The Math of Social Distancing | Finding the Milky Way's Edge

Science News

MAGAZINE OF THE SOCIETY FOR SCIENCE & THE PUBLIC ■ APRIL 25, 2020

MASTER FARMERS

Insects have been tending crops for millions of years

I'M FIGURING OUT BETTER WAYS TO HARNESS IT."

Anna Braun
Chemistry & Chemical Engineering

I've been working with Professor Rebecca DeVasher focusing on the degradation of perovskite photovoltaic cells. It's a material that could make solar panels a lot more affordable, which would be better for everyone. My hard work at Rose-Hulman landed me an internship at the Department of Energy in Colorado (two years in a row!) and scored me one of the best national academic awards out there—the Goldwater Scholarship. I bet you'll shine here, too.

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COVER Leaf-cutter ants haul bits of leaves to feed the fungus farms that nourish the ant colonies. *Ross/Tom Stack Assoc/ Alamy Stock Photo*

FROM TOP: ARIEL SKELLEY/DIGITALVISION/GETTY IMAGES; S.A. WILBERT, J.L. MARK WELCH AND G.G. BORISY/*CELL REPORTS* 2020; J. ZILHÃO *ET AL*/*SCIENCE* 2020

Susan Milius, your guide to the peculiarities of nature

Reading a story by Susan Milius is like going for a ramble in the woods. You set out expecting to see the same old trees and squirrels, only to be surprised by the orange flash of a fox, get lured off-trail by morels poking up through the duff, and then delight in an unexpected carpet of bluebells. This issue's cover story, "The first farmers" (Page 16), is no exception.

I was unaware that certain insects qualify as farmers by our snobby human standards, or that those insects have been tending specialized crops for millions of years. Milius, *Science News*' life sciences writer, leads us through the strange realms of ants, beetles and termites that farm, and introduces us to the scientists who are thinking about what we humans can learn from the insects. We even embark on an ant-sized expedition, joining Milius as she watches leafcutter ants trudge across the University of Texas at Austin's Brackenridge Field Laboratory, bearing home minuscule snippets of leaves. "It's like looking down at a few cupcake sprinkles on the floor, each giving just the tiniest jiggle per ant step," Milius writes.

It's safe to say that most children don't dream of covering organismal and evolutionary biology when they grow up. Milius came to that fate by a route almost as long, comparatively, as that of the leaf-cutter ants. But there were early hints at the destination. Milius recalls her mother taking her on long walks near their home in rural Virginia, teaching little Susan how to identify flowers along the way. "I learned my first Latin names of wild flowers before I could read," Milius says.

Her love of writing led her to journalism, including a stint as a magazine lifestyle editor. One day, at a barbecue symposium, the lifestyle editor suddenly realized that chronicling rubs and marinades was not her destiny. In her purse, she had a number to call about a science-writing job. She stood up, walked out and made the call.

At *Science News*, Milius has enlightened and charmed readers on the astonishing variety and ingenuity of nonhuman life. Memorable headlines include "How these tiny insect larvae leap without legs," "The flowers that give us chocolate are ridiculously hard to pollinate" and "It's official: Termites are just cockroaches with a fancy social life." As features editor Cori Vanchieri puts it: "The wonder that Susan finds in the natural world moves all of us editors to be adventurous in our use of language and to inject more fun into stories."

Milius claims that she's not a great naturalist, but she does carry a little 10x magnifier with her "in hopes of finding something fun." Social distancing has postponed forays with the local mushroom club, but she's glad she brought home a beginners guide to grasses when we made the shift to remote work in March. "I find them just about impossible to ID, so it seemed a good project for a long-haul shutdown."

Milius has never regretted ditching the barbecue beat for evolutionary biology. "What has evolved is so much more peculiar and surprising than what I can imagine," Milius tells me. We're all the better for that career change.
—Nancy Shute, Editor in Chief

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SSP

Learn with unity

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– *Derek Postma, Video Game Programming and Computer Science Teacher at Hamilton High School, Hamilton, Michigan*

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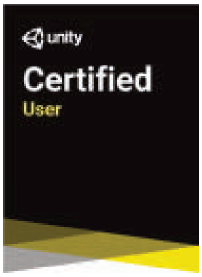

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Excerpt from the May 2, 1970 issue of *Science News*

50 YEARS AGO

Superconductivity under pressure

Cooling certain metals to temperatures near absolute zero turns them into superconductors, substances without electrical resistance, in which currents flow without power loss. In recent years it has become apparent that in some cases pressure as well as cooling has something to do with inducing superconductivity. Metals are found that are not superconducting under normal pressure but become superconducting under both pressure and cooling.

UPDATE: Extreme pressures can produce superconductors that work at higher temperatures than any other materials known, recent studies reveal (see Page 10). Squeezed to more than a million times Earth's atmospheric pressure, hydrogen sulfide is a superconductor at up to 203 kelvins (−70° Celsius), and a superconductor of lanthanum and hydrogen reportedly works at a record-breaking 260 kelvins (−13° C). Scientists hope to find a superconductor that doesn't require pressure or cooling. That could revolutionize electronic devices and reduce energy losses in the power grid.

THE SCIENCE LIFE

Two adventurers endure an Arctic winter for science

This tiny hut on Svalbard in the Arctic is the only shelter for 140 kilometers, and is home for at least nine months to two citizen scientists.

Hilde Fålun Strøm and Sunniva Sorby are taking citizen science to the extreme.

In August, the two women moved into a hunting cabin dubbed Bamsebu on the Norwegian archipelago of Svalbard. The hut is the only shelter for 140 kilometers. Polar bears prowl the area. It's not unusual for the chill to reach around –30° Celsius.

The conditions are so harsh that few scientists collect data from the area during winter. That's where Fålun Strøm and Sorby come in — gathering observations that could help reveal how rapid warming is changing Arctic ecosystems. Both women have plenty of experience on frozen ground. Sorby, who has worked for more than two decades in Antarctica as a historian and guide, has skied to the South Pole as well as across the Greenland ice cap. Fålun Strøm has lived 23 years in Svalbard and is versed in dogsledding and hunting.

"It's as if all of my years in Svalbard have prepared me for this," Fålun Strøm says. Still, the nine-month Arctic sojourn has been rough. There is no running water, so the women thaw chunks of ice. The pair also chop wood to keep the oven ablaze for cooking and heating. Venturing outside requires layers of clothing and a gun to guard against polar bears.

Hilde Fålun Strøm (left), Sunniva Sorby (right) and their dog, Ettra, are living under rough conditions in Svalbard that many scientists don't experience.

"We photograph incessantly," snapping foxes, reindeer, polar bears and beluga whales for the Norwegian Polar Institute, Sorby says. The observations may give insight into how Arctic animals are adapting to warmer weather.

In November, the women encountered a polar bear that had hunted a reindeer — an odd sighting, as the bears normally eat seals. Scientists think polar bears may be forced to change eating habits as warmer ocean currents shrink the sea ice where the bears hunt seals.

For NASA, the two are photographing different types of clouds and observing auroras seen only in 24-hour darkness.

And the women are collecting phytoplankton samples for the citizen science project FjordPhyto, which studies how freshwater from melting glaciers affects marine phytoplankton. In Antarctica, studies have shown a shift to smaller phytoplankton, resulting in less food for fish and krill. The Arctic samples could reveal if that's happening in the north.

The three months of polar night, from October to February, opened a new world to Sorby. "When the night sky is full of stars, planets, satellites and the aurora ... I feel showered with lights."

Sorby says the plan to return home in May is on hold due to the coronavirus pandemic. "It will be surreal to think of leaving this simple, purposeful life and coming back to a world that has been turned upside down." — *Maria Temming*

BOTH: HEARTS IN THE ICE

SCIENCE STATS

Taking more steps per day is linked to longevity

However you can fit more steps in your day, it may be worth the effort. Scientists have found an association between how many steps a person takes and the risk of dying for any reason.

In a study of nearly 5,000 people, the annual death rate among those taking fewer than 4,000 steps per day (a distance of roughly three kilometers) was 76.7 per 1,000 people per year. But among those who managed 4,000 to 7,999 steps per day, the death rate plummeted to 21.4 per 1,000 people. And it got even better for the next group: Among those taking 8,000 to 11,999 daily steps, the annual death rate was 6.9 per 1,000, researchers report in the March 24/31 *JAMA*.

The researchers did not find a link, however, between mortality risk and the intensity of the steps — that is, the number of steps per minute, or the pace. And while the study suggests that more steps may lower the risk of mortality, it's also possible that people who are healthier to begin with take more steps.

Study participants, who were at least 40 years old, wore accelerometers that tracked their steps for up to a week. Researchers collected the data from 2003 to 2006. Over the next 10 years, a total of 1,165 participants died. — *Aimee Cunningham*

<4,000 steps per day	4,000–7,999 steps per day	8,000–11,999 steps per day
Mortality rate 76.7 per 1,000 people	Mortality rate 21.4 per 1,000 people	Mortality rate 6.9 per 1,000 people

SOURCE: P.F. SAINT-MAURICE *ET AL*/*JAMA* 2020

INTRODUCING

Carnivore fills a gap in the dinosaur fossil record

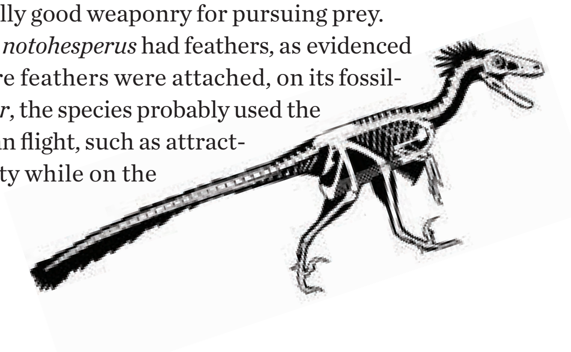
A wolf-sized warrior, kin to the fierce and feathered *Velociraptor*, prowled what is now New Mexico about 68 million years ago.

Dineobellator notohesperus was a dromaeosaur, part of a group of swift and agile predators that are distantly related to *Tyrannosaurus rex*. The discovery of this new species (skeleton illustrated below) suggests dromaeosaurs were diversifying, and becoming better at pursuing prey, right up to the end of the age of dinosaurs, researchers report March 26 in *Scientific Reports*.

That age ended with the close of the Cretaceous Period about 66 million years ago, when a mass extinction event wiped out all nonbird dinosaurs. A gap in the fossil record for dromaeosaurs around that time led some scientists to wonder if the group was in decline before going extinct. The new find suggests otherwise, says paleontologist Steven Jasinski of the State Museum of Pennsylvania in Harrisburg.

Starting in 2008, Jasinski and colleagues collected at least 20 fossilized pieces of the species from the Bisti/De-Na-Zin Wilderness, a rapidly eroding region of northwest New Mexico's badlands. Analyses of muscle attachment sites on the forelimbs suggest the dinosaur was unusually strong for a dromaeosaur, capable of a tight grip with both its hands and feet. That grip was likely stronger than that of *Velociraptor*, giving the new species especially good weaponry for pursuing prey.

Like other dromaeosaurs, *D. notohesperus* had feathers, as evidenced by the quill nobs, bumps where feathers were attached, on its fossilized limbs. But like *Velociraptor*, the species probably used the feathers for purposes other than flight, such as attracting mates, camouflage or agility while on the hunt. — *Carolyn Gramling*



CLOCKWISE FROM TOP: ANDREW TURNER/UNIV. OF PLYMOUTH; S. JASINSKI; T. TIBBITTS

RETHINK

Legos last long at sea

If you've ever had the misfortune of stepping barefoot on a Lego, you know the plastic building blocks have no give. Now, scientists have found another consequence of the toy's indestructibility: A single Lego could take hundreds of years to break down in the ocean.

Gauging how long it takes for plastic to disintegrate in seawater is tough, as it's hard to date debris with unknown origins. But Legos are easily identified by their shapes. And because chemical additives used to make Legos changed over time, each brick's composition holds clues about when it was made.

Using an X-ray fluorescence spectrometer, researchers measured the chemical compositions of Legos washed onto beaches in southwest England since 2010 (some shown above). Those chemical fingerprints identified bricks made in the 1970s and 1980s. The Legos were assumed to have been lost to sea around the time of their purchase.

To estimate how worn down Legos got during 30 to 40 years at sea — due to factors such as abrasive sediments and exposure to sunlight — the weathered Legos were matched with versions of the same bricks kept in collections.

Weathered Legos had 3 to 40 percent less mass than those in good condition. That suggests a Lego would take about 100 to 1,300 years to break down completely at sea, the team reports in the July 2020 *Environmental Pollution*.

Plastic bottles break down in the sea in decades. But plastics with Lego-like sturdiness, used in electronics and other consumer products, appear likely to endure far longer. — *Maria Temming*

News

BODY & BRAIN

Blood plasma may combat COVID-19

Studies will test a therapy derived from patients who recovered

BY AIMEE CUNNINGHAM

At the end of March, patients critically ill with COVID-19 in New York City and Houston became the first in the United States to receive a promising experimental treatment. But the therapy, authorized for emergency use by the U.S. Food and Drug Administration, wasn't concocted in a lab. It came from other patients.

