the lake into an ocean.
— Beth Geiger

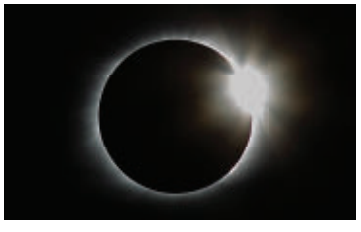
Read more: **sciencenewsforstudents.org/arctic-ocean**

AUGUST 19, 2017

SOCIAL MEDIA

Eclipse pics

Across the United States, people flocked outside to view the total solar eclipse on August 21. *Science News* asked readers to send us their eclipse photos, and we weren't disappointed. The photo below, taken by J.P. Lawrence in Makanda, Ill., shows the diamond ring effect. This effect is caused by the moon's rugged surface letting light shine through as the moon almost completely blocks the sun. See more reader photos at **bit.ly/SN_eclipsepics**



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Going rogue

*Astronomers estimate that wandering Jupiter-mass planets without a parent star are about a tenth as common as once believed, **Ashley Yeager** reported in "Giant solo planets are in limited supply" (SN: 8/19/17, p. 10).*

Online reader **Brian Bixby** wondered how often such a rogue planet would come close to our solar system and proposed that one near the Kuiper Belt or Oort cloud could send swarms of comets headed toward Earth.

"Based on rough estimates, there could be a rogue planet closer to the solar system than the closest star system, Alpha Centauri, which is 4.3 light-years away," **Yeager** says. But that's still a lot of space for a rogue planet to roam, so it is unlikely that it would come very close to our solar system. "Even if a rogue did come relatively close, it may not pose that much of a threat," she says. "Comets in the Oort cloud are probably widely spaced too, so it is unlikely that the comets would encounter a rogue or come near enough for it to send even one comet hurtling toward Earth."

Australian pushback

*New dating of ancient artifacts from Australia, including the oldest known polished ax heads, suggests that humans may have first set foot in the region 65,000 years ago, **Maria Temming** reported in "Humans' arrival in Australia redated" (SN: 8/19/17, p. 10).*

If the first Australians arrived by sea, they would have needed tools more advanced than primitive axes to get there, **Stephen Wimbourne** wrote online.

The first human colonists may have come by sea, says archaeologist **Peter Hiscock**. If they did, they probably came in bamboo boats, which wouldn't have required axes or more advanced tools to make. In fact, axes at that time were hardly primitive. "In other parts of the world, [axes] were not invented until much later," **Hiscock** says. Australia is home to a number of hardwood tree species, so the ax would've been a crucial, cutting-edge invention.

Over the exomoon

*Data from the Kepler space telescope hint at the existence of an exomoon — a moon orbiting a planet orbiting a distant star, **Lisa Grossman** reported in "Possible exomoon spotted" (SN: 8/19/17, p. 15).*

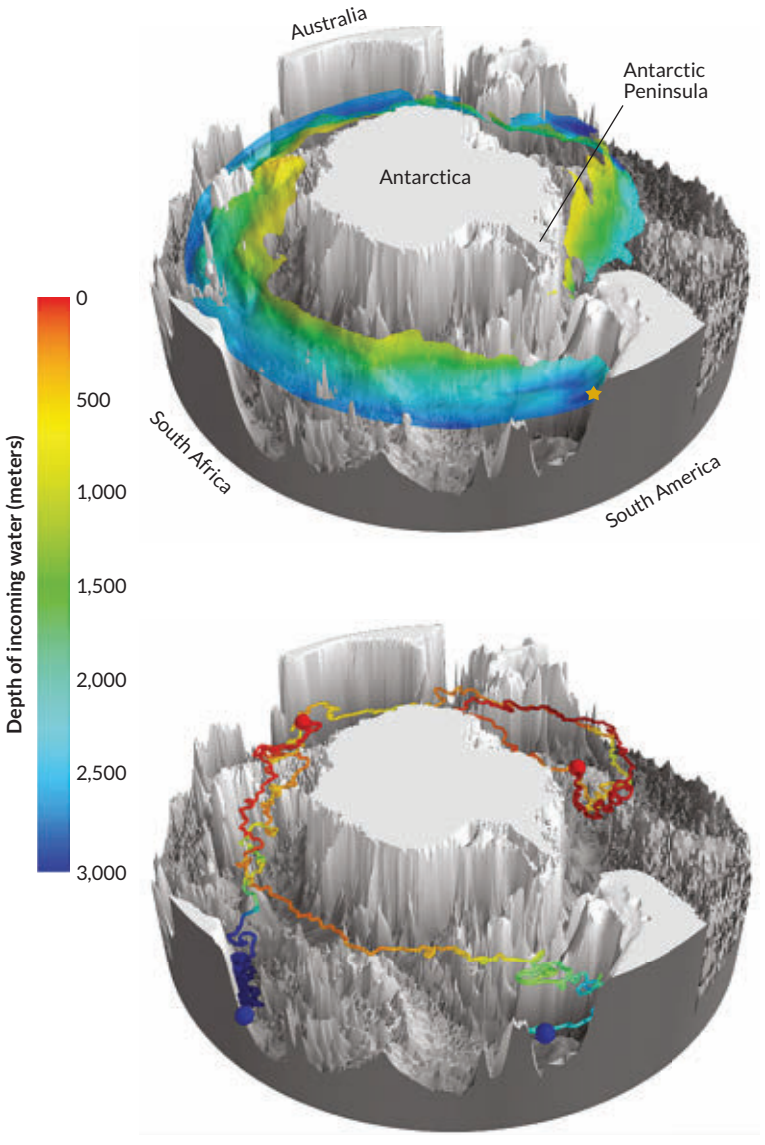
Online reader **Robert Stenton** wondered if the exomoon might instead be part of a double-planet system.

