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A New Kind of Shape

Treating Hypochondria

The Science of Curiosity

How Horses Made the Modern World

New archaeological finds are rewriting an ancient story

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The Surprising New History of Horse Domestication

Archaeological and genetic discoveries topple long-standing ideas about the domestication of equines

By William T. Taylor

Mark Harvey

The world we live in was built on horseback. Many people today rarely encounter horses, but this is a recent development. Only a few decades ago domestic horses formed the fabric of societies around the globe. Almost every aspect of daily life was linked to horses in an important way. Mail was delivered by postal riders, people traveled by horse-drawn carriage, merchants used horses to transport goods across continents, farmers cultivated their land with horsepower, and soldiers rode horses into battle.

Scholars have long sought to understand how the unique partnership between humans and horses got its start. Until recently, the conventional wisdom was that horses were gradually domesticated by the Yamnaya people beginning more than 5,000 years ago in the grassy plains of western Asia and that this development allowed these people to populate Eurasia, carrying

their early Indo-European language and cultural traditions with them.

Now new kinds of archaeological evidence, in conjunction with interdisciplinary collaborations, are overturning some basic assumptions about when—and why—horses were first domesticated and how rapidly they spread across the globe. These insights dramatically change our understanding of not only horses but also people, who used this important relationship to their advantage in everything from herding to warfare. This revised view of the past also has lessons for us today as we consider the fate of endangered wild horses in the steppes. And it highlights the essential value of Indigenous knowledge in piecing together later chapters of the horse-human story, when domesticated horses moved from Eurasia into the rest of the world.

The genus *Equus*, which includes horses, asses and zebras, originated around four million years ago in North America. Over the next few million years its members began dispersing across the Beringia land bridge between what is now Russia and Alaska and into Asia, Europe and Africa. Horses are among humanity's oldest and most prized prey animals. Perhaps the first indisputable evidence for hunting with weapons by early members of the human family comes from horse-rich archaeological sites such as Schöningen in Germany, dating to some 300,000 years ago. The unique lakeshore environment there preserved not only the remains of a band of horses but also the immaculately crafted wood spears that humans used to dispatch them. For millennia wild horses remained a dietary staple for early *Homo sapiens* living in northern Eurasia. People were keen observers of these animals they depended on for food: horses featured prominently in Ice Age art, including in spectacular images rendered in charcoal on the limestone walls of France's Chauvet Cave more than 30,000 years ago.

Horses served as muses for Ice Age people, who captured their likenesses in spectacular works of art, such as the images in France’s Chauvet Cave that date to more than 30,000 years ago.
Heritage Images/Getty Images

Tracking the transition from this ancient predator-prey connection to early domestication—which includes such activities as raising, herding, milking and riding horses—can be challenging. Researchers studying the deep past rarely have the luxury of written documents or detailed imagery to chronicle changing relationships between people and animals. This is especially true in the Eurasian steppes—the cold, dry, remote grasslands where scientists suspect that the first horse herders emerged, which stretch from eastern Europe nearly to the Pacific. In the steppes, cultures have long been highly mobile, moving herds to fresh pastures with the changing seasons. Their way of life left behind archaeological assemblages that can be shallow, poorly preserved and difficult to study. Indeed, much of what we know about the origins of horse domestication comes from a single, powerful scientific source: the bones of ancient horses themselves.

But it wasn’t until much later that people domesticated horses, as evidenced by burials at sites such as Novoil’inovskiy in Russia dating to the early second millennium B.C.E.
Emma Usmanova

As an archaeozoologist, I seek to understand the origins of domestication through the study of horse bones from archaeological sites. In the early days of this kind of scientific inquiry into domestication, some researchers looked for patterns in the size, shape or frequency of these bones over time. The basic logic behind this approach is that if horses were living in close contact with people, their bones might have become more widespread or more variable in shape and size than in earlier periods, whether because people were breeding them for particular

traits or because they were putting the horses to work in ways that altered the animals' bodies over the course of their life, among other factors.

Burials of horses and chariots establish that early domesticated horses were used for transport.
William T. Taylor

But it turns out that looking for these types of patterns in the archaeological record is a little bit like reading tea leaves. Changes in the shape or number of horse bones found at ancient sites could be caused by any number of other things, from environmental change to shifting human diets or even sampling errors. At best, these indicators give us only an indirect way to trace the origin of herding or riding.

A stronger, more scientific understanding of horse domestication began to take shape in the 1990s. Building on the work of some earlier scholars, archaeologist David Anthony of Hartwick College in New York State and his colleagues identified direct evidence for domestication in horse remains, publishing their findings in *Scientific American*. When horses are used by people for transportation, they sometimes develop a particular pattern of damage on their teeth from the equipment that is used to control

them. This damage, known as bit wear, can often be seen on the lower second premolar of horses ridden with metal mouthpieces, or bits. Anthony and his colleagues found bit wear in an ancient horse from a Ukrainian site known as Deriyevka, which was thought to have been home to an archaeological culture known as the Yamnaya people. Although the Deriyevka horse had not been directly dated, its association with the Yamnaya culture suggested that herders in the Eurasian steppes might have been raising and riding domestic horses by the fourth millennium B.C.E. or even earlier.

The Deriyevka horse seemed to tie together a number of loose threads in scientists' understanding of ancient Eurasia. Beginning after 6,000 years ago, during a period called the Eneolithic (also sometimes known as the Copper Age), large human burial mounds known as kurgans appeared across much of eastern and central Europe and the western steppes. Over the years many archaeologists and scholars hypothesized a connection linking kurgans, the spread of Indo-European languages and the first horse domestication. Specifically, they proposed that the Yamnaya people tamed horses in the Black Sea steppes and then swept across Eurasia on horseback, bringing their burial customs and an early form of Indo-European language—which is believed to have given rise to many languages spoken today, including English. On the heels of Anthony's discovery, this framework, known as the kurgan hypothesis, gained wide currency in academic literature and popular consciousness.

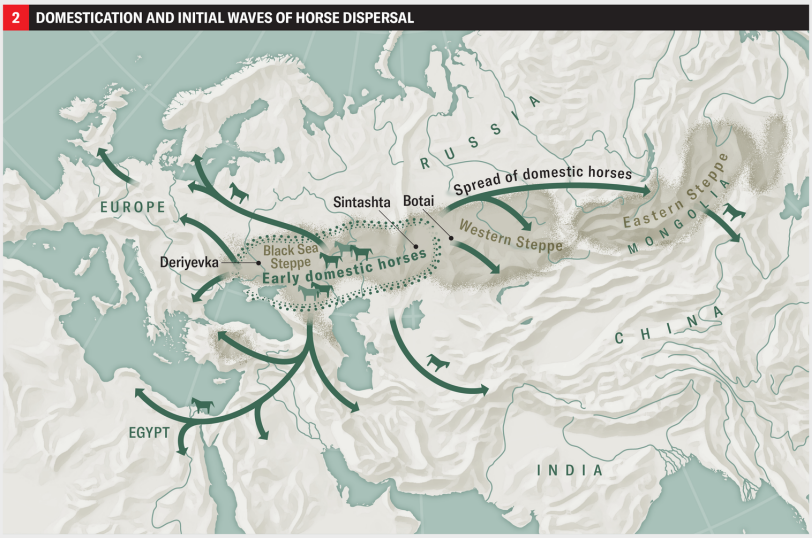
Unfortunately, the Deriyevka horse was not what it seemed. A decade later direct radiocarbon dating of the remains showed that the animal wasn't nearly as old as Anthony thought. Instead it had lived and died sometime in the early first millennium B.C.E., when domestic horses and horseback riding were already widespread and well documented. But rather than rejecting the kurgan hypothesis entirely, archaeologists continued to explore other animal-bone assemblages from the western steppes dating to around the same