The treatment is convalescent plasma, the liquid component of blood taken from someone who has survived an infection, in this case COVID-19. With no proven treatments yet, U.S. researchers are racing to set up clinical trials to test how effective convalescent plasma is against SARS-CoV-2, the virus that causes COVID-19. If those clinical trials demonstrate the plasma is beneficial, that could lead to FDA approval for wider use.

A vaccine is still more than a year away (*SN: 3/14/20, p. 6*). In trying to manage COVID-19 over the next several months, the question is, "what kind of treatments could we administer that could truncate this pandemic?" says pathologist John Roback of Emory University School of Medicine in Atlanta. The top candidates are repurposed drugs (*SN: 3/28/20, p. 20*) and convalescent plasma, he says.

A patient in Xingtai, China, who has recovered from COVID-19 donates plasma, the liquid part of blood containing antibodies against the new coronavirus. Efforts to collect plasma are ramping up in the United States.

MU YU/XINHUA/ALAMY LIVE NEWS

To fight a virus, the immune system develops antibodies, proteins that bind to the virus and impede infection. Antibody production takes about a week or two, after initial exposure to a virus or vaccine. But once that has occurred, the immune system will quickly respond to the next exposure. In some cases, this immunity lasts decades or lifelong.

Convalescent plasma can provide antibodies immediately, but they last for only a short time, weeks to maybe months.

To see if convalescent plasma can stop COVID-19 or improve symptoms, a group called the National COVID-19 Convalescent Plasma Project is working to set up three clinical trials.

One randomized clinical trial is designed to investigate whether plasma can prevent infection in people exposed to COVID-19 by a family member or other close contact, says project member Shmuel Shoham, an infectious disease physician at Johns Hopkins University School of Medicine. The trial will test plasma from recovered COVID-19 patients against a placebo — plasma collected before the start of the epidemic in December, he says.

Another trial plans to test whether plasma can keep hospitalized people with moderate disease from needing intensive care, Shoham says. And a third trial aims to study whether the therapy helps the most critically ill patients.

Convalescent plasma has been used against outbreaks of SARS and MERS, two other coronavirus diseases. But studies that showed some benefit didn't compare the treatment against a placebo. That's also true for the first studies using plasma for COVID-19. In one, five COVID-19 patients on mechanical ventilation received plasma 10 to 22 days after being admitted to a hospital in China. As of March 25, three patients had been discharged after a little over 50 days in the hospital, and two were in stable condition 37 days after the transfusion, researchers report online March 27 in *JAMA*. Although the patients improved, they also had gotten antiviral drugs, so it's unclear which therapy, if any, had an impact.

For the U.S. trials, scientists will study donated plasma to see whether it contains neutralizing antibodies, says project member and infectious disease physician Jeffrey Henderson of Washington University School of Medicine in St. Louis. This type of antibody prevents a virus from entering a host cell, thereby stopping infection. Data so far suggest that SARS-CoV-2's spike protein, which the virus uses to bind to human cells, is a target of neutralizing antibodies.

Researchers suspect this type of antibody is what makes convalescent plasma effective. And the idea also hints at when using the plasma may be most beneficial.

Early in the disease, the virus infects cells and hijacks cell machinery to make many copies of itself. "But as the disease progresses, the tissue damage done by the virus is more difficult to reverse and isn't necessarily reversed by something that is solely targeted towards the virus itself," such as antibodies, Henderson says. The body's inflammatory response can be contributing to the damage.

It doesn't mean that plasma wouldn't help someone critically ill, he says. "We have so much to learn, of course, but we're thinking the antibodies may prevent the virus from expanding its numbers." ■

To get the latest news on COVID-19, visit www.sciencenews.org/coronavirus

MATH & TECHNOLOGY

Is there a safe gathering size?

Banning all meetings may not be needed to curb COVID-19

BY DANA MACKENZIE

A question has perplexed officials trying to curb the COVID-19 pandemic: How large a group of people is too large?

As the coronavirus spread, officials across the United States urged limits on large gatherings, repeatedly revising the definition of "large." First, meetings of over 1,000 were discouraged, then 250, 100, 50 and 10. Finally, many states banned all nonessential gatherings.

But no scientific rationale has been cited for any particular number. Getting the right answer is crucial. Too large and you don't control the epidemic. Too small, and people's lives and livelihoods may be upended for insufficient benefit.

"I am not aware of any quantitative modeling informing those decisions," says Lydia Bourouiba, a physicist and epidemiologist at MIT.

Now, a study provides one road map for coming up with an answer. There is no gathering size that can eliminate all risk. But there is a threshold between curbing the epidemic and having it spread like wildfire, and that number is most likely not zero, the researchers conclude. The research could have implications not only for slowing the pandemic, but also for figuring out how to return to normal life without causing a surge in cases.

In the study, posted online March 12 at arXiv.org, modelers showed mathematically how an epidemic can be controlled without banning all get-togethers. The model includes a version of the "friendship paradox," which says that your friends in a social network on average have more friends than you. When an epidemic strikes such a network, large gatherings are especially bad because they attract people who have more contacts than average — and hence are more likely to already be infected.

It's possible to determine the dividing line between an effective and an ineffective intervention, the team found. In one hypothetical epidemic, if you banned gatherings larger than 30, the epidemic would rage on. But if you banned groups larger than 20, it would die out. The threshold for this particular social network model, in which the friendship paradox was fairly strong, was 23.

In Everett, Wash., officials cordoned off a playground to prevent groups from gathering. Other cities and states across the country have taken similar steps to prevent coronavirus transmission.

"I'm confident that there is a threshold," says Laurent Hébert-Dufresne, a computer scientist at the University of Vermont in Burlington who developed the model. "I don't have confidence in the exact number 23." The threshold for COVID-19 is unknown, and, he adds, "the cutoff could be very population specific."

What's significant, Bourouiba says, is the idea of computing the safe group size. A maximum group of "23 leading to a collapse of the epidemic has to be taken with a grain of salt," she says. "But the concept is important, because sheltering at home is not going to be sustainable forever."

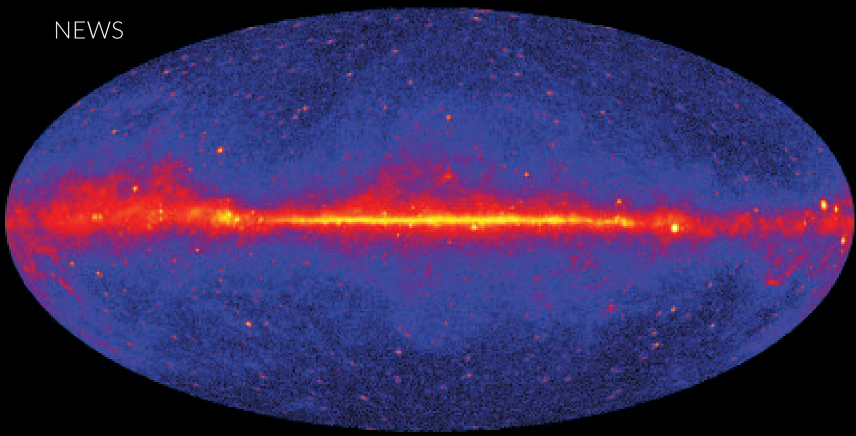
Officials' recommendations have been based in part on the idea that the risk of a large group increases as the square of the group size. A gathering that is 10 times larger will offer 100 times as many "transmission opportunities," says epidemiologist Marc Lipsitch of the Harvard T.H. Chan School of Public Health.

But this rough calculation underestimates the danger of large meetings, Hébert-Dufresne says, because of the friendship paradox. It also doesn't take into account epidemic dynamics.

The model in the study, which hasn't been peer-reviewed, represents gatherings as highly connected cliques, in which all people are exposed to all the others. Hébert-Dufresne, who worked with colleagues at Université Laval in Quebec City, compares an epidemic in such a network to a bonfire. There's kindling, which gets the first flame started, and larger branches, which transmit the fire. In the model, small gatherings are the kindling; large gatherings are the branches. To keep the fire from spreading, you don't need to remove the kindling, only the branches.

Telling the difference between kindling and branches is where the model comes in. The dividing line depends on three factors: the disease transmission rate, the distribution of clique sizes and the distribution of clique membership, including how many cliques highly social people belong to. The last two numbers are unknown, Hébert-Dufresne says. But with enough data on social networks, it might be possible to figure them out.

The model is far from being the last word. It ignores many kinds of heterogeneity, such as the age structure of the population. Other models take these variables into account. "You can incorporate an incredible amount of detail," says Lauren Ancel Meyers, an epidemiologist at the University of Texas at Austin, "but then it takes many simulations to extract general results." And that can take a lot of time — something that is in short supply right now. ■



The Milky Way's stellar disk glows in red and yellow in this gamma-ray image. A halo of dark matter that engulfs the disk emits no light, making it hard to measure the galaxy's total size.

ATOM & COSMOS

Astronomers find Milky Way's edge

Our galaxy reaches almost 2 million light-years across

BY KEN CROSWELL

Our galaxy is a whole lot bigger than it looks. The Milky Way stretches nearly 2 million light-years across, new work finds, more than 15 times wider than its luminous spiral disk. The number could lead to a better estimate of how massive the galaxy is and how many other galaxies orbit it.

Astronomers have long known that the Milky Way's brightest part, the pancake-shaped disk of stars that houses the sun, is some 120,000 light-years across. Beyond this stellar disk is a disk of gas. A halo of dark matter, presumably full of invisible particles, engulfs both disks and stretches far beyond them. Because that halo emits no light, its diameter is hard to measure.

Astrophysicist Alis Deason of Durham University in England and colleagues used nearby galaxies to locate the Milky Way's edge. The diameter is 1.9 million light-years, give or take 0.4 million light-years, the team reports February 21 in a paper posted at arXiv.org.

To put that size into perspective, imagine a map in which the distance between the sun and the Earth is just one inch. If the Milky Way's heart were at Earth's center, the galaxy's edge would be four times farther away than the moon actually is.

Deason's team ran computer simulations of how giant galaxies like the Milky Way form. The team sought cases where two giant galaxies arose side by side, like the Milky Way and Andromeda, our nearest giant neighbor (*SN: 6/13/15, p. 8*), because each galaxy's gravity tugs on the other and affects its outskirts. The simulations show that just beyond the edge of a giant galaxy's dark halo, the velocities of small nearby galaxies drop sharply.

Using existing telescope observations,

ATOM & COSMOS

Ocean on Pluto would be original

Liquid water may be common in the outer solar system

BY LISA GROSSMAN

A suspected subsurface ocean on Pluto might be old and deep. Images from NASA's New Horizons spacecraft suggest that Pluto has had an ocean since shortly after the dwarf planet formed 4.5 billion years ago, and that the ocean surrounds and interacts with the rocky core.

If so, oceans could be common at the solar system's edge — and may be able to support life.

In 2015, New Horizons revealed that despite being nearly 6 billion kilometers from the sun, Pluto had signs of an ocean of liquid water beneath the dwarf planet's icy surface (*SN Online: 9/23/16*).

How much liquid water there is, how long it's been there and how much it may have frozen over time were hard to tell. The new work, which was to be presented in March at the canceled Lunar and Planetary Science Conference, dug into those questions.

Planetary scientist Carver Bierson of the University of California, Santa Cruz and colleagues considered two possible histories for the ocean. If Pluto had a "cold start," any subsurface water would first have been frozen before melting under heat from decaying radioactive elements in Pluto's core, only to partially freeze again over time. In that scenario, the team expected to see cracks and ripples across Pluto's surface ice from contraction as the ice melted and then expansion as water refroze. Contracting would make the ice crumple into mountainlike features; expanding would stretch the ice and create faults.

The team's second scenario envisioned a "warm start" for Pluto, where the ocean would have been liquid for nearly all of Pluto's existence. In that case, the surface ice would show only cracks from the sea expanding as it partially froze. And that's exactly what Bierson's team found.

In a separate study, planetary scientist Adeene Denton of Purdue University in West Lafayette, Ind., and colleagues considered the impact that formed Sputnik Planitia, a lobe of Pluto's heart-shaped basin. Because of how New Horizons flew by Pluto, the view of half of the dwarf planet is fuzzy. But surface lines are visible on the opposite side of Pluto from Sputnik Planitia, Denton's team reported in October 2019 at arXiv.org. Those lines might be the imprints of shock waves from an impact that formed the basin.

"If the impact is large enough ... the planet itself can act like a lens and focus the wave energy at the exact opposite point on the planet from the impact," Denton says. Pluto's internal structure

FERMI LAT COLLABORATION/DOE AND NASA

the team found a similar plunge in the speeds of small galaxies near the Milky Way. This occurred at about 950,000 light-years from the Milky Way's center, marking the galaxy's edge, the scientists say. The edge is 35 times farther from the galactic center than the sun is.

Although dark matter makes up most of the Milky Way's mass, the simulations reveal that stars should also exist at these far-out distances.

Astronomers could refine the location of the Milky Way's edge by discovering more small galaxies nearby. Astronomers could also look for stars at the boundary, says astrophysicist Mike Boylan-Kolchin of the University of Texas at Austin. The farthest stars will be very dim, but future observations should be able to find them.