Researchers have yet to make additional observations of the object. At this point, it could be a moon or part of a planetary tango, **Grossman** says.

A double-planet system has yet to be discovered, although Pluto and Charon may be an example of a double system of dwarf planets. In a double-planet system, two planets orbit each other and a common center of gravity located outside of both planets. If the center of gravity is within one of the celestial bodies, though, then the other body would be considered a moon.

Correction

In the fascinating facts about tick biology presented in the Editor's Note in the August 19 issue (*SN: 8/19/17, p. 2*), the amount of weight a tick can gain from a single blood meal was incorrect. Though ticks can consume more than 200 times their weight in blood, they salivate much of the water in the blood back into the host. Total weight gain is thus closer to 100 times the unfed weight. This is equivalent to an average U.S. man gaining nearly 20,000 pounds in a single meal.



How deep water surfaces around Antarctica

There's no signpost to mark it, but about 3,000 meters underwater off the southeast coast of South America, a stream of deep water from the Atlantic Ocean spills into the Southern Ocean. Now new maps reveal in 3-D how the path of that water, called the North Atlantic Deep Water and shown in the top map, spirals southeastward (clockwise from star) and up toward the surface around Antarctica.

The incoming water, part of the global conveyor belt of currents circulating throughout the oceans, is relatively warm and salty compared with the rest of the Southern Ocean. Researchers marshaled ocean temperature and salinity data to broadly map the deep water's path. The data show that some of the water upwells close to the continental shelf along the western Antarctic Peninsula. Such intrusions have been linked to the melting of ice shelves (one region of Antarctic Peninsula melting shown at bottom).

For a detailed look at what controls the upwelling, the researchers turned to high-resolution climate and ocean simulations to track virtual particles traveling in the deep water (bottom map). For example, two particles (dark blue dots) enter in water from the Atlantic and spiral clockwise toward the surface (red dots).

This and other simulations show that five key spots at large ridges and plateaus drive most of the upwelling. Deep water passing these features spawns whirlpools that in turn push the water southward and upward, the researchers report August 2 in *Nature Communications*. Deep water entering the Southern Ocean from the Indian and Pacific oceans follows a similar pattern.

"Until now, we mostly thought about upwelling as this really broad thing that's just happening everywhere" in the Southern Ocean, says study coauthor Veronica Tamsitt of the Scripps Institution of Oceanography in La Jolla, Calif.

Understanding this upwelling matters because the deep water carries a lot of heat and carbon. As the climate changes, Southern Ocean upwelling may increase, which could accelerate ice shelf melting, release more carbon into the atmosphere and limit the ocean's ability to absorb heat and carbon dioxide from the atmosphere. Today, the Southern Ocean accounts for almost half of the anthropogenic CO_2 and 75 percent of the heat that the world's oceans soak up from the atmosphere. — *Emily DeMarco*

MAPS: V. TAMSITT *ET AL/NAT. COMMUN.*; PHOTO: JO CREBBIN/SHUTTERSTOCK

Watch simulated particles spiral around Antarctica at **bit.ly/SN_DeepWater**

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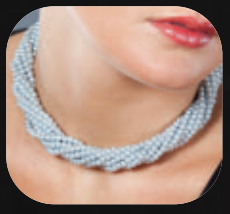

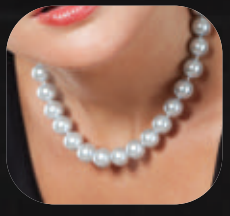

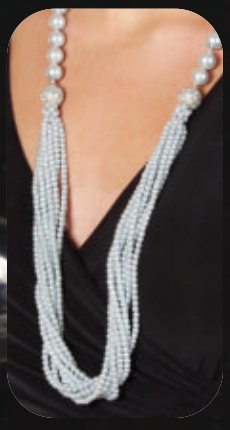

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