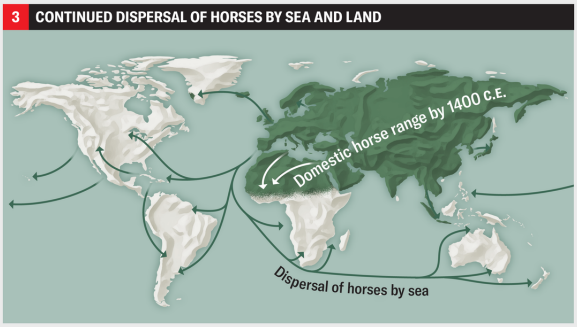
period, searching for horse bones to validate the idea. During this search one site in particular drew renewed interest: Botai, located in northern Kazakhstan.

Horses on the Move

Horses originated around four million years ago in North America. Over the next few million years they began crossing the Beringia land bridge between what is now Russia and Alaska into Asia, Europe and Africa. Spears and horse bones from the site of Schöningen in Germany show that early humans were hunting horses some 300,000 years ago. It was not until hundreds of thousands of years later that people domesticated horses. Archaeologists long held that the Yamnaya people were the first to domesticate horses, starting after 6,000 years ago, based on evidence from sites such as Deriyevka in Ukraine and others.

New genomic analyses, however, indicate that the ancestors of modern domestic horses originated in the Black Sea Steppe around 2200 B.C.E. Some of the earliest archaeological traces of horse domestication come from sites associated with Russia's Sintashta culture. By the middle of the second millennium B.C.E., domestic horses had reached civilizations from Egypt and the Mediterranean to Scandinavia and East Asia. Later, people transported them to the Sahel savanna of Africa, the Great Plains of North America, the Pampas of South America, and island nations of Australasia and the Pacific.





Daniel Huffman

Botai sits some distance east of the Yamnaya homeland. Despite lacking any obvious cultural connections to the Yamnaya, Botai is also located in the western steppes, and like Deriyevka, it dates to the fourth millennium B.C.E. Most interesting, the animal-bone assemblage recovered from excavations at Botai contained huge numbers of horses. In fact, among thousands of animal bones from Botai, almost all were from horses. Working with these materials, archaeologists began to discuss the relevance of Botai's horses to the question of early domestication.

Early on, the Botai domestication debate was a spicy one. First Anthony and his colleagues suggested that the strange surface shape of some Botai teeth was also a form of bit wear, hinting that the Botai horses were ridden. Soon, though, Sandra Olsen, now at the University of Kansas, identified the same features in wild horses, meaning they could not be taken as proof of domestication on their own. Scholars also looked at contextual aspects of the Botai site, including the architectural layout, speculating that post holes and backfilled pit houses filled with organic material could be leftover traces of corrals and corral cleaning.

Still, other scientists remained skeptical—for good reason. Some Botai horses were found with harpoons directly embedded in their ribs, obviously killed by hunters. An even bigger problem with connecting Botai to domestication, though, was the age and sex patterns among the animals found at the site. In a managed herd of horses, those chosen for slaughter are either very young or very old because breeding-age animals are needed to ensure the herd's fertility and survival. Marsha Levine and her colleagues pointed out, however, that Botai's bone assemblage consisted mainly of the remains of mostly healthy adults. Moreover, the site contained large numbers of breeding-age females, as well as some fetal and neonatal horses from pregnant mares. The slaughter of these animals would be devastating to the fertility of a domestic herd, but evidence of it is common in archaeological sites where wild animals were hunted for food.

This healthy disagreement over domestication at Botai was temporarily quashed in 2009, when a high-profile publication in the journal *Science* brought together new evidence apparently showing that people from Botai milked and rode horses. The authors looked at the shape of the bones of horses at Botai and argued they were similar to the modern domestic horse, *Equus caballus*. Using emerging techniques for the study of ancient biomolecules, scientists also analyzed ceramic shards from Botai and found residues that seemed to have come from ancient horse fats. These residues, though not diagnostic of milk on their own, had anomalous isotope values, suggesting they could have originated from milk.

The most important new argument, though, was that some Botai horses displayed a different kind of tooth damage that the researchers said could be more securely linked to use of a bridle. With new results from Botai strengthening confidence in the idea of horse domestication during the fourth millennium B.C.E., the kurgan hypothesis returned to paradigm status.

In the decade and a half since Botai revived the kurgan hypothesis, our archaeozoological tool kit for understanding ancient horses has grown by leaps and bounds. And one by one these new techniques and discoveries have begun to erode the connections between Botai and horse domestication. In a recent study, my colleagues and I analyzed dozens of wild horses from Ice Age sites across North America. Our research showed that the key features interpreted as evidence of bridle and bit use at Botai were probably the result of natural variation rather than horse riding or horse equipment.

Moreover, we now know that many other aspects of horse riding can leave a recognizable signature in an animal’s teeth and bones. Halters, saddles and harnesses can make distinctive marks. And different activity patterns, from heavy exertion to confinement, also have identifiable impacts. For instance, the pressure from mounted riding or from pulling a carriage or chariot can each cause unique

problems in a horse’s vertebral column or lower limbs. Even early veterinary practices such as dentistry are sometimes visible in the archaeological record. So far none of these more reliable indicators of domestication have been found in Botai horses.

Horses from the site of Botai are now known to have belonged to a wild horse species, Przewalski’s horse, that was hunted for food. Conservation efforts are currently underway to restore this highly endangered species.
Sven Zellner/Agentur Focus/Redux

We can also look to DNA for clues. Improvements in ancient-DNA sequencing now allow scientists to reconstruct partial or whole genomic sequences from archaeological remains. Analysis of DNA from ancient people and animals has yielded some rather remarkable findings, documenting, for example, the migration of Yamnaya people from eastern Europe as far east as Siberia and Mongolia during the late fourth millennium B.C.E. These same techniques have shown no evidence of interaction between Yamnaya people and Botai, however.

Likewise, new techniques for recovering ancient proteins from human dental plaque have shown no evidence of horse milk in the diet of the people who lived at Botai. In fact, horse milk apparently didn’t become widespread in western Asia until the first millennium B.C.E., 3,000 years after the Yamnaya and Botai.

The most devastating blow to the kurgan hypothesis came accidentally from a 2018 genomic study by Charleen Gaunitz of the University of Copenhagen, Ludovic Orlando of the Center of Anthropobiology and Genomics of Toulouse in France and their colleagues that showed Botai horses were not the ancestors of domestic horses at all. Rather they were members of another horse species that still survives today, known as Przewalski's horse. Przewalski's horse is a close relative of domestic horses but one that has never been managed as a domestic animal in recorded history.