The measurement should also help astronomers tease out other galactic properties. For instance, the larger the Milky Way, the more massive it is — and the more galaxies should revolve around it, says astronomer Rosemary Wyse of Johns Hopkins University. There are about 60 known Milky Way satellites, but many more likely await discovery. ■

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would have controlled how those shock waves shuddered through the dwarf planet. So looking at the cracks in the surface ice could give clues to the thickness of the proposed ocean and the core's chemistry. Denton's team ran computer simulations of an impact to look for clues.

To explain the lines on the backside of the basin, not only would Pluto need a big ocean, at least 150 kilometers thick, but the core must have minerals that form through interactions between rock and water. Astrobiologists think that such water-rock interactions could provide energy and nutrients for life, Denton says.

The possibility that Pluto has a habitable ocean raises the odds that other icy objects in the Kuiper Belt, the region beyond Neptune's orbit, do too, says planetary scientist James Tuttle Keane of NASA's Jet Propulsion Laboratory in Pasadena, Calif. "This lays out one of the coolest hypotheses that a future Pluto mission could test." ■

ATOM & COSMOS

Quasar winds are galactic influencers

Energetic outflows can help explain why star production stops

BY LISA GROSSMAN

Black holes in the distant universe blow winds with hundreds of times the energy of all the stars in the Milky Way combined. These great gusts, called quasar outflows, carry enough material away from their galaxies to eventually shut down star formation, astronomers report in six papers published in the April *Astronomical Journal Supplement*.

"We found the three largest, most energetic outflows anyone has ever found," says Nahum Arav of Virginia Tech in Blacksburg. "At that size, they're a serious influencer for the evolution of the galaxy."

Arav and colleagues used the Hubble Space Telescope to study outflows from 10 quasars, active supermassive black holes in the hearts of distant galaxies that can outshine the galaxies themselves. An outflow's gas is invisible, but as quasar light filters through the gas, atoms and ions absorb specific wavelengths of light, revealing outflow properties.

Illustrations often show outflows as twin jets streaming from a black hole perpendicular to the galaxy's disk of stars. But the gas probably flows out in all directions, Arav says, and spreads like the surface of an expanding balloon.

Galaxy evolution theories say outflows could propel gas and dust away from the galactic center, enriching the material between galaxies with heavy elements and shutting off star formation. Such shutdowns could explain why there are fewer big galaxies in the modern universe than simulations suggest there should be.

"Theorists could show very easily, with back-of-the-envelope physics, that if the outflows have enough energy," they will end star formation, Arav says. But previous studies with ground-based telescopes found energies that were too low.

Hubble revealed quasar light in the high-energy ultraviolet wavelength range, which turns out to be where most of the matter in the outflows can be seen. Each quasar had three outflows on average, surrounding the black hole like nesting dolls. Most of the outflows extended 300 to 6,500 light-years from the central black hole — far enough to have a big influence on the galaxy, Arav says. About half of the outflows were energetic enough to affect their galaxy's fate.

The most energetic winds carried 5×10^{30}, or 5 million trillion trillion, gigawatts. The total energy of all Milky Way stars is about 10^{28} gigawatts.

Astronomer Jane Charlton of Penn State is glad to see that quasar outflows are important for galactic evolution. She had started to wonder if quasars alone would be enough, or if some unknown galactic process was needed. "This work is saying that it is probably enough." ■

A quasar is often illustrated, as here, with twin jets of gas coming from its galaxy's disk. But gas probably flows out in all directions.

NASA, ESA, J. OLMSTED/STSCI

MATTER & ENERGY

Superconductor waves are real

Discovery may help explain high-temperature superconductivity

BY EMILY CONOVER

Physicists have finally captured a superconductor's wave.

The first direct evidence of a phase of matter known as a pair-density wave helps reveal the physics that underlies high-temperature superconductors, which conduct electricity without resistance at surprisingly high temperatures. The wave was detected using a scanning tunneling microscope, researchers report in the April 2 *Nature*.

Previous experiments had hinted that pair-density waves existed in these materials. But without direct proof, scientists couldn't advance their understanding of superconductors. "Investigating and proving this phase not only might exist, but actually does exist is very important," says theoretical physicist Eun-Ah Kim of Cornell University, who wasn't involved in the work.

High-temperature superconductors wowed physicists when the materials came on the scene in the 1980s. They conduct electricity without resistance at about 100 kelvins (about –173° Celsius) or higher (*SN: 1/20/18, p. 11*).

Although still chilly, such temperatures are much easier to attain than the nearly absolute zero temperatures required for many superconductors. The materials' discovery led to hopes that a room-temperature superconductor could soon be found, possibly leading to new technologies such as vastly more energy-efficient electric grids and magnetically levitated trains.

But, decades later, such a superconductor has yet to materialize. What's more, scientists still don't fully understand the physics that makes these materials so special. In particular, "we want to understand the microscopic mechanism of how superconductivity occurs in those materials," says physicist Kazuhiro Fujita of Brookhaven National Laboratory in Upton, N.Y. Now, scientists are drawing a bit closer to a solution.

In a superconductor, electrons buddy up into Cooper pairs, a partnership that allows them to slip smoothly through the material without resistance. In these materials, scientists observe a gap in the energies of electrons, rather than a continuous spectrum.

In a high-temperature superconductor, physicists predicted, the gap in electron energies would periodically vary across the surface of the material in a strange kind of wave. That effect might be linked to another unusual state that exists in the same materials at higher temperatures, called the pseudogap phase. That state inhabits a strange purgatory. It's neither superconducting nor insulating: It conducts electricity but not all that well.

Fujita and colleagues detected the wave by skimming across the surface of a superconducting compound — a bismuth-based copper oxide — with a scanning tunneling microscope. The microscope has an extremely thin tip that detects electrons that pass across the space between the superconductor and tip via a quantum process known as tunneling. In this case, the researchers also affixed a tiny piece of superconductor to the microscope's tip to search for electrons tunneling from one bit of the superconductor to another. The energy gap, the team reported, periodically varied across the surface of the material in a wave, as predicted.

"This is actually a direct measurement of the pair-density wave component," says theoretical physicist Eduardo Fradkin of the University of Illinois at Urbana-Champaign. "It's a really exciting experiment."

The pseudogap phase may be important in the quest to increase the temperature range of high-temperature superconductors. The new result could help scientists understand that phase better by illuminating how these materials behave as they warm up. ■

GENES & CELLS

Squid take genetic editing to a weird place

Longfin inshore squid edit their genetic information somewhere scientists didn't expect. The animals (one shown) have been found to tweak strings of RNA outside of a nerve cell's nucleus. This messenger RNA, or mRNA, carries a cell's blueprints for building proteins.

All creatures edit their RNA, but those changes typically take place inside the nucleus and are then exported to the rest of the cell. The ability to make edits in cytoplasm, the jellylike material that makes up much of a cell, may let a squid make mRNA adjustments on the fly. That skill could help produce proteins tailored to meet a cell's needs and hone crucial cell processes, researchers report online March 23 in *Nucleic Acids Research*.

Joshua Rosenthal of the Marine Biological Laboratory in Woods Hole, Mass., and colleagues discovered an mRNA-editing protein called ADAR2 in both the cytoplasm and nucleus of squid nerve cells. ADAR2 extensively edited mRNA within cytoplasm taken from cells.

The finding could help researchers develop RNA-editing techniques. Edits to DNA are permanent, but because RNA is transient, edited genetic information would disappear when the RNA is broken down. "If you make a mistake, it's not nearly so dangerous," Rosenthal says. "If you make mistakes in DNA, you're stuck with it." — *Erin Garcia de Jesus*

ROGER HANLON

GENES & CELLS

Tooth protein is linked to eye disorder

Find may lead to a remedy for a type of macular degeneration

BY ALEX FOX

Deposits at the back of the eye of a mineral found in tooth enamel could hasten the progression of age-related macular degeneration, the leading cause of deteriorating eyesight in people over 50.

Researchers have identified a protein called amelotin that seems to be involved in producing these deposits, which are the hallmark of "dry" age-related macular degeneration, or AMD, the most common of the two forms of the disease.

"Wet" AMD, the more severe version of the disease, can be treated with injections, but there is no treatment for dry AMD. "Finding amelotin in these deposits makes it a target to try to slow the progression of mineralization, which, if it's borne out, could result in new therapies," says ophthalmologist Imre Lengyel of Queen's University Belfast in Northern Ireland, who wasn't involved in the work.

These deposits contain a mineralized calcium called hydroxyapatite, first documented in 2015, and appear beneath the retinal pigment epithelium, a layer of cells on the outside of the retina that keeps light-sensing rods and cones healthy. The deposits may worsen vision by blocking the flow of oxygen and nutrients needed to nourish the light-sensitive retinal cells. In wet AMD, blood vessels intrude into the retina and often leak. Both forms of AMD distort a person's central vision, the focused, detailed sight needed for reading and recognizing faces.

In a study in the May *Translational Research*, researchers grew retinal pigment epithelial cells and then subjected them to a form of stress that may be common in aging eyes: a lack of nutrients.

"One of the problems with this disease and with aging is that blood vessels aren't delivering the blood they used to, and that loss of nutrients and oxygen could be driving the course of the disease," says ophthalmologist Graeme Wistow of the National Eye Institute in Bethesda, Md.

After Wistow and colleagues deprived the cells of nutrients for nine days, a gene involved in producing amelotin called *AMTN* switched on and initiated production of the protein, which in turn caused hydroxyapatite deposits to form. Blocking the gene's activity prevented the deposits from forming. The team also found amelotin in cadaver eyes that had suffered from dry AMD, concentrated in areas with large hydroxyapatite deposits.

"The best possible outcome would be finding a way to inhibit amelotin or its gene expression in a way that prevented or delayed the deposition of hydroxyapatite," Wistow says. That "might allow people to keep their vision a bit longer."

Lengyel wants to see the results verified in mice or lab-grown cells that more closely resemble a living human eye. ■

Shellfish and other seafood unearthed at Figueira Brava, a cave in Portugal, point to Neandertals' use of marine resources.

HUMANS & SOCIETY

Neandertals ate a buffet of seafood

Excavations reveal the hominids acted a lot like *Homo sapiens*

BY BRUCE BOWER

Surf's up, Neandertals. Our close evolutionary cousins obtained shellfish and other marine munchies along Europe's Atlantic coast with all the savvy and gusto of ancient humans in southern Africa, say archaeologist João Zilhão of the University of Barcelona and colleagues.

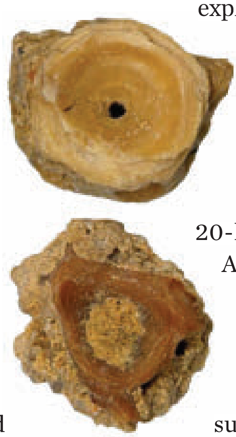
Neandertals consumed a diverse menu of sea and land foods while occupying Figueira Brava cave in Portugal for extended periods between about 106,000 and 86,000 years ago, Zilhão's group says. Excavations there show for the first time that Neandertals matched Stone Age *Homo sapiens* in their ability to exploit seafood rich in brain-enhancing fatty acids, the scientists report in the March 27 *Science*. This discovery adds to controversial evidence that Neandertals engaged in various behaviors once thought to have characterized only *H. sapiens*, such as creating cave art and elaborate personal ornaments (*SN: 4/8/15, p. 7*).

The extensive seaside activity expands on some evidence of Neandertals collecting shells at a Mediterranean site (*SN: 2/15/20, p. 5*). Other excavations had suggested Neandertals occasionally gathered, hunted or scavenged sea animals starting about 110,000 years ago.

But repeated bouts of Neandertal foraging at Figueira Brava over about 20,000 years point to coastal activity as extensive as that of *H. sapiens* who harvested shellfish at South Africa's Pinnacle Point between 164,000 and 120,000 years ago (*SN: 8/13/11, p. 22*), Zilhão says.

Intensive shellfish collecting requires tracking of the tides and the seasons, "certainly one of the hallmarks of behavioral adaptability of early Neandertals [in Europe] and modern humans in South Africa," says Katerina Douka, an archaeologist at the Max Planck Institute for the Science of Human History in Jena, Germany.

Zilhão regards Neandertals as an ancient *H. sapiens* variant, not a separate species as they are often portrayed. "The early *H. sapiens* of Europe, people whom we came to know as Neandertals, exploited marine resources at least as intensively as, if not more intensively than, [Stone Age] South Africans living in comparable habitats and circumstances."



Eel spine bones (shown) were among the seafood remains found at Figueira Brava cave.

Figueira Brava lies on the 20-kilometer-long coastline of Arrábida, a mountain range 30 kilometers south of Lisbon. It's the only place on Europe's Atlantic coast where present-day shorelines and ancient, submerged shorelines are short distances apart, Zilhão says. So only here would Neandertals have caught seafood and brought it back to nearby caves such as Figueira Brava, rather than immediately eating the catch before making a long trek inland.

Excavations unearthed a range of seafood from a time when Neandertals, but not *H. sapiens*, lived in Europe.

Menu items included mussels, limpets, eels and even sharks, which could have been caught in shallow water or when trapped in large rock pools by ebbing tides. Other foods included tortoises, seals, ducks, geese, red deer, horse, a kind of wild goat called an ibex, now-extinct wild cattle called aurochs and pine nuts. Burned pieces of wood in excavated sediment came from fires, probably used for cooking, warmth or both, the researchers say.

Discoveries at Figueira Brava challenge past assertions that Neandertals' seaside visits were rare and unplanned, says Clive Finlayson, an evolutionary ecologist at the Gibraltar National Museum. "Neandertals were every bit human," he says.

But archaeologist Manuel Will of the University of Tübingen in Germany disagrees. "The new study narrows the gap between *H. sapiens* and [Neandertals] but does not close it," he writes in a commentary in the same issue of *Science*.

Taking into account nearly 60 coastal sites occupied either by Neandertals or *H. sapiens* between about 300,000 and 40,000 years ago, *H. sapiens* more intensively exploited coastal resources, Will says. For instance, shell beads, a demanding ornament to make, have mainly been found at *H. sapiens* sites.

But shell beads are not necessarily signs of intensive seafood consumption, Zilhão says. Klasies River, a *H. sapiens* coastal site in South Africa that's rich in shellfish remains, has not yielded shell beads, he says. The key point, he says, is that the density and diversity of Neandertals' seafood at Figueira Brava equals or exceeds that at South African *H. sapiens* sites. ■

ALL: J. ZILHÃO *ET AL*/*SCIENCE* 2020

HUMANS & SOCIETY

Relic's origins may refute tie to Jesus

Nazareth Inscription's marble is traced to a Greek quarry

BY BRUCE BOWER

A mysterious tablet bearing a Roman emperor's orders from about 2,000 years ago has long been thought by some scholars to refer to early Christian claims of Jesus' resurrection from a tomb in the Middle Eastern village of Nazareth. But new research has opened an entirely different possibility — that the marble slab recorded a general demand for law and order after Greek islanders vandalized the tomb of their recently deceased ruler.

If the Christian theory is correct, the document bearing 22 lines of Greek text, known as the Nazareth Inscription, would probably have been written on a piece of Middle Eastern marble. If the theory is true, the tablet would also be the oldest object linked to early Christianity.

Instead, a chemical analysis of the marble puts its origins in a quarry on the Greek island of Kos, near southwestern Turkey, says a team led by Roman historian Kyle Harper of the University of Oklahoma in Norman. That suggests the unnamed emperor's edict, decreeing that anyone who disturbs tombs and graves or destroys corpses be killed, was a response to a break-in at the grave of a Kos tyrant named Nikias, the researchers report in the April *Journal of Archaeological Science: Reports*. Nikias ruled Kos during the 30s B.C. before being overthrown.

News of people on Kos dragging Nikias' body from its resting place and scattering the bones apparently spread by word of mouth and created a scandal. Not long after that incident, one Greek poet used the life of Nikias as an example of a reversal of fortune. The researchers propose the tablet was probably issued by the first Roman emperor, Augustus, as a call for law and order in the eastern Mediterranean. The tablet's message and the style of the inscribed Greek lettering suggest the document dates to between about 2,100 and 1,900 years ago.

"It was completely unexpected that the [Nazareth Inscription] stone came from Kos," Harper says. "Our argument about the tyrant Nikias is not 100 percent certain, but it's the best explanation we have."

Chemically connecting the Nazareth Inscription marble to Kos "is entirely novel," says Christopher Jones, a Classics historian at Harvard and authority on ancient Greek and Roman inscriptions. But there are still questions about whether the document concerns the assault on Nikias' tomb, Jones says.

Nikias had been a supporter of Roman general Mark Antony, who with Egypt's Cleopatra was defeated by Octavian — the future emperor Augustus — in a civil war that ended in 31 B.C. It's unclear why Augustus would have responded to an attack on the tomb of someone who had supported his political enemy, Jones says.

If the edict came from Augustus, it's possible it was part of a broader effort to deter attacks on rulers' tombs in the Middle East and Asia Minor, a region covering much of Turkey and adjacent lands, suggests John Bodel, a historian of ancient Rome at Brown University in Providence, R.I. Inscriptions and legal texts from that time refer to such incidents, typically aimed at the graves of autocratic, corrupt local rulers, Bodel says.

A new study suggests the Nazareth Inscription records a Roman order issued after a Greek ruler's tomb was vandalized.

The attack on Nikias' tomb "may have been pretty spectacular," but it wasn't an oddity, he says. Kos lies off the coast of Asia Minor, where public attacks on local rulers' tombs initially spread, historians have argued. That's one reason why Roman historians have long doubted claims that the Nazareth Inscription referred to early Christianity, Bodel says.

Harper's team analyzed two small samples of marble powder drilled from the back of the Nazareth Inscription. An unusual chemical composition was identified, characterized by elevated levels of a specific form of carbon, carbon-13, and unusually low levels of a specific form of oxygen, oxygen-18. Among marble quarries previously studied throughout the Mediterranean, that makeup most closely matched a marble source on Kos.

Archaeologist Robert Tykot of the University of South Florida in Tampa agrees that the edict was probably written on Kos marble. But further studies are needed to confirm that conclusion, including a comparison of strontium and manganese signatures in the marble with those characterizing different Mediterranean quarries, he says.

Without a firm date for when the Nazareth Inscription was carved, it's possible the object was inscribed during the 1800s by someone with access to Kos marble and the ability to write in the appropriate version of Greek, cautions Tykot. An expertly faked artifact from the dawn of Christianity would have proved irresistible to wealthy antiquities collectors at the time.

The inscription's origins and context have been a mystery for 90 years, since the text of the document was published in 1930. Wilhelm Froehner, an antiquities collector, acquired the item in Paris in 1878. He wrote in his notes that the object had been "sent from Nazareth," a claim that can't be verified.

An unscrupulous antiquities dealer could have misled Froehner about the inscribed tablet's place of origin to increase the object's value as a purported relic of early Christianity. But Froehner never specified the seller's name.

"How exactly Froehner acquired the stone will probably always remain obscure," Harper says. ■

EARTH & ENVIRONMENT

A rainforest once grew in Antarctica

High greenhouse gas levels warmed the area millions of years ago

BY CAROLYN GRAMLING

Once upon a time, there was a rainforest near the bottom of the world.

Buried sediment extracted from the seafloor off West Antarctica contains ancient pollen, fossilized roots and chemical evidence of a diverse forest that flourished millions of years ago, less than a thousand kilometers from the South Pole.

The sediment offers the southernmost glimpse yet into just how warm Earth was during the mid-Cretaceous Period, between 92 million and 83 million years ago. By analyzing traces of vegetation in the sediment, researchers reconstructed climate conditions at the site. Average annual temperatures were about 13° Celsius (about 55° Fahrenheit), with summertime temperatures reaching as high as 20° or 25° C, the team reports in the April 2 *Nature*.

The mid-Cretaceous is known to have been one of the warmest periods on Earth in the last 140 million years, based in part on analyses of fossils and sediment collected from the seafloor closer to the equator. Atmospheric carbon dioxide levels were thought to have been at least 1,000 parts per million. (Today's CO_2 levels average around 407 ppm, the highest in the last 800,000 years.)

But for a forest to thrive so far south, even more potent greenhouse conditions must have existed than previously thought, with CO_2 levels between 1,120 and 1,680 ppm, says marine geologist Johann Klages of the Alfred Wegener Institute in Bremerhaven, Germany.

"It shows us the extreme potency of carbon dioxide — what carbon dioxide can really do," he says. "Even without light for four months, [Antarctica] could still have a temperate climate."

Researchers Tina van de Flierdt (left) and Johann Klages (right) analyze seafloor sediments that revealed Antarctica's lush past.

Klages and colleagues analyzed a 30-meter-long sediment core retrieved from within the Amundsen Sea Embayment, where today the fast-melting Thwaites and Pine Island glaciers drain into the sea. Just by looking at the core, Klages says, the researchers knew it was special: The bottom three meters of sediment, corresponding in time to the mid-Cretaceous, showed traces of roots.

"We've seen many cores from Antarctica, but we've never seen anything like that," Klages says.

The pollen in the core suggested that this soggy, ancient forest was home to conifers, ferns and flowering shrubs, as well as mats of bacteria. Sediment analyses showed no traces of salt, suggesting a freshwater environment.

Between 92 million and 83 million years ago, a diverse rainforest (shown in this artist's reconstruction) flourished within about 1,000 kilometers of the South Pole.

The forest data are also strong evidence that Antarctica was largely ice-free during the mid-Cretaceous, Klages says. High CO_2 alone wouldn't have been enough to keep temperatures balmy so close to the pole. If a bright white ice sheet were present, for example, it would have reflected much of the incoming sunlight back into space, keeping the land cold. Vegetation has the opposite effect, absorbing more solar heat and amplifying greenhouse warming.

The study offers "an unambiguous record of not just warmer conditions, but a diverse forest flora," says geologist Julia Wellner of the University of Houston. "This paper is a great reminder that, just because there [is] a continent sitting at the South Pole, [that] doesn't mean it necessarily has to have ice everywhere, or even be particularly cold."

Wellner says it is difficult to make direct parallels between this finding and how Antarctic glaciers may melt due to modern climate change. Today's atmospheric CO_2 levels are well below mid-Cretaceous levels, but climbing. And continental landmasses have moved over millions of years — pushed and pulled by Earth's shifting tectonic plates — leading, in part, to ocean and atmospheric circulation patterns that differ from those of the deep past.

The study does highlight the powerful role of different feedbacks, such as the presence or absence of ice cover, to the overall climate, Wellner says. What role such feedbacks might play in the future is not yet clear. The current, existing Antarctic ice sheet, for example, could theoretically temper runaway greenhouse warming, even as CO_2 continues to accumulate in the atmosphere.

"Ice present on the planet is a big gift," Klages agrees. "And [we] should do everything we can to keep it." ■

Small ants plant seeds and cultivate the flowery *Squamellaria* species for shelter plus sweet floral feasts.

THE FIRST FARMERS

Could our agricultural role models have six legs? **By Susan Milius**

To picture this farm, imagine some dark blobs dangling high up in a tree.

Each blob can reach "about soccer ball size," says evolutionary biologist Guillaume Chomicki of Durham University in England. From this bulbous base, a *Squamellaria* plant eventually sprouts leafy shoots and hangs, slumping sideways or upside down, from its host tree's branches. In Fiji, one of the local names for the plant translates as "testicle of the trees."

Some *Squamellaria* species grow in clusters and teem with fiercely protective ants. As a young seedling blob plumps up, jelly bean–shaped bubbles form inside, reachable only through ant-sized doorways. As soon as a young plant cracks open its first door to daylight, "ant workers start to enter and defecate inside the seedling to fertilize it," Chomicki says.

The idea that ants tend these plants as farmers gave Chomicki one of those surprise-left-turn moments in science. In a string of papers published since 2016, he and colleagues share evidence for the idea that the *Philidris nagasau* ants may be the first known animals other than humans to farm plants. (The other known insect farmers cultivate fungi.) Chomicki's latest paper, in the Feb. 4 *Proceedings of the National Academy of Sciences*, reports that ants planting seeds of their blobby crop make trade-offs, going for full sun and maximizing the rewarding, sweet flowers rather than planting in the shade, where plants would have higher nitrogen.

Until Chomicki's work, biologists accepted only three groups of fungus-farming insects as achieving the essentials of full agriculture and so rivaling human efforts. Select types of beetles, termites and ants each tamed different fungi, tending their much-needed food crop from sowing to harvest.

Humans didn't farm any food before roughly 12,000 years ago as far as we know. Insects started much earlier. Even leaf-cutter ants, relative newcomers to farming, have been growing their specialized crops for about 15 million years.

To compare agriculture in insects and humans, entomologists, archaeologists and other specialists have held three gatherings in the last six years searching for principles and perhaps some practical advice. (A press fellowship from the Konrad Lorenz Institute for Evolution and Cognition Research paid for me to attend the 2019 symposium in Klosterneuburg, Austria.)

The fungus farms of leaf-cutter *Atta* ants and their close relatives invite comparisons with human farms. Both kinds of farmers do things that look unsustainable, such as growing single crops at a vast scale and applying pesticides. Yet the ants have managed to persist for millions of years.

G. CHOMICKI

Biologists have long mused about whether we humans can make our farms more robust by imitating the practices of ants and other small farmers. That question sounds especially pertinent when human agriculture is heading for big challenges, such as predicted population growth and climate change.

How to learn from ancient farmers isn't an easy question though. Evolution hones by competition, not design, so there are some goofy tactics out there among the insect marvels. Now is a great era for such discussions, because researchers are paying more attention to smaller, odder insect farms. Scientists have barely begun to explore the ways beetles grow fungi, or the quirks of the ants that grow their own plants.

Farmers vs. not-quites

Just what counts as true farming makes a fine starter for impassioned conversations among scientists. (Perhaps the fungi are farming the ants, one longtime expert argues.) In this article, true agriculturists are defined as those who habitually plant a crop, tend it, harvest it and depend on its success.

Plenty of other creatures — social amoebas, a marsh snail, a damselfish, for instance — have evolved ways to encourage food to appear where and when they want it. Impressive as those feats are, plenty of scientists don't consider those lifestyles full-on agriculture.