Recent archaeological and genetic insights into horse domestication have relevance for understanding the horse human relationship today. Discoveries of an ancient saddle and other tack in Mongolia show that steppe cultures helped to invent technology that is still in use.
J. Bayarsaikhan

Some scientists remain convinced that Botai has some connection to early domestication but now suggest that the site represents an earlier, failed effort at taming and control of Przewalski's horse. In their 2018 study, Gaunitz and her colleagues went so far as to argue that modern Przewalski's horses might be the escaped descendants of domesticated Botai horses, a conclusion that many others in the scientific community felt was unsupported.

The Botai debate has had important real-world impacts for Przewalski's horse. In the 20th century Przewalski's horses went

extinct in the wild, and zoo populations dwindled almost to the single digits. In recent decades these horses have returned from the brink through a careful captive-breeding program, and they have been reintroduced into some areas of Central Asia. This past June a new band of Przewalski's horses from the Prague Zoo was released into the grasslands of central Kazakhstan, marking the first return of this species to the region in two centuries.

In the long term, the success and funding of such conservation projects may hinge heavily on public support, making it imperative to get the story straight. Media attention around Botai has sometimes generated headlines suggesting that Przewalski's horses "aren't wild after all" and are instead domestic escapees. Narratives like these are no longer supported by the archaeological data and can imperil ongoing protection, conservation and restoration of habitat for this highly endangered species.

Despite some lingering controversy over Botai, the available data emerging from new scientific approaches to studying the past paint a much clearer picture of horse domestication than we've ever had before. The recent spate of genomic sequencing and radiocarbon dating of horse bones from across Eurasia has all but disproved the kurgan hypothesis. Such data show us that important cultural developments in the fourth millennium B.C.E.—including the Yamnaya migration and the dissemination of kurgans and Indo-European culture—probably took place many centuries before the first horses were domesticated, aided by the spread of other livestock such as sheep, goats and cattle and the use of cattle to pull wagons. Meanwhile many steppe people still hunted wild horses for meat.

New genomic analyses led by Pablo Librado of the Institute of Evolutionary Biology in Barcelona and Orlando indicate that the ancestors of modern domestic horses originated in the Black Sea steppes around 2200 B.C.E., nearly 2,000 years later than previously thought. Although we do not yet know exactly the

details of their initial domestication, it is clear based on the timing that these horses belonged to post-Yamnaya culture. Patterns in the ancient genomes suggest that in the early centuries of domestication, the horse cultures of the western steppe were selectively breeding these animals for traits such as strength and docility.

Horses have figured prominently in the traditions and values of the Lakota and many other Native Nations across the Great Plains and Rockies.
Courtesy of the Global Institute for Traditional Sciences

This revised timeline for horse domestication is part of a growing body of evidence that casts the Yamnaya legacy in a new light.

Early Indo-European cultures such as the Yamnaya are sometimes portrayed in popular culture in a nationalist manner, with links drawn between their supposed domestication of the horse, impressive transcontinental migrations, and cultural dominance. Now science indicates that the Yamnaya probably didn't domesticate horses at all, and their migrations were not necessarily heroic conquests. For example, new genomic data show that by around 5,000 years ago Yamnaya migrants reached as far as central Mongolia, where they are known as the Afanasievo culture. Although these migrants may have helped spread sheep, goats and cattle into East Asia, initially it seems their impact was limited to a few mountain regions of the eastern steppe. After the Yamnaya arrival, it would be almost 2,000 years before horses showed up in the region. And genomic analyses suggest that their Afanasievo descendants had little lasting genetic effect on later populations.

The revelation that people domesticated horses much later than previously thought resolves what was always a nagging problem with the kurgan hypothesis. If horses were domesticated in the Eneolithic, why did it take centuries for much of their impact to show up in the archaeological record? Under the kurgan model, researchers often framed horse domestication as a gradual development to explain why it took so long for horses to move beyond the steppes and revolutionize trade and conflicts, for instance. When we look at our records of the past with this revised time frame for horse domestication in mind, there appears to be the rapid, disruptive and dynamic development we expected to see after all.

In our new understanding it seems that almost as soon as people tamed horses, they began using them for transport. Some of the earliest robust archaeological evidence of horse domestication comes from burials of horses paired with chariots dated to around 2000 B.C.E. at sites associated with Russia's Sintashta culture. Radiocarbon-dating and genetic records show that within only a few centuries domestic horses spread over huge swaths of the

Eurasian continent. In some cases, their expansion was peaceful: as availability of horses grew across the steppes, new people incorporated horses, herding and transport into their way of life. In other instances, domesticated horses reached new locales through destructive conquests by marauding charioteers. Some cultures riding this wave of horse-drawn expansion were Indo-European; others weren't.

A nomadic family corrals livestock on horseback in Central Mongolia.
Timothy Allen/Getty Images

By the middle of the second millennium B.C.E., horsepower had reached civilizations from Egypt and the Mediterranean to Scandinavia in the north and Mongolia and China in the east. In many cases, the arrival of horses upended the balance of power. For example, when horses first arrived in China during the late Shang dynasty, around 3,200 years ago, they were mostly a novelty for the elite. But within little more than a century a rival power, the Western Zhou, was able to marshal its strength and skill in chariotry to bring a dramatic end to Shang rule. In very short order, horses went from being a steppe curiosity to the foundation of authority for one of the largest civilizations of East Asia.

In addition to clearing up these early chapters of the human-horse story, scientific archaeology has also uncovered connections between the horse cultures of the distant past and our world today.

Archaeological discoveries and genomic data from the steppes and deserts of Central Asia are revealing the ways that horses and horseback riding helped humans form networks, trade routes and empires linking the ancient world in new ways.

On horseback, people traveled steppe networks and the Silk Roads to move goods, plants, animals, ideas and even early pandemic diseases across Eurasia and beyond. These emerging transcontinental connections can be directly observed in the archaeological record. In Mongolia, a royal tomb from the early steppe kingdom of the Xiongnu dating to somewhere around 100 B.C.E. was found to contain a silver plate with a picture of the Greek demigod Hercules on it. Historical records document expeditions from China to Central Asia's Ferghana Valley in search of horses, an early step in the formation of the Silk Roads trade routes, and during the height of the Tang Dynasty, a thriving trade sent horses from the Tibetan Plateau and the Himalaya to lowland China in exchange for tea. Recent DNA sequencing of the plague-causing bacterium *Yersinia pestis* suggests that the earliest strains of the virus that devastated Europe first emerged deep in deserts, mountains and steppes of Central Asia before spreading along the horse-powered steppe corridors and Silk Roads in the early 14th century.

The corridors and connections that ancient equestrians forged persist today: Ancient travel routes across the Mongolian steppe are now receiving makeovers with Chinese financing to serve as high-speed highways for motor vehicle transit. Even the state highway I take for my daily commute in Boulder, Colo., got its start as a 19th-century postal road.

New archaeology discoveries show that steppe cultures helped to invent or spread important technologies that improved control over horses and are still used today. In Mongolia, my collaborators and I have discovered immaculately preserved ancient tack from some 1,600 years ago. This riding technology, which includes a wood

frame saddle and iron stirrups, shows that steppe cultures helped to develop these equestrian devices, which gave riders greater seat stability and the ability to brace or stand in the saddle—significant advantages when it came to mounted warfare. These tools became a standard part of horse equipment in cultures all over the world, from the caliphates of Islam to the Viking explorers of the high Arctic.

Archaeological science also allows us to trace the spread of domesticated horses out of Eurasia as people transported them to such places as the Sahel savanna of Africa, the Great Plains of North America, the Pampas of South America, and even island nations of Australasia and the Pacific, where horses shaped cultures across more recent periods. This work is showing some surprising results.

Recently I worked with a large team of scientists, scholars and Indigenous knowledge keepers to see what archaeology, genomics and Indigenous knowledge systems could tell us about the history of domesticated horses in the U.S. The prevailing view among Western scientists was that Native American peoples did not begin caring for horses until after the Pueblo Revolt of 1680, when Pueblo people in what is now New Mexico overthrew Spanish colonizers. Through our collaboration we found that Native nations from across the Plains and Rockies adopted horses at least a century earlier than was ever chronicled in European historical records. This finding confirms perspectives preserved in some oral traditions and Tribal histories and mirrors our scholarship from similar archaeological contexts in Patagonia.

Many Indigenous horse cultures, for whom a connection with horses is a source of strength, resilience and tradition, are now drawing on collaborative and interdisciplinary archaeological scholarship in their efforts to correct narratives, conserve traditional horse lineages and secure a place for horses in our changing world.

In many ways, the disappearance of horses from daily life in the past century has been as rapid and jarring as their initial domestication 4,000 years ago. In most corners of the world speedy mechanization has replaced trails with pavement and horse transport with engine-powered or electric alternatives. These days, along the Front Range of the Rockies, people wearing jeans and cowboy hats once designed for life in the saddle are more likely to be found shopping at Whole Foods than slinging lassos.

But the threads linking our ever changing present to the distant past are never far if you know where to look. Resolution of some of the most urgent problems of the 21st century—from saving endangered species to conserving cultural knowledge and traditions—will require a clear-headed and scientifically grounded understanding of the millennia-long relationship between human and horse.

William T. Taylor is an archaeozoologist at the University of Colorado Boulder. He studies the relationship between people and animals, with a focus on horse domestication. Taylor is author of *Hoof Beats: How Horses Shaped Human History* (University of California Press, 2024).

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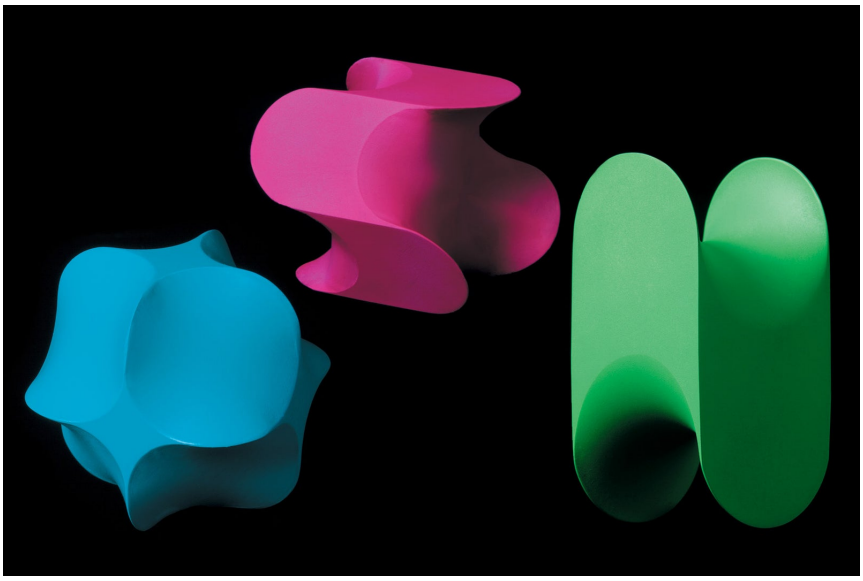
https://www.scientificamerican.com/article/horse-domestication-story-gets-a-surprising-rewrite

Mathematicians Discover a New Kind of Shape That’s All over Nature

Mathematicians have found a new kind of shape with connections to nature and art

By Elise Cutts



Photographs of 3D-printed shapes show soft cells derived from space filling polyhedra. Blue is derived from a truncated octahedron, pink is from a hexagonal prism and green is from a cube.
Jelle Wagenaar

How few corners can a shape have and still tile the plane?” mathematician Gábor Domokos asked me over pizza. His deceptively simple question was about the geometry of tilings, also called tessellations—arrangements of shapes, called tiles or cells, that fill a surface with no gaps or overlaps. Humans have a preoccupation with tessellation that dates back at least to ancient Sumer, where tilings featured prominently in architecture and art. But in all the centuries that thinkers have tinkered with tiles, no one seems to have seriously pondered whether there’s some limit to how few vertices—sharp corners where lines meet—the tiles of a tessellation can have. Until Domokos. Chasing tiles with ever

fewer corners eventually led him and his small team to discover an entirely new type of shape.

It was the summer of 2023 when Domokos and I sat at a wood picnic table at the Black Dog, a cozy spot for pizza and wine just a few blocks from the Budapest University of Technology and Economics, where Domokos is a professor. He reached across the table to grab a paper pizza menu and flip it over, revealing a blank underside, and gestured to me to grab a pen. The midsummer sky was taking on shades of orange and indigo as I filled the menu with triangles. Domokos watched expectantly. “You’re allowed to use curves,” he finally said. I started filling the page with circles, which of course can’t fill space on their own. But Domokos lit up. “Oh, that’s interesting!” he said. “Keep going, you can mix shapes. Just try to keep the average number of corners as low as possible.”

I kept going. My page of circles filled with increasingly desperate, squiggly forms. Domokos’s pizza Margherita had long since disappeared, but he wasn’t quite ready to leave. A quick glance at my crude drawing wasn’t enough to determine its average number of corners, let alone the minimum possible. But the right answer must have been something less than the triangle’s three—otherwise, the question would be boring.

That observation seemed to satisfy the mathematician, who revealed that the real answer is two. “That’s an easy question,” he said. “But what about 3D?”

> “This is a tool that can reasonably describe, at least to me, a wide range of more physically relevant things than just polyhedrons stuck together.” —Chaim Goodman-Strauss, mathematician

Now, more than a year after that evening at the pizza shop, Domokos has the answer. Finding it was an exciting, frustrating challenge that ultimately led him and three colleagues to discover

“soft cells,” shapes that can fit together to completely fill a flat surface or a three-dimensional space with as few corners as possible. In two dimensions, soft cells have two corners bridged by curves. But in 3D, these curvy, almost organic forms have no corners at all. Once the researchers identified the new shapes, they began to see them all over the place—in nature, art and architecture. The results have now been published in the journal *PNAS Nexus*.