Several thousand species of the group called ambrosia beetles make up the biggest of the three insect groups that humans deign to call true farmers. Florida's avocado growers have become urgently interested in the invading redbay ambrosia beetle (*Xyleborus glabratus*) because it raises a fungus that can destroy the innards of avocado trees. Fungus farming has evolved independently at least 11 times among these beetles, says forest entomologist Jiri Hulcr of the University of Florida in Gainesville. A few ambrosia species tunneling into trees bring along a fungus that can digest wood's tougher molecules. Most ambrosia fungal farms, though, are just scavenging nutrients in the dying tree. Still, the fungus gets nutrients, then the beetles eat the fungus.

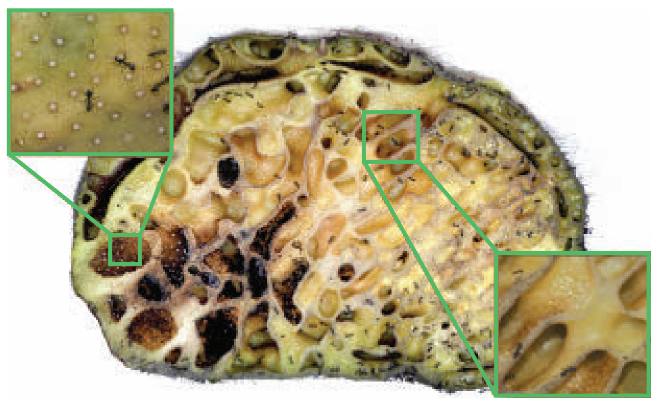
A similar outsourcing of digestion feeds a second group of true farmers, around 330 species of termites in the subfamily Macrotermitinae. The termites collect bits and scraps of dead plant material and feed it to a fungus coddled in cozy caves dug out by the termites. Then the tiny farmers feast on the fungus. The showiest of these termites are the African *Macrotermes*, which are master builders as well as farmers. Above ground they create mounds of hard, red-orange mud several meters high and as jagged as the Alps. The mini-mountains are porous, able to channel airflow and manage temperatures for the fungus caves within. The farm feeds the offspring of a king and outsize queen, which, in one species, is reported to produce some 20,000 eggs a day.

Atta girls

The most famous big-scale insect farmers invented their own Kansas. Fungus-farming ants started out modestly in agriculture as long as 60 million years ago. But around 15 million years ago, the *Atta* leaf-cutter ants and some close relatives went big. Today, each nest grows a single genetic strain of fungus at an industrial scale. A farm is a vast monoculture, a one-crop wonder like some corporate expanse of wheat rippling to the horizon.

One *Atta* nest can grow big enough to feed 7 million residents. Imagine Chicago with more than twice as many people, all growing their food inside city limits — and the ant city still would have more residents and more food. Of course every citizen of this double-Chicago spends a lifetime dining on mostly one food.

The dark lump above, a *Squamellaria* plant, is not part of the tree it hangs from. It's a member of the coffee family, cultivated on sunny branches as part of lumpy plantations created by *Philidris nagasau* ants.



Ants find homey cavities in the base of a *Squamellaria* blob (cross section shown). The plant naturally forms both knobby-walled zones (left inset) perfect for latrines and smooth-surfaced living spaces (right).

BOTH: G. CHOMICKI

Macrotermes michaelseni termites in South Africa also took up farming, bringing home bits of dead plants to feed a fungus garden (left). *Macrotermes bellicosus* colonies nourished by their fungal garden build large aboveground mounds (right) with a hard exterior and sophisticated ventilation.

Atta leaf cutters are the ants that trek through so many nature documentaries. Nothing says tropical forest like a few seconds of a tiny *Atta* forager dwarfed under her huge leaf shard. Those leaf haulers even got a close-up in the 1994 animated *Lion King* movie, never mind that no real-life leaf cutters live in Africa.

Some *Atta* ants live in the southern United States, however. So when I took a trip to Austin in January, Ulrich Mueller, a researcher who has spent decades studying fungus farmers at the University of Texas, offered to lead a mini-expedition to search for local leaf cutters.

I get my first glimpse of *Atta texana* about 10 steps into the main research building of the Brackenridge Field Laboratory. On a wall hangs a see-through teaching aid that resembles a two-story hamster palace with a tiny moving ant here and there. In one of the clear plastic boxes connected by walkway tubes lies what looks like an old gray bath sponge that really ought to be thrown out. Up close it seems more alien: irregular, micro-pocked, with zones of swampy dark brown fading to something close to pale flesh.

Leaf-cutter ants may be the most famous insect farmers. *Atta texana* ants (shown on their fungus) can provide most of the food for a colony with millions of ants.

This fungal heap is why all those leaf haulers truck their green snippets in long lines on ant highways. The ants don't eat the greenery. They poop on it, a pretreatment that encourages the fungal digestive enzymes. Then the ants deposit their little leaf confetti on the fungus heap to wait for lunch to grow.

"This is their stomach," Mueller says. The fungal heap digests the greenery that the ants' guts can't. Feeding an ant nest full of fungus takes so much greenery that one nest of a South American *Atta* ant can become one of the neighborhood's major plant eaters.

Protecting the crop

To a human, this great grazing fungal stomach appears too uniform for the ants' own good. Each nest grows just one fungus clone, says Mueller, who has dug up bits, sampled, compared and resampled over the course of years. A human farm that grows only one or even two crop varieties invites disaster. If a pest or disease can crack the defenses of those few varieties, the whole crop is gone. Think Irish potato famine.

These ant species, however, have cultivated monocultures for millions of years. Some even use pesticides to fight a pest, swiping an invading fungus with a toxin secreted by *Pseudonocardia* bacteria, which thrive in an ant's specialized pocket or body crease. Humans struggle with pests evolving resistance. For example, some Colorado potato beetles have evolved some resistance to 56 pest-killer ingredients. So how do ants keep their crops going?

For one thing, ants keep a close eye on their crops, catching

CLOCKWISE FROM TOP LEFT: AVALON/PHOTOSHOT LICENSE/ALAMY STOCK PHOTO; GFC COLLECTION/ALAMY STOCK PHOTO; ALEX WILD/UNIV. OF TEXAS AT AUSTIN and treating problems early. Mueller estimates that a farmer ant passes each bit of fungus in a garden multiple times a day. Humans call this micro-monitoring of crops "precision agriculture" and see its value for human farms too.

Also, ants may be ahead of humans in fostering beneficial microbiomes. The way ants transplant bits of garden to start a new patch could be one of the big differences between ant and human agriculture, Mueller says. Humans plant just the seed or the cutting. But when ants need to get some fungus going in a new spot, they nip out a chunk of the whole garden and move it — fungus plus whatever bazillion microbes are entangled.

The ants are replicating an entire microbial community, Mueller says. The ant farmers don't need to know microbiology or anything except that a tuft of fungus tastes healthy. That way a microbial ensemble gets passed along that's compatible with the crop and is a good mix against current menaces. "The ants figured out 60 million years ago ... how important these interstitial microbes are," Mueller says.

Questionable practices

While *Atta* ants may manage their external gut's microbiome admirably, some other ant farming practices look wasteful.

The fungus that *Atta* and some close relatives grow as their only crop is not super-efficient at breaking down compounds in the leaves. "It just takes the easy-to-digest stuff," Mueller says. In turn, when the ants eat this fungus, they treat it more like an apple tree than like a window box of salad greens. Ants nip off the plump, pickable tidbits called gongylidia that fatten at the ends of strands of this particular fungus. Plenty of the rest of the fungus is wasted.

There are seemingly more efficient options. One ant species found at the Brackenridge Field Lab, in the *Cyphomyrmex* genus, tends pale yellow to amber chunks of yeast that the ants eat like grapes, without even seeds to spit into the trash. Plus these farmers don't have to cut fresh leaves to feed the farm. Instead, the ants fertilize by bringing in an available waste product: caterpillar droppings.

The *Atta* ants' efforts to collect so much greenery look inefficient by comparison. To explain the process up close, Mueller and grad student Tristan Kubik lead me out of the lab into the Brackenridge woods. This balmy, blue-sky January afternoon ought to be perfect for ants hauling leaves.

To find some foragers, Kubik, a third-generation insect enthusiast, stalks with the intensity of a cat. It takes me a minute to realize what he's pointing at: little shreds of green that give the smallest irregular twitches. It's like looking down at a few cupcake sprinkles on the floor, each giving just the tiniest jiggle per ant step, and all barely out of sync. These are leaf cutters carrying home their greenery.

The bitty jiggles are micro-steps, and the home nest is not even within human sight yet. Just one foraging trip that's a middling distance from the nest, say 75 meters, could take about two hours round trip on smooth ground. These *A. texana* ants, however, venture twice as far. All that for just one sliver, maybe the size of a fingernail paring, of some leaf. The word that pops to mind is "ridiculous."

ALEX WILD

A lot of leaf snippets need to be cut off greenery and hauled home and then snipped some more to feed a giant fungal garden. *Atta cephalotes* ants will often clear a path to bring supplies to the nest.

In human steps, the nest is just a several minutes' stroll away. Nests look strangely undramatic viewed from above. The biggest one we see that afternoon lies on a gentle bank with a minor reddish splotch or two of soil erosion among gnarled winter trees. With coaching, I see several modest finger-poke–sized holes in the ground. I wonder how many thousands of ants might be toiling beneath our boots. Mueller debates with himself: "three million ... maybe five?"

Cutting leaves into bits is a lot of work. To make tiny confetti out of one square meter of leaf surface means cutting back and forth and around a distance of 2.9 kilometers, researchers estimated in 2016 in *Royal Society Open Science*, after observing a lab colony of *A. cephalotes*. The energy that goes into feeding the farm sounds all too familiar.

Fungi as a crop don't photosynthesize as plants do and so can't make lunch out of sunlight. It might be more fair to compare a fungus farm not to a wheat field, but to cattle or pigs in human-run feedlots. Each calorie of food, be it slivers of leaf clippings or railroad cars of soy beans, needs to be grown or collected and then hauled in by farmers. Giant feedlots run by ants have the same relentless supply challenges that human ones do.

Look natural

It doesn't surprise Ford Denison that some people see drawbacks in viewing ant farms as agricultural role models. Denison is author of the 2012 book *Darwinian Agriculture*, and he participated in the 2019 Konrad Lorenz symposium. At the University of Minnesota in St. Paul, Denison studies agricultural sustainability and thinks about how to strategically copy from nature.

Ambrosia beetles dig tunnels into trees for their fungus farms (top). The fungi take in nutrients from the tree, and become beetle chow. Within a tunnel (bottom), *Euwallacea* beetles raise daughters that mate with their lone, blind brother (below), then set off to create more tunnel farms.

BOTH: J. HULCR

Just because we see a farmlike marvel of an ant nest or a sustainable mixed-species forest doesn't mean mimicking its full form would be a great idea. The thing to do, he says, is to look for the details that evolution has tested for millions of years against other options.

Evolution certainly did not test the monoculture form of ant nests through competition. The ants can't grow their fungus any other way. If there's more than one strain of fungus in a farm, "there's chemical warfare," he says. One strain typically kills its rival, even if they're growing in separate chambers.

"Their long-term use of monoculture may be evidence that monoculture can be sustainable," Denison says. Humans looking for natural models, however, should probably aim for a higher bar. Monoculture farming among these ants "certainly doesn't mean that it's better than polyculture," he says. Cultivating more diverse farms might have eased pest problems. But who knows? Ants with one crop never competed against ants with more than one.

Back to the trees

Other insect farms certainly have quirks that look as if they evolved under intense competition. Consider the treetop *Squamellaria* blobs, which face challenges in recycling nitrogen.

Nitrogen is often a precious commodity for plants like *Squamellaria* that don't live in soil. For these plants, which have forged a space station lifestyle clinging to tree branches high above the ground, the *P. nagasau* ants may be cherished deliverers of nitrogen or other nutrients. The ants also offer vital defense, rushing to attack intruders that try to nibble a seed or a leaf from their bulbous farms.

As payback, the plant offers absolutely necessary shelter for the ants and food that's convenient but replaceable in a pinch. The flowers of *Squamellaria* plants hold a sweet appeal for ants. When the petals fall off, the flower pauses in development for days, and ants visit to feed on a sugary rim with a shot of amino acids at the flower base.

In six *Squamellaria* species, as the plants grow and open more entrances to their inner cavities, the ants move in through tiny doorways and raise young. A large plant can host around 10,000 ants, and a whole ant colony can expand its boundaries to embrace multiple plants, even a mix of lumpy species.

In the plants' bases, some chambers form smooth inner walls while other cavities sprout widely spaced little knobs. Ants tend eggs and larvae in the smooth-sided chambers. The knobby-walled cavities, Chomicki thinks, serve as ant latrines and garbage dumps. From the plant point of view, these chambers serve as donation centers for nitrogen-rich ant excretions.

The knobby walls' uptake of nitrogen is "very, very efficient," Chomicki says. He has injected different concentrations and tracked plants keeping up with massive influxes.