Although soft cells hadn’t been categorized by mathematicians before—no one had noticed or named them in an academic paper—they abound in art and nature, from the architecture of Zaha Hadid, “Queen of the Curve,” to the forms of zebra stripes. Krisztina Regős, Domokos’s graduate student, found the first natural 3D soft cell tucked away in the chambers of the nautilus shell, an object that’s become iconic for showcasing the convergence of math and biology. “They were in front of our eyes the whole time,” Regős says. This connection to such a famous shape led Domokos to fear that his group would be scooped. He swore his collaborators to secrecy until their discovery was ready to be published. (It came out in September.) At the end of his lesson over pizza, he even took the paper menu, folded it up and pocketed it. Just to be safe.

In retrospect, it should have been obvious that soft cells exist, says mathematician Joseph O’Rourke of Smith College, who wasn’t involved in the study. But to think to ask such a question, “to even imagine that you can tile space with no vertices,” he says, is original. “I found that quite surprising and very clever.”

“This is a tool that can reasonably describe, at least to me, a wide range of more physically relevant things than just polyhedrons stuck together,” says mathematician Chaim Goodman-Strauss of the University of Arkansas, an expert on tiling. “Just look at the foam in a glass of beer, and you’ll know they’re onto something.”

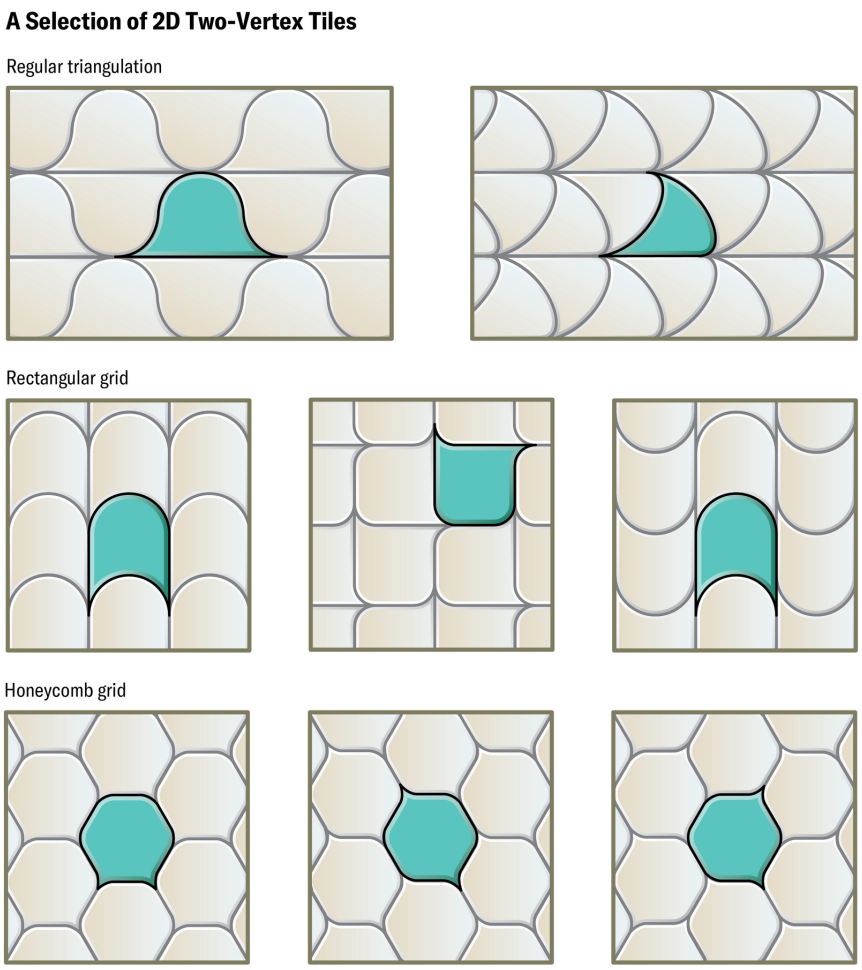
Years ago Domokos developed a mathematical tool for describing tessellations based on their average properties rather than the shapes of individual cells. The idea grew out of work on natural mosaics, such as cracked rock faces. Using averages captures the essence of the tessellation without imposing unnatural rigidity.

As Domokos and Regős explored the rules governing the average properties of mosaics, they realized something: it didn't seem possible to get the average number of vertices (corners) per tile below two. From there it wasn't much of a leap to realize that a monotile—a tile that fills the plane only with copies of itself, such as the regular hexagons of a honeycomb or squares of a checkerboard—couldn't have fewer than two vertices. This rule hadn't been recognized before.

When Domokos and Regős couldn't find any previous work on the subject, the duo realized they had something interesting on their hands. But they felt out of their geometric depth when it came to translating their discovery into a formal mathematical rule. They recruited geometer Ákos G. Horváth, who also works at the Budapest University of Technology and Economics, to their cause.

Horváth soon devised an algorithm that could warp polygonal tilings of the plane into tilings of shapes with just two vertices. Using it, the team devised rounded, soft, two-vertex tiles from regular tilings of triangles, hexagons and rectangles. The hexagonal tiles they used look like hexagons that have had two corners stretched out and the rest ground down to rounded nubs. The square-derived tiles are more diverse. One looks like a deformed square, but the others resemble shingles, fish scales, lentils and the flukes of whales. The two types of tiles derived from triangles look a bit like a hill and a ship's sail.

Then, Domokos says, "we started to fantasize about what it is in 3D."

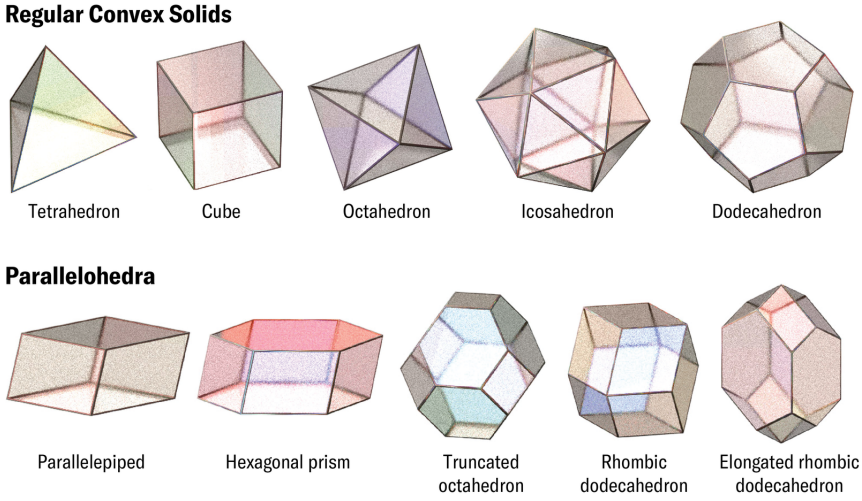


Jen Christiansen; Source: “Soft Cells and the Geometry of Seashells,” by Gábor Domokos, Alain Goriely, Ákos G. Horváth and Krisztina Regős; February 6, 2024; arXiv:2402.04190 (*tile reference*)

People have been imagining 3D tessellations at least since Plato’s time. He built his model of the universe around tessellations of the five regular convex solids: tetrahedron, cube, octahedron, icosahedron and dodecahedron. Tessellations of the first four shapes should build the classical elements of earth, air, water and fire, respectively, Plato figured. The dodecahedron was the stuff of the cosmos. Plato was wrong about more than this esoteric cosmology. Only the cube can actually fill 3D space as a monotile —with exact copies of one shape—without gaps and overlaps (unless the space itself is curved). But cubes squished and stretched into parallelepipeds (shapes with six parallelograms for faces) can fill space, too. And in 1885 Russian crystallographer Evgraf Fedorov cataloged a set of five shapes called the parallelohedra—3D forms that can be packed together without any rotation. These shapes include the cube and the hexagonal prism familiar from

honeycombs, as well as the more esoteric rhombic dodecahedron, elongated dodecahedron and truncated octahedron.

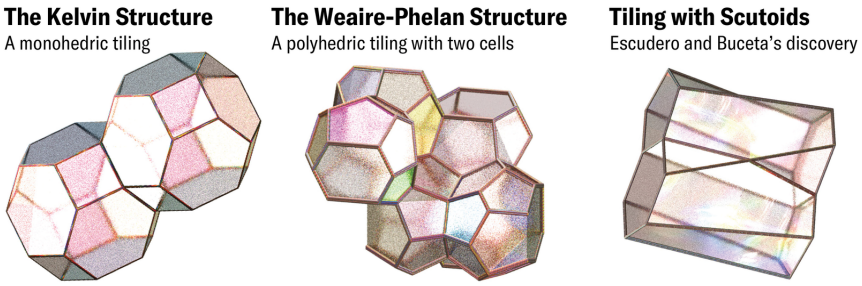
All these shapes are polyhedra with flat faces and straight edges. But 3D shapes with curves can fill space, too—although the ready examples are only slightly bent and have obvious corners. Tellingly, the known examples all emerged from questions about nature, not abstract mathematics. In 1887 British mathematician William Thomson, also known as Lord Kelvin, posed a puzzle: What arrangement of cells or bubbles of equal volume minimizes the surface area of the interfaces between them? In other words, what is the optimal foam?



Violet Frances

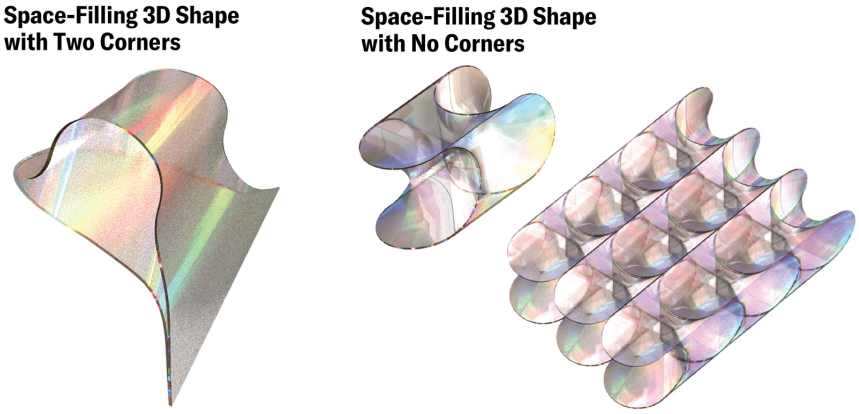
Kelvin’s first solution was a tessellation of slightly warped truncated octahedra. In a 1994 paper, physicists Denis Weaire and Robert Phelan, both then at Trinity College Dublin, beat Kelvin’s structure with a tessellation of two different warped polyhedra. And in 2018 a team of biophysicists led by Luis M. Escudero of the University of Seville and Javier Buceta of the Institute for Integrative Systems Biology in Spain discovered a new shape called a scutoid, resembling a warped honeycomb, which the body’s epithelial cells assume to pack optimally in tissues that need to bend and curve. Still, no one seems to have asked how few corners a space-filling solid can have. The Hungarian team’s leap

to 3D was, at first, a leap of faith. “We had not the faintest idea. Not even a hunch,” Domokos says.



Violet Frances

When the trio eventually identified a space-filling 3D shape with just two corners, Domokos thought they’d found their answer. “I got completely obsessed with this whole thing,” he says. “And I wrote a paper proving that the minimum number [of corners] in three dimensions is two.” The proof grew out of a simple assumption that Domokos thought was trivial. But as months came and went, he slowly started to realize that the assumption wasn’t so minor after all—and it might even be wrong. “He wanted to send this article to me and Ákos for Christmas. Then for New Year’s Eve. And then later and later,” Regős recalls, fighting back a grin. “And then he found an example with zero. So that was that.” The shape was itself a proof: in three dimensions, it is possible to tessellate space with objects that have no corners at all.



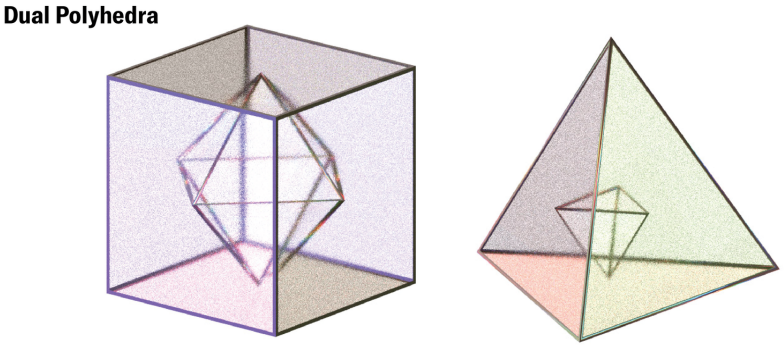
Violet Frances; Source: “Soft Cells and the Geometry of Seashells,” by Gábor Domokos, Alain Goriely, Ákos G. Horváth and Krisztina Regős; February 6, 2024; arXiv:2402.04190 (*reference*)

Finding that first soft cell answered one question and opened up countless more. The researchers wondered, for instance, whether

space-filling shapes with exactly one corner could exist. Domokos eventually found one. When he sketched it out on a blackboard for Regős and Horváth, they were “disgusted,” he says. It was an ugly shape—a warped form with no symmetries that looks like something dreamed up by an alien. But somewhere in that ugliness, Regős glimpsed possibility. “I just saw it one day and realized,” she says. “We can do this edge-bending thing and create the softness.”

Regős’s intuition was that she could create soft cells by bending the edges of normal, pointed polyhedra. At each vertex where three edges met, she’d grab two edges and coerce them into curves that ran parallel to the remaining edge where the vertex was before. A closed solid in 3D space must enclose 4π degrees of curvature, which are usually concentrated at vertices. Regős was smearing out that curvature over edges instead. “It took days and days and days to convince me that what she’s doing is not completely rubbish,” Domokos says.

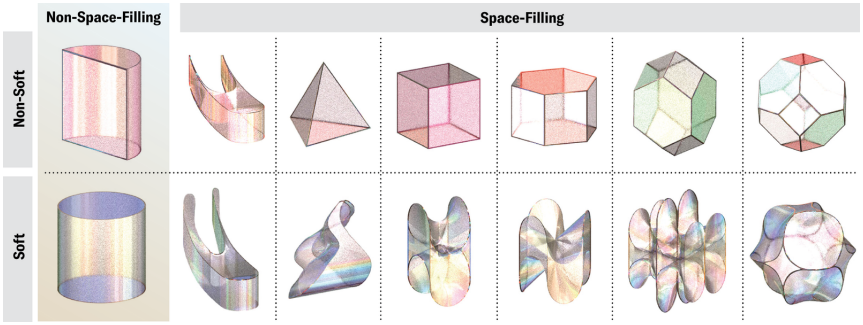
Regős had trouble describing her method for bending edges in mathematical language. But then she realized the process could be boiled down to an easily solved 2D problem from graph theory. Every polyhedron has a dual—another polyhedron whose faces correspond to its edges and vice versa. The team showed that if it’s possible to find a path along the edges of a polyhedron’s dual that visits each of its vertices exactly once—what’s called a Hamiltonian circuit—it’s also possible to warp that shape into a cornerless, space-filling soft cell.