Ants check all the boxes for truly farming in the six species, Chomicki argues. He has videotaped ants planting *Squamellaria* seeds by tucking them under tree bark. Ants then defend the seeds from leaf beetles and other predators, even attacking inquisitive scientists. This vigorous defense in the treetop world could count as yet another chore in tending the farm.

"The ants are directly consuming food they fertilize with their feces," says one of Chomicki's coauthors, ecologist Toby Kiers of Vrije Universiteit Amsterdam. Fertilizer pollution is a hot topic in the Netherlands. In Kiers' vision of a more sustainable future, field crops get their fertilizer from the manure in neighboring pastures, so a former waste product circles back into something useful.

Take inspiration from the ants, she urges. A blob farm is "like the ultimate circular economy." ■

Explore more

- Guillaume Chomicki *et al.* "Trade-offs in the evolution of plant farming by ants." *Proceedings of the National Academy of Sciences*. February 4, 2020.

Actual size is approximately 20 mm

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At War Over Reading

Separating fact from fiction to teach kids the basics

By Emily Sohn

On a chilly Tuesday back in January, my 7-year-old son's classroom in Minneapolis was humming with reading activities. At their desks, first- and second-graders wrote on worksheets, read independently and did phonics lessons on iPads. In the hallway, students took turns playing a dice game that challenged them to spell out words with a consonant-vowel-consonant structure, like *wig* or *map*.

In another part of the classroom, small groups of two or three children, many missing their two front teeth, took turns sitting on a color-block carpet with teacher Patrice Pavek. In one group, Pavek asked students to read out loud from a list of words. "Con-fess," said a dimpled 7-year-old named Hazel, who sat cross-legged in purple boots and a black fleece. Pavek reminded Hazel that a vowel sound in the middle of a word changes when you put an *e* at the end. Hazel tried again. "Con-fuse," she said. "Beautiful!" Pavek beamed.

When Hazel returned to her desk, I asked her what goes through her mind when she gets to a word she doesn't know. "Sound it out," she said. "Or go to the next word." Her classmates offered other tips. Reilly, age 6, said it helps to practice and look at pictures. Seven-year-old Beatrix, who loves books about unicorns and dragons, advocated looking at both pictures and letters. It feels weird when you don't know a word, she said, because it seems like everyone else knows it. But

Many U.S. teachers are not using the most science-based approaches to teach reading.

learning to read is kind of fun, she added. "You can figure out a word you didn't know before."

Like the majority of schools in the United States, my son's district uses an approach to reading instruction called balanced literacy. And that puts him and his classmates in the middle of a long-standing debate about how best to teach children to read.

The debate — often called the "reading wars" — is generally framed as a battle between two distinct views. On one side are those who advocate for an intensive emphasis on phonics: understanding the relationships between sounds and letters, with daily lessons that build on each other in a systematic order. On the other side are proponents of approaches that put a stronger emphasis on understanding meaning, with some sporadic phonics mixed in. Balanced literacy is one such example.

The issues are less black and white. Teachers and reading advocates argue about how much phonics to fit in, how it should be taught, and what other skills and instructional techniques matter, too. In various forms, the debate about how best to teach reading has stretched on for nearly two centuries, and along the way, it has picked up political, philosophical and emotional baggage.

In fact, science has a lot to say about reading and how to teach it. Plenty of evidence shows that children who receive systematic phonics instruction learn to read better and more rapidly than kids who don't. But pitting phonics against other methods is an oversimplification of a complicated reality. Phonics is not the only kind of instruction that matters, and it is not the panacea that will solve the nation's reading crisis.

Cutting through the confusion over how to teach reading is essential, experts say, because reading is crucial to success, and many people never learn to do it well.

According to U.S. government data, only one-third of fourth-graders have the reading skills to be considered proficient, which is defined by the National Assessment of Educational Progress as demonstrating competency over challenging subject matter. And a third of fourth-graders and more than a quarter of 12th-graders lack the reading skills to adequately complete grade-level schoolwork, says Timothy Shanahan, a reading researcher at the University of Illinois at Chicago.

Those struggles tend to persist. As many as 44 million U.S. adults, or 23 percent of the adult population, lack literacy skills, according to U.S. Department of Education data. Those affected may be able to read movie listings, or the time and place of a meeting, but they can't synthesize information from long passages of text or decipher the warnings on medication inserts. People who can't read well are less likely than others to vote, or read the news or secure employment. And today's technology-based job market means students need to achieve more with reading than in the past, Shanahan says. "We are failing to do that."

Lessons in decoding

The vast majority of children need to be taught how to read. Even among those with no learning disabilities, only an estimated 5 percent figure out how to read with virtually no help, says Daniel Willingham, a psychologist at the University of Virginia in Charlottesville and author of *Raising Kids Who Read*. Yet educators have not reached consensus on how best to teach reading, and phonics is the part of the equation that people still argue about most.

The idea behind a systematic phonics approach is that children must learn how to translate the secret code of written language into the spoken language they know. This "decoding" begins with the development of phonological awareness, or the ability to distinguish between spoken sounds. Phonological awareness allows children, often beginning in preschool, to say that *big* and *pig* are different because of the sound at the beginning of the words.

Once children can hear the differences between sounds, phonics comes next, offering explicit instruction in the connections between letters, letter combinations and sounds. To be systematic, these skills need to be taught in an organized order of concepts that build on one another, preferably on a daily basis, says Louisa Moats, a licensed psychologist and literacy expert in Sun Valley, Idaho. Today, phonics proponents often advocate for the simple view of reading, which emphasizes decoding and comprehension, the ability to decipher meaning in sentences and passages.

Support for phonics has been around since at least the 1600s, but critics have also long expressed concerns that rote phonics lessons are boring, prevent kids from learning to love reading and distract from the ability to understand meaning in text. In the 1980s, this kind of thinking led to the rise of whole language, an approach aimed at making reading joyful and immersive instead of mindless and full of effort.

By the 2000s, a more all-around and phonics-inclusive approach called balanced literacy was gaining popularity as the leading theory in

Five essentials

A meta-analysis of 38 studies found five components of reading instruction were most helpful to students.

Phonemic awareness
Knowing that spoken words are made of smaller segments of sound called phonemes

Phonics
The knowledge that letters represent phonemes and that these sounds can combine to form words

Fluency
The ability to read easily, accurately, quickly and with expression and understanding

Vocabulary
Learning new words

Comprehension
The ability to show understanding, often through summarization

SOURCE: NATIONAL READING PANEL

competition with phonics-first approaches.

In a 2019 survey of 674 early-elementary and special education teachers from around the United States, 72 percent said their schools use a balanced literacy approach, according to the Education Week Research Center, a nonprofit organization in Bethesda, Md. The implementation of balanced literacy, however, varies widely, especially in how much phonics is included, the survey found. That variation is probably preventing lots of kids from learning to read as well as they could, decades of research suggests.

In the late 1990s, with the reading wars in full swing, the National Institute of Child Health and Human Development brought together a panel of about a dozen reading experts to evaluate the evidence for how best to teach reading. The National Reading Panel's first task was to figure out which types of teaching tasks to include in the analysis, says Shanahan, a panel member. Ultimately, the group chose eight categories and conducted a meta-analysis of 38 studies involving 66 controlled experiments from 1970 through 2000. The results showed support for five components of reading instruction that helped students the most.

Two components that rose to the top were an emphasis on phonological awareness and phonics. Studies included in the analysis showed that higher levels of phonological awareness in kindergarten and first grade were predictors of better reading skills later on. The analysis couldn't assess the magnitude of benefits, but children who received systematic phonics instruction scored better on word reading, spelling and comprehension, especially when phonics lessons started before first grade. Those children were also better at sounding out words, including nonsense words, Shanahan says.

Vocabulary development was another essential component, as was a focus on comprehension. The final important facet was a focus on achieving fluency — the ability to read a text quickly, accurately and with proper expression — by having children read out loud, among other strategies.

Even before the panel released its results in 2000, numerous studies and books from as early as the 1960s had concluded that there was value in explicit phonics instruction. Studies since then have added yet more support for phonics.

In 2008, the National Early Literacy Panel, a government-convened group that included Shanahan, considered dozens of studies on phonological awareness (including phonemic awareness, the ability to identify and manipulate individual sounds in spoken words) plus phonics instruction in preschool and kindergarten. Children who got decoding instruction scored substantially better on tests of phonological awareness compared with those who didn't. The benefit was equivalent to a jump from the 50th percentile to the 79th percentile on standardized tests, suggesting those students were better prepared to learn how to read.

Likewise, a 2007 meta-analysis of 22 studies conducted in urban elementary schools found that minority children who received phonics instruction scored the equivalent of several months ahead of their minority peers on several academic measures. Studies have not addressed whether phonics might help close demographic achievement gaps, but research suggests that whole language approaches are less effective in disadvantaged populations than in other groups.

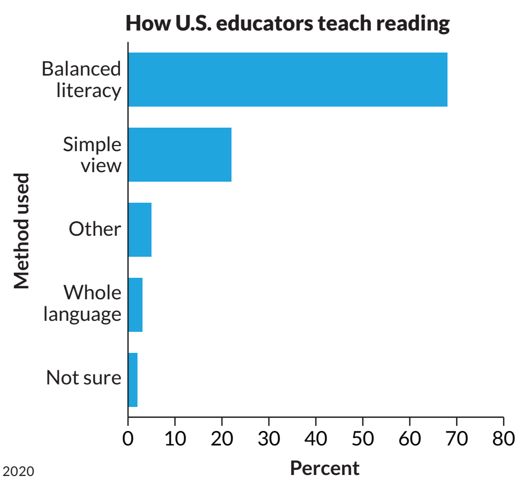
"There are several thousand studies at least that converge on this finding," Moats says. "Phonics instruction has always had the edge in consensus reports." It is difficult to quantify how substantial the gains are from explicit phonics instruction, partly because the bulk of published research is full of ambiguities. Randomized trials are rare. Studies tend to be small. And in schools where teachers have autonomy to respond to students at their discretion, control groups are often not well-defined, making it hard to tell what phonics-focused programs are really being compared with, or how much phonics the control groups are getting. The reality of instruction can differ from classroom to classroom, even within the same school. And students who aren't getting intensive phonics at school may have the blanks filled in at

Teacher's choice In a random sample of almost 700 U.S. early-elementary and special education teachers, most reported using a method called balanced literacy to teach reading. The simple view of reading, focused on phonics, was a distant second.

Balanced literacy
Instruction includes a bit of everything, usually with some phonics.

Simple view
The emphasis is on phonics, with a focus on two skills: decoding and language comprehension.

Whole language
Instruction emphasizes whole words and phrases in meaningful contexts, including a strategy called three cuing.

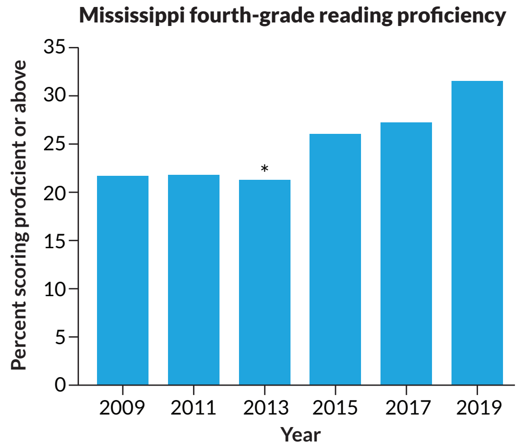


SOURCE: EDWEEK RESEARCH CENTER 2020

E. OTWELL

home, where parents might sound out words and talk about letters while reading bedtime stories.

The data that are available suggest that kids who get systematic phonics lessons score the equivalent of about half a grade level ahead of kids in other groups on standardized tests, Shanahan says. That's not a giant leap, but it helps. "Overwhelmingly in studies, both individually and in a meta-analysis where you're combining results across studies, if you explicitly teach phonics for some amount of time, kids do better than if you don't pay much attention to that or if you pay a little bit of attention to [phonics]," he says.



A boost with phonics
After adding explicit phonics instruction statewide in 2013, Mississippi reported the nation's largest improvement in reading scores among fourth-graders.
SOURCE: NATIONAL ASSESSMENT OF EDUCATIONAL PROGRESS 2019

Real experiences

Some of the most compelling evidence to support a phonics-focused approach comes from historical observations: When schools start teaching systematic phonics, test scores tend to go up. As phonics took hold in U.S. schools in the 1970s, fourth-graders began to do better on standardized reading tests.

In the 1980s, California replaced its phonics curriculum with a whole language approach. In 1994, the state's fourth-graders tied for last place in the nation: Less than 18 percent had mastered reading. After California re-embraced phonics in the 1990s, test scores rose. By 2019, 32 percent achieved grade-level proficiency.

Those swings continue today. In 2019, Mississippi reported the nation's largest improvement in reading scores; the state had started training teachers in phonics instruction six years earlier. For the first time, Mississippi's reading scores matched the nation's average, with 32 percent of students showing proficiency, up from 22 percent in 2009, making it the only state to post significant gains in reading in 2019.

England, too, started seeing dramatic results after government-funded schools were required in 2006 to teach systematic phonics to 5- to 7-year-olds. When the country implemented a test to assess phonics skills in 2012, 58 percent of 5- and 6-year-olds passed. By 2016, 81 percent of students passed. Reading comprehension at age 7 has risen, and gains seem to persist at age 11. These population trends make a strong case for teaching phonics, says Douglas Fuchs, an educational psychologist at Vanderbilt University in Nashville.

Despite the evidence that children learn to read best when given systematic phonics along with other key components of a literacy program, many schools and teacher-training programs either ignore the science, apply it inconsistently or mix conflicting approaches that could hinder proficiency. In the 2019 Education Week Research Center survey, 86 percent of teachers who train teachers said they teach phonics. But surveyed elementary school teachers often use strategies that contradict a phonics-first approach: Seventy-five percent said they use a technique called three cuing. This method teaches children to guess words they don't know by using context and picture clues, and has been criticized for getting in the way of learning to decode. More than half of the teachers said they thought students could understand written passages that contained unfamiliar words, even without a good grasp of phonics.

The disconnect starts at the top. In a 2013 review of nearly 700 teacher-training institutions, only 29 percent required teachers to take courses on four or five of the five essential facets of reading instruction identified by the National Reading Panel. Almost 60 percent required teachers to complete coursework on two or fewer of the essentials, according to the National Council on Teacher Quality, a research and policy group based in Washington, D.C.

In 2019, the Education Week Research Center also surveyed 533 postsecondary educators who train teachers on how to teach reading. Only 22 percent of those educators said their philosophy was to teach explicit, systematic phonics. Almost 60 percent said they support balanced literacy. And about 15 percent thought, contrary to evidence, that most students would learn to read if given the right books and enough time.

"The majority of classrooms in this country continue to embrace instructional practices and programs that do not include systematic instruction in foundational skills like phonemic awareness and phonics and spelling," Moats says. "They just don't do it."

E. OTWELL

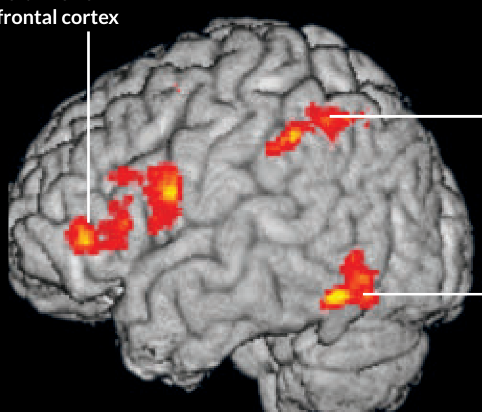
This is your brain on reading

Reading is a relatively new activity for the human brain, which hasn't had time to evolve specialized areas devoted to the task. Instead, our brains enlist areas, such as the visual system, that originated for other reasons, says Guinevere Eden, a neuroscientist at Georgetown University in Washington, D.C. An object like a tree or a lion needs to be recognizable from any angle, she says. But when we read, we need to override that kind of pattern recognition to distinguish, say, *b* from *d*, two letters that look identical to a beginning reader.

To translate squiggles and dots into sounds, several key brain areas, in both the visual and language systems, get involved. And how involved those areas are during reading shifts with increasing mastery, according to brain-imaging studies from the last two decades. When early or experienced readers sound out an unfamiliar word, they tap into the posterior and superior temporal lobes and inferior parietal lobe, which are involved in language and sensory processing. When the brain encounters a familiar word, on the other hand, the visual cortex takes over, suggesting that known words become like any other object that the brain recognizes instantly. As a person's reading skills improve and the mental menu of familiar words grows, activity is more pronounced in the visual cortex during reading, Eden says.

Eden uses brain scans to understand what goes wrong in children with reading disabilities, who have trouble sounding out words. One of her goals is to evaluate interventions for children with dyslexia to see if the interventions target the brain processes that are most impaired.

Despite heavy marketing by companies that sell reading products using brain scans as evidence that the companies' methods help children learn to read, Eden says that imaging studies cannot yet answer questions about which types of reading instruction are best for children, with or without reading disabilities. *— Emily Sohn*



This fMRI scan shows activity (red and orange) in areas known to be involved in reading, including the left inferior frontal cortex, inferior parietal lobe and the inferior temporal cortex, which is part of the visual cortex. In adults with dyslexia, those areas are less active during reading.

At my son's Minneapolis school, reading specialist Karin Emerson told me about her early days teaching kindergarten, first and second grades in the 1990s. She was trained to use a whole language approach that included the three cuing technique.

Emerson described a typical reading lesson: "I'm going to show you a big book, and I'm going to cover up all of the letters of the word except the *b*, and I'm going to say, 'Look at this page. It says this is a …' What do you think it's going to say?" Then she would point out the butterfly in the picture and ask the students to think about whether the *b* sound could refer to anything in the picture. "What does butterfly start with? A 'b-uh.' Do you think it's going to be butterfly? I think it is going to be butterfly. It is."

Eight years later, Emerson switched from classroom teacher to reading specialist, helping third-graders who weren't reading yet. Many were the same students she had taught to read in younger grades. After reviewing the reading research, she implemented systematic phonics. By the end of third grade, students in her groups advanced an average of two grade levels. She now encourages early-grade teachers to add at least 20 minutes of phonics a day into literacy lessons.

Looking back to her classroom-teaching days, Emerson says parents often told her they were concerned that their children weren't reading yet. "I would say, 'Oh, they'll be fine because they're well spoken, they're bright and you're reading to them.' Well they weren't fine," Emerson says. "Some people learn how to read super easy, and that's great. But most people need to be taught, and there's a pretty big chunk who need to be taught in a systematic way."

While learning about ongoing battles over reading instruction, I have been marveling at my son's transformation from nonreader to reader. One recent afternoon, he came home from school and told me that he had learned how to spell the word "A-G-A-I-N." I asked him how he would spell it if it looked like it sounded. He worked it out, one sound at a time: "U-G-E-N." We agreed the English language is pretty strange. It's amazing anyone learns to read it at all. ■

Explore more

- National Reading Panel. "Teaching children to read." February 27, 2000.

Emily Sohn is a freelance journalist based in Minneapolis.

G.F. EDEN *ET AL/NEURON* 2004

Texas Tech University Bands Together to Help Health Care Workers Battling COVID-19

The Texas Tech University community is coming together to help fight the spread of the coronavirus (COVID-19). In response to a shortage of personal protective equipment (PPE) for health care workers, researchers across Texas Tech have donated thousands of items from their laboratories. Staff from the Texas Tech University Health Sciences Center picked up the collected PPE: more than 107,000 gloves, more than 2,000 masks, more than 2,500 gowns and two ultraviolet light sterilization units.

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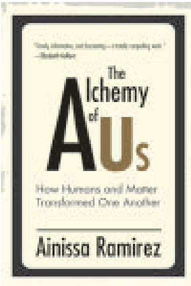

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BOOKSHELF

Materials science has changed humankind

Humans have continually wielded materials, from steel to silicon, in new ways to send technology leaping forward. But those technologies have unintentionally molded our bodies and society, materials scientist and science writer Ainissa Ramirez argues in *The Alchemy of Us*.

Increasingly precise clocks — based on steel springs and then quartz crystals — kept society humming along in unison. But with the Industrial Revolution's focus on factory schedules, humans became ever more obsessed with time, and our sleep habits suffered. Likewise, electric lights made with carbon filaments let people work and play for longer hours, but upset circadian rhythms, with a variety of negative health impacts.

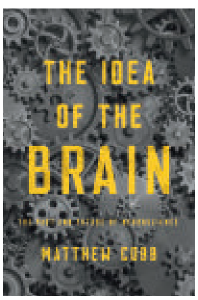
But the knock-on effects haven't been all bad: Telegraph wires of iron and copper allowed news to travel quickly across the United States beginning in the 1840s. The technology's demand for short communications helped shape the clipped style of American newspapers, whose reporters used the technology to send dispatches from afar. That style inspired the concise, clear prose of Ernest Hemingway, Ramirez argues.

Packed with engaging, little-known stories from the history of science, the book provides sharp, straightforward explanations of the materials science behind these tales. Ramirez carefully selects the characters in her narratives, making for a refreshing departure from the lone scientific genius trope. Instead, we meet Ruth Belville, who carried around a highly accurate pocket watch and "sold time" in early 20th century England, and chemist Caroline Hunter and photographer Ken Williams, Polaroid employees who in the 1970s fought their employer over the use of instant photography to monitor South Africans during apartheid.

Bucking the tendency for hero worship in histories of science, Ramirez notes the failings of the figures she profiles. For example, Samuel Morse, known for his work on the telegraph, supported slavery and railed against immigrants.

The author's excitement is infectious: As she raves about the "marvelous metamorphosis that occurs when carbon combines with iron" to make steel, the substance suddenly seems wondrous, with cakelike layers that make it both malleable and strong. Steel reappears in later chapters, weaving into stories of technologies that hinged on improved steel production.

The connections Ramirez draws between seemingly disparate ideas in science and culture are engaging. Throughout the book, the message is somber, but hopeful: Materials change us in ways we hadn't expected. But by being aware of these effects, society can choose how to respond. *— Emily Conover*



The Idea of the Brain
Matthew Cobb
BASIC BOOKS,
$32

BOOKSHELF

How our ideas about the brain have evolved

Neuroscientists love a good metaphor. Through the years, plumbing, telegraph wires and computers have all been enlisted to help explain how the brain operates, neurobiologist and historian Matthew Cobb writes in *The Idea of the Brain*. And like any metaphor, those approximations all fall short.

Cobb leads a fascinating tour of how concepts of the brain have morphed over time. His writing is clear, thoughtful and, when called for, funny. He describes experiments by neurosurgeon Wilder Penfield, who zapped awake patients' brains with electricity to provoke reactions. Zapping certain places consistently dredged up memories, which Cobb calls "oneiric experiences." His footnote on the term: "Look it up. It's exactly the right word." I did, and it was.

Cobb runs though the history of certain concepts used to explain how the brain works, including electricity, evolution and neurons. Next comes a section on the present, which includes discussions of memory, circuits and consciousness. Cobb offers tastes of the latest research, and a heavy dose of realism. Memory studies have made progress, but "we are still far from understanding what is happening when we remember," Cobb writes. Despite big efforts, "we still only dimly understand what is going on when we see." Our understanding of how antidepressants work? "Virtually non-existent."

This real talk is refreshing, and Cobb uses it to great effect to argue that neuroscience is stymied. "There have been many similar moments in the past, when brain researchers became uncertain about how to proceed," he writes. Scientists have amassed an impressive stockpile of brain facts, but a true understanding of how the brain works eludes us.

Don't expect a computer metaphor to help. Like a computer, the brain's main job is to process information. But some experts argue that because brains are biological — they evolved within the vagaries of a body — they operate in ways that a machine doesn't (*SN: 9/3/16, p. 18*).

Cobb reckons that, among other reasons, the mere existence of such objections is a harbinger of the end of the computer metaphor. But that doesn't mean the comparison was a waste. Metaphors clarify thoughts, he writes, and scientists would do well to ponder what might replace the concept.

He ends the book with a creative exercise in looking ahead to what the future might hold. The possibilities include the creation of conscious machines, or even having to accept that there is no brain theory to be found. Still, "our current ignorance should not be viewed as a sign of defeat," Cobb writes, "but as a challenge." *— Laura Sanders*

Science News *for* Students

Science News for Students is an award-winning, free online magazine that reports daily on research and new developments across scientific disciplines for inquiring minds of every age — from middle school on up.

How to cope as COVID-19 imposes social distancing

To limit the spread of COVID-19, people across the world have been asked to stay close to home. *Science News for Students* talked to U.S. kids about what concerns this "social distancing" has caused. Topping their list? Missing out on trips and activities and fear of family falling ill. Anxiety about this is totally normal and mostly a good thing, notes psychologist Amy Lee of the Cleveland Clinic. But such anxiety can become unhealthy when it doesn't shut off. She and other experts offer kids tips to deal with these troubling times. — *Sheila Eldred*

Read more: www.sciencenewsforstudents.org/covid-19-social-distancing

Silk can be molded into strong medical implants

Silk is a natural material that breaks down in the body over time. That's one reason doctors like it for medical implants. Plus, few people are allergic to it. But silk medical materials haven't had a long shelf life. Until now. Biomedical engineers have figured out how to extract silk proteins and freeze-dry them into a powder. The engineers can then mold the powder into really durable parts — ones stronger than wood. And being "biocompatible," these silk parts can be implanted for use as screws or drug-delivery devices. — *Sid Perkins*

Read more: www.sciencenewsforstudents.org/silk-medical

Before working on spacecraft, this engineer overcame self-doubt

At times, Tiera Fletcher wanted to be a mathematician, an inventor, a scientist and an architect. But when she was 11, she figured it out. She wanted to build rockets and airplanes. Today, she's a structural engineer who has helped design vehicles that may someday shuttle people to the moon or Mars. She wants kids to realize that believing in themselves is an important part of reaching their goals. As part of the Pathways to STEM Success series, sponsored by Arconic Foundation, she shared her experiences and advice with *Science News for Students*. — *Carolyn Wilke*

Read more: www.sciencenewsforstudents.org/spacecraft-engineer

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MARCH 14, 2020

News you can use

Hundreds of readers have written to Science News *about COVID-19. Some people want to know more about the coronavirus (see COVID-19 Q&A, right). Others have asked about practical steps they can take to reduce their risk of catching it.*

Reader **Jen Cole** wondered how she could disinfect her phone. "So much contradictory information out there," **Cole** wrote.