Violet Frances

With that condition set, Horváth could finally write a mathematical 3D edge-bending algorithm. By mapping an infinite category of polyhedral tilings to soft tilings, he proved the existence of an infinite class of soft cells. In other words, for every polyhedron—a 3D shape with flat polygonal faces—that could fill space with itself, there must also be a curved soft cell.

To O'Rourke, the edge-bending algorithm is the most beautiful and significant part of the paper. The elegance comes from uniting two entirely different fields of mathematics. Hamiltonian circuits are purely combinatorial (having to do with the mathematics of counting)—they have "nothing to do with geometry," O'Rourke explains. "But here you're very much in geometry. And yet you need this combinatorial condition. So I find that very nice."



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As they came to understand the mathematics of 2D soft cells, the mathematicians began to realize that the shapes existed beyond their sketches and notes. "They were right under our noses," Domokos says. The team started to see planar mosaics of two-vertex tiles everywhere, from muscle tissue to zebra stripes. Once, on a walk through Budapest, Regős even saw them in the curvy crisscross of a metal safety grate.

At the same time, the trio was finding more and more 3D soft cells—Regős added warped versions of four parallelohedra, as well as tetrahedra, to Domokos's first shape, a warped cube. But the researchers struggled to identify these 3D soft cells in the real world. That changed when, about a year after Domokos first found

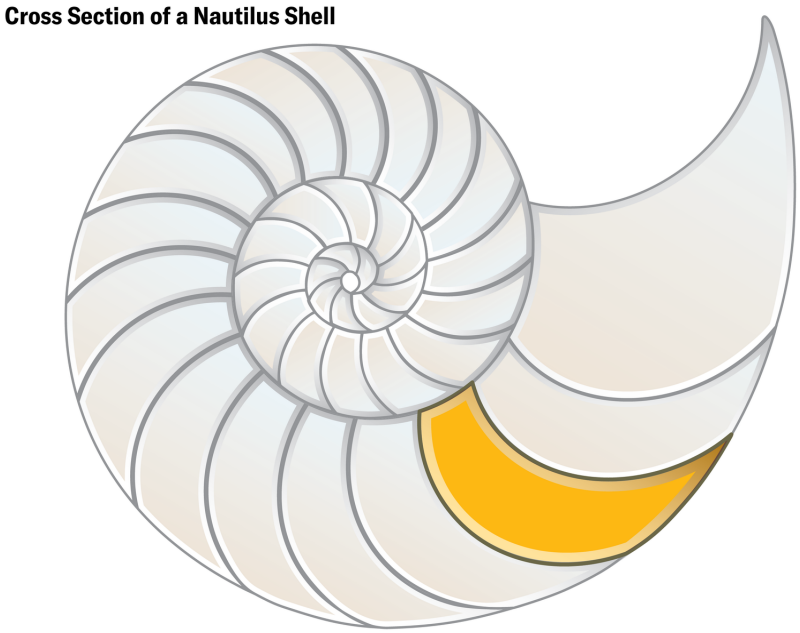
the edge-bent cube, he realized he'd seen it somewhere before—not in nature but in architecture.

About a decade earlier, architect Viki Sándor and a group of students at the University of Vienna had concocted an unusual design for a Cirque du Soleil performance center. The building was never constructed, but it got some attention in architectural circles. Its fundamental building block was a shape that looks almost exactly like Domokos's cubic soft cell.

Sándor's project started as a warm-up exercise around the theme of "balance," says the architect, now at the Austrian Institute of Technology. The building had to be modular, so they divided it into cubic blocks, each to be designed by a different person. By coincidence, the design was inspired by a self-balancing shape called the gömböc, discovered in 2006 by Domokos and structural mechanics researcher Péter Várkonyi. Sándor and her teammates liked the gömböc's contrast of thinness and fatness and wanted a similar shape that would fit different modules together. They found their answer in the C-shaped curves of a tennis ball. "If you cut along the C-shape, then you get a very thin and a very fat element. And the gömböc follows this principle," Sándor says. Cutting curved surfaces into tubes or prisms turned out to be a good method for constructing soft cells—not just in theory or design but also in nature.

Regős found the first natural 3D soft cell in a flash of intuition. One day out of the blue she e-mailed Domokos a picture of a cross section of a nautilus shell. Domokos replied that it was a nice example of 2D soft cells. Regős wrote back: no, they were 3D soft cells. "It doesn't look soft at all," Domokos thought. "I mean, it has corners." But Regős was insistent. So Domokos bought two nautilus shells and presented them to Regős and Horváth for inspection. They played with the shells for 30 minutes or so before giving up. Even if they could convince themselves just by looking

at the shells, Domokos says, “you cannot send in a shell to a paper as an attachment.”



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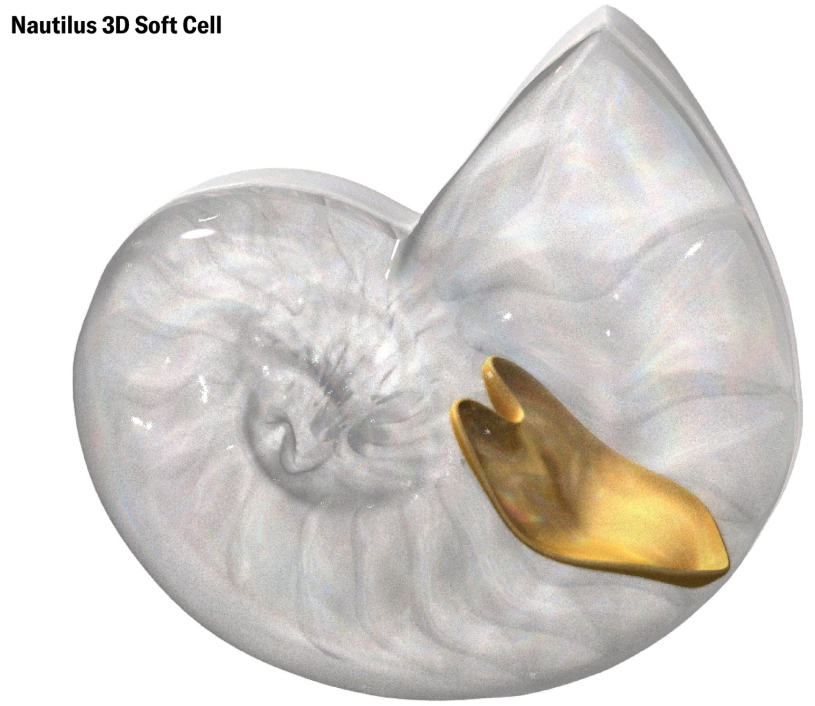
The idea might have died there if not for a freely available set of micro CT scans published by the D’Arcy Thompson Zoology Museum at the University of Dundee in Scotland. Domokos found the scans online and spent hours “crawling around inside” the shells, looking for corners. He couldn’t find any.