A household cleaning wipe that has at least 70 percent isopropyl alcohol will work, says molecular biology and senior writer **Tina Hesman Saey**. Avoid bleach and spraying products directly on your phone, as that may introduce too much moisture.

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Going viral

Bats' immune defenses let the animals safely carry viruses, such as Marburg and Ebola, that can cause deadly outbreaks in people, ***Erin Garcia de Jesus*** *reported in "Why bat viruses are so dangerous" (SN: 3/14/20, p. 7).*

Reader **Lori J. Stratton** wondered how viruses from bats spread to humans.

Viruses can spill over from bats into people in a variety of ways, says **Garcia de Jesus**. People can contract Ebola and Marburg by eating infected bats, eating produce contaminated with infected bat saliva or urine, or through other contact with infected bats' bodily fluids, according to the U.S. Centers for Disease Control and Prevention. The winged mammals also can transmit the viruses to chimpanzees, gorillas, monkeys and other animals, which can then infect people.

Reader **Fauzi Saleem** wondered if an amino acid from bat milk could be used to treat people with COVID-19. Bats can transmit immune proteins, which are made of amino acids, to offspring through milk.

It's unclear if bats are the direct source of the new coronavirus, **Garcia de Jesus** says. Scientists know that the virus came from bats at some point, but it may have taken a detour through another animal first (*SN Online: 3/26/20*). "Even so, no single amino acid on its own will protect an animal from an infectious disease," she says. The amino acid must be part of an antibody or another part of the immune response." Bat antibodies wouldn't help people because bats' immune systems are vastly different from the human immune system. "Our immune defenses would probably try to fight off the bat antibodies as well as the virus," she says.

COVID-19 Q&A

Science News *reporters* ***Tina Hesman Saey***, ***Aimee Cunningham***, ***Jonathan Lambert*** *and* ***Erin Garcia de Jesus*** *are following the latest research to keep you up to date on the coronavirus pandemic. As the virus spreads, the team is answering reader questions about COVID-19.*

"Does the initial amount of viral particles inhaled affect the severity of the disease?" reader **John Salmon** asked.

Researchers are still in the early stages of figuring out whether the number of viral particles that launch an infection influences disease severity. While that appears to be the case for influenza, more research is needed to know if it's true for COVID-19.

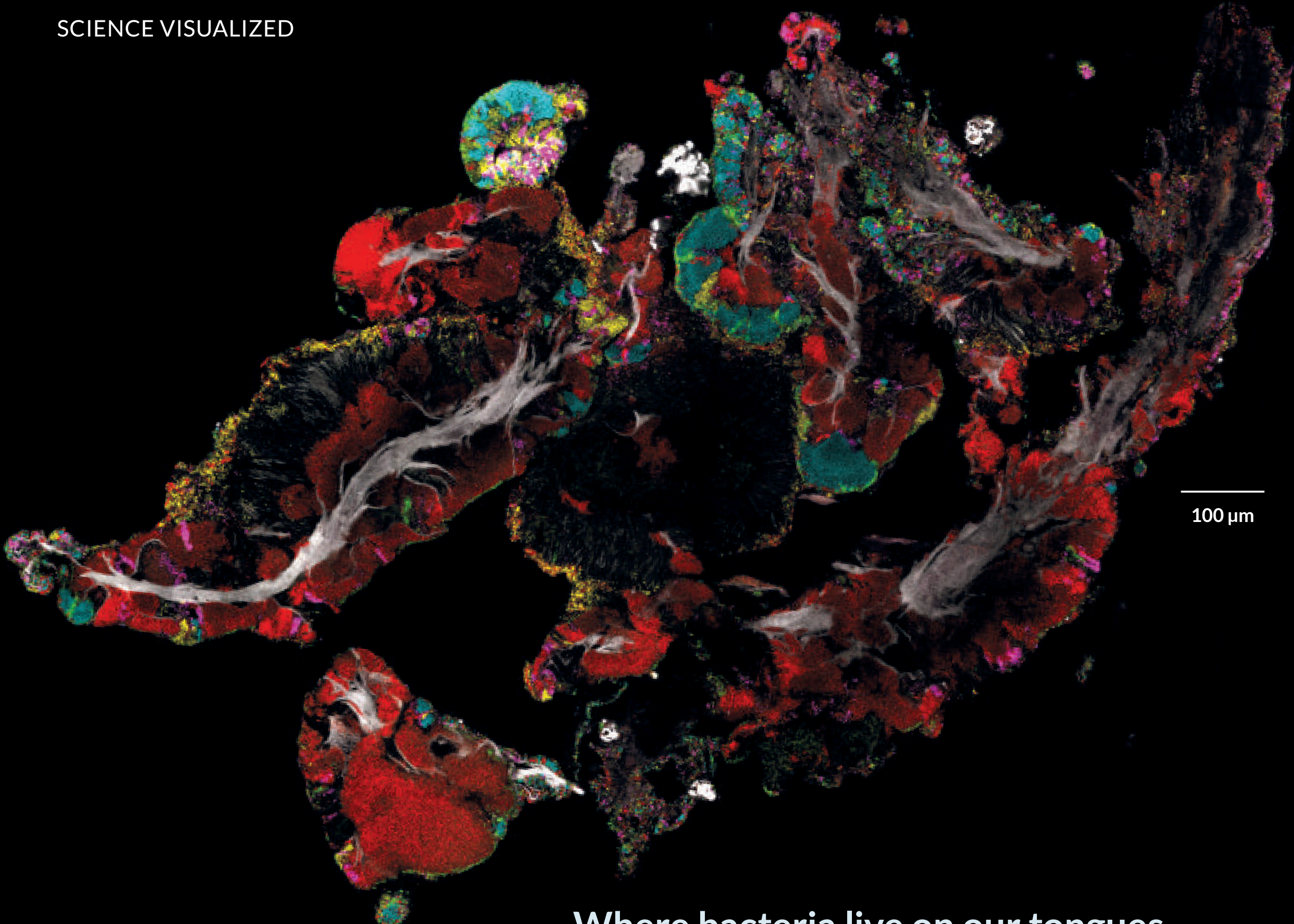
Some preliminary research hints that infected patients who have more virus in their bodies, or higher viral load, over the course of an infection may have more severe disease. Researchers tracking the viral load of patients hospitalized with COVID-19 in Nanchang, China, found that patients with more severe disease had a viral load 60 times as high on average as that of patients with mild cases, the team reported March 19 in the *Lancet*. But other studies of patients in Italy and China have found no association between viral load and disease severity.

Reader **Terry Provost** asked about the rates of false-positive and false-negative results for COVID-19 diagnostic tests.

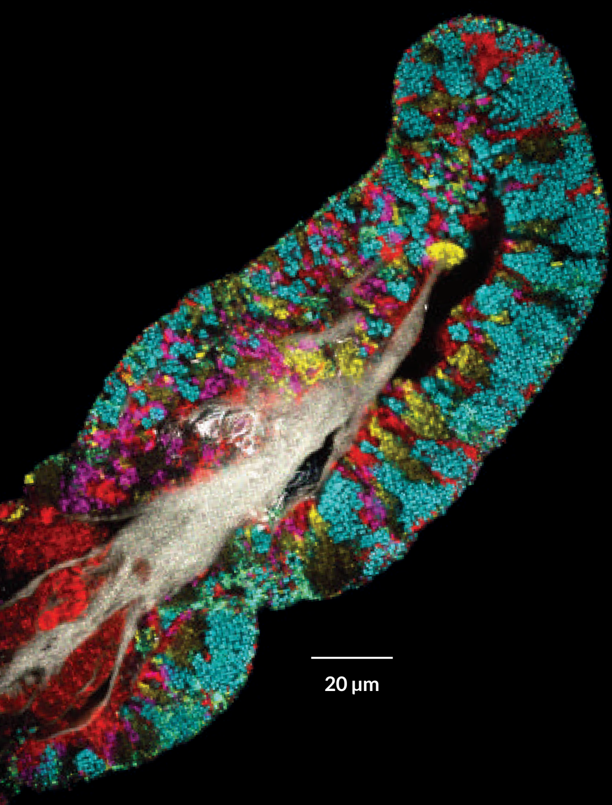
False positives, where someone is told they have the virus but really don't, are likely rare. Diagnostic tests use a technique called real-time RT-PCR to detect small amounts of the virus's genetic material. If the virus's RNA is present in a throat or nasal swab, RT-PCR finds it and amplifies it, resulting in a positive test. If there is no RNA from the virus, there is nothing for RT-PCR to amplify.

False negatives may be more common. One small study, posted online February 17 at medRxiv.org, found that tests that rely on nasal swabs failed to detect the virus in around 30 percent of previously confirmed cases. Throat swab tests failed to detect nearly 40 percent of confirmed cases. When this magazine went to press, the study had yet to be peer-reviewed.

A negative test result does not rule out the possibility of having COVID-19, and any final diagnosis should be made by a clinician.



Where bacteria live on our tongues



Myriad microbes dwell on a human tongue, and scientists have now gotten a glimpse at the neighborhoods that bacteria build for themselves there.

Bacteria grow in a thick film around human cells (gray, with a clump above and a single human cell at left) scraped from the tongue's surface. In those films, different types of microbes (shown with different colors) cluster in patches, researchers report in the March 24 *Cell Reports*.

This pattern suggests that individual bacterial cells first attach to a tongue cell's surface and then grow in layers to form larger clusters and create miniature environments that bacterial species need to thrive.

"It's amazing, the complexity of the community that they build right there on your tongue," says microbiologist Jessica Mark Welch of the Marine Biological Laboratory in Woods Hole, Mass.

She and colleagues had people scrape the top of their tongues with plastic scrapers. Then the team tagged various types of bacteria with colored markers to see how the community was structured. Microscope images showed that while the overall patchwork appearance of that community was consistent across cells from different samples and people, the specific composition of bacteria varied.

Knowing how bacteria are arranged on the tongue could uncover how the microbes work together to maintain their environments and keep a host healthy. *—Erin Garcia de Jesus*

BOTH: S.A. WILBERT, J.L. MARK WELCH AND G.G. BORISY/*CELL REPORTS* 2020

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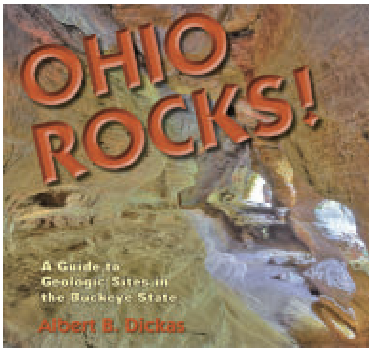

At first consideration, any natural bridge appears unnatural. How did it form and when, and how long will it last? Answers can be found at the topographic oddity forming the centerpiece of Rockbridge State Nature Preserve.

Some 350 million years ago, during the Mississippian Period, sand deposited across central Ohio by rivers was being compacted into rock—the Black Hand Sandstone. As time passed, the development of vertical fractures, the inevitable result of erosion and weathering, altered the complexion of the sandstone. Then, 2.6 million years ago, the Pleistocene ice ages began to cast a cool shadow across the countryside.

Meltwater from the glaciers flowed across the sandstone and into the fractures, forming cliffs over which developing rivers cascaded as waterfalls. The power of falling water, in harmony with percolating groundwater, slowly fashioned cavelike alcoves in the softer, lower layers of the sandstone, each recess roofed by an overhanging section of resistant rock. Rockbridge began life as one of these alcoves.

As the depth of the alcove increased to the stature of a cave and then became even deeper, portions of the cave's roof collapsed along a segment of an upstream fracture, creating a skylight. The skylight separated the main cliff face from a residual segment of the roof that remained as a lintel, which spanned a tributary of the Hocking River. Once the skylight formed, Rockbridge reached maturity.

Today, with a span of 92 feet, a maximum clearance of 40 feet, and a width that varies from 6.5 to 25 feet, Rockbridge securely holds the title of the "best known" and "longest" of all Buckeye natural bridges. It is, however, an ephemeral feature, doomed by the relentless forces of erosion and weathering. While it lasts, it gracefully spans not only a shaded sylvan brook, but also the gap between the Mississippian and Quaternary Periods of geologic time. On the other hand, considering its isolation from the hurly-burly of the modern world, maybe it is merely a bridge to nowhere.

The 40-foot drop of a Hocking River tributary highlights the steep-walled configuration of the Rockbridge skylight, evidence that one or more vertical fractures had a big influence on its formation.
—Courtesy of the Ohio Department of Natural Resources, Division of Geological Survey

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Halfway into our ambitious trek through the rain forest I had to remind myself that "Nothing good comes easy." These days it seems that every business trip to Brazil includes a sweltering hike through overgrown jungles, around cascading waterfalls and down steep rock cliffs. But our gem broker insisted it was worth the trouble. To tell you the truth, for the dazzling emeralds he delivered, I'd gladly go back to stomping through jaguar country.

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