Violet Frances; Source: “Soft Cells and the Geometry of Seashells,” by Gábor Domokos, Alain Goriely, Ákos G. Horváth and Krisztina Regős; February 6, 2024; arXiv:2402.04190 (*reference*)

No one on the team knew the first thing about shells. But Domokos knew someone who did: Alain Goriely, a physicist and applied mathematician at the University of Oxford who had studied chambered seashells. Domokos was nervous to tell anyone outside his small group about the project, especially now that they’d discovered soft cells inside the nautilus shell—a favorite form among mathematicians fond of natural shapes. It would have been easy to scoop their idea and publish it first. But Domokos had known Goriely for decades, so he decided to take a risk and call him. Not long after, he and Regős were on a plane headed for Oxford.

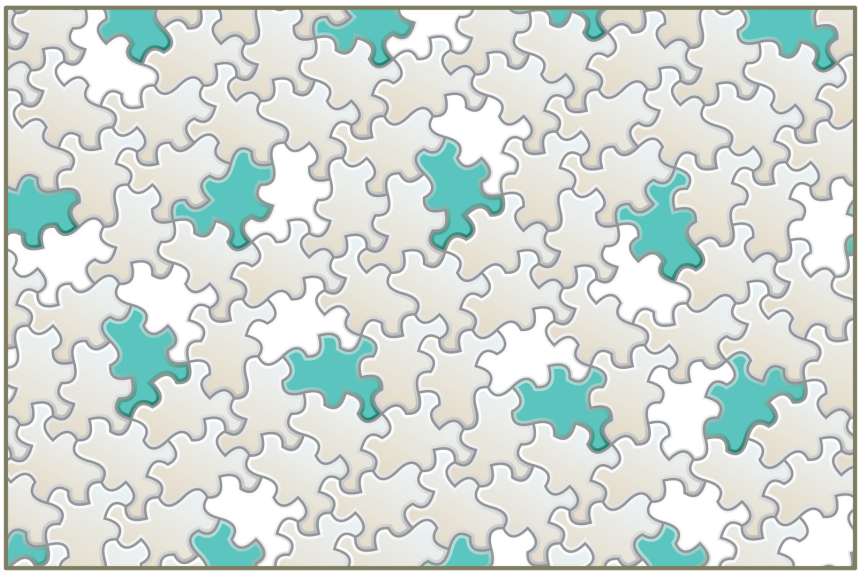
Goriely was immediately gripped by the discovery of soft cells within the nautilus shell. “I find it is quite natural for shapes in nature to go that way because forming sharp corners is very costly,” Goriely says. Biological cells are soft, and surface tension will naturally round them off unless the organism expends energy to build rigid structures that can hold pointier shapes. And cells within a living thing want to fill space efficiently with few gaps.

In their three frantic days at Oxford and the months that followed, Goriely and the Hungarians identified more and more examples of soft cells in nature and art. Zebra stripes, river estuaries, cross sections of onions, seashells, heads of wheat, red blood cells, plants and fungi all resembled 2D soft cells. And in architecture, 2D soft cells lend futuristic, organic forms to many buildings by architect Zaha Hadid. They also appear in sketches of tatami and clothing by Japanese artist Katsushika Hokusai, who made the famous 1831 painting *The Great Wave off Kanagawa*, as well as in the art of Victor Vasarely, the "grandfather" of the optical art movement.

Goriely helped the team find another example of 3D soft cells, too: the chambers of ammonite shells. Then Regős concocted a geometric model that produces shapes similar to the seashell examples from first principles. Soft cells like those in the nautilus shell are easily made by intersecting a prism with curved surfaces —an echo of the process Sándor and her team used to design the Cirque du Soleil building. "What's nice is that architects have intuitively reached that [process] also," Goriely says. "From our understanding, they've reached it with the same types of requirements: they wanted to soften the structure."

The work establishes a "useful vocabulary" for exploring soft shapes, Goodman-Strauss says—a vocabulary that opens up new mathematical questions. What categories of soft monotiles exist? What groups of soft shapes can and cannot tile space? Domokos wonders how softness relates to aperiodicity, the ability to tile a plane without creating a repeating pattern. The discovery of the first aperiodic monotiles—single shapes that fill space with only copies of themselves but never repeat a pattern—made headlines last year. Domokos and Regős were curious about what would happen if they applied their edge-softening algorithm to the "spectre" tiling, the first truly aperiodic monotile. But they were surprised to discover that its softened version couldn't tile a plane alone.

2D Spectre Tiles



Jen Christiansen; Source: “A Chiral Aperiodic Monotile,” by David Smith, Joseph Samuel Myers, Craig S. Kaplan and Chaim Goodman-Strauss; May 28, 2023; arXiv:2305.17743 (*reference*)

Arkansas’s Goodman-Strauss and Craig S. Kaplan of the University of Waterloo in Ontario, who both contributed to the discovery of the first aperiodic monotiles, didn’t find it surprising at all. Mathematicians are just starting to explore aperiodic monotiles, and there are many questions left to answer, Kaplan says.

Despite the seeming ubiquity of soft cells in nature, the link between the mathematics of these shapes and biology is, for now, just a visual observation. Domokos admits that this is a weak point of the work and would like to establish the reasons they are so common in nature. “A lot of the paper is about visual similarity, and that’s very unusual,” he says. Exploring this link further appears promising, though, Kaplan says. “I do like the motivation: just the simple claim that nature doesn’t like sharp features, so let’s investigate that from a mathematical perspective. It’s a nice opening gambit from which you can develop a rich theory.”

And the concept of soft cells could turn out to be useful down the line, Goodman-Strauss says—“not necessarily to the biologists of today but the biologists 30 years from now.” Perhaps the mathematics of soft cells will ultimately capture something real

about soft matter—the malleable materials that make up most of our world, from the blood in our veins to the liquid-crystal display you might be reading on right now.

Questions about soft geometry are particularly tricky to study because they tend to defy disciplinary boundaries. Domokos struggled for months to find a journal that would publish the team's "outlandish" manuscript mixing math, art and biology. That's not surprising to Goodman-Strauss. Asked where he thinks soft cells belong in the scientific landscape, he doesn't skip a beat. "I think," he says, "the only answer is it belongs to the future."

Elise Cutts is a science writer based in Austria. She has written for *Scientific American*, *Quanta*, *National Geographic*, and other outlets.

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https://www.scientificamerican.com/article/mathematicians-discover-a-new-kind-of-shape-thats-all-over-nature

Buried at Sea

Changing the ocean's chemical and biological makeup could force it to pull vast amounts of planet-warming carbon from the atmosphere. But is that a line we want to cross?

By Jamie B. Palter

Eglė Plytnikaitė

Every oceanographer I know who is studying the controversial idea of coaxing the ocean to absorb extra carbon dioxide from the atmosphere remembers the moment they decided to start this contentious work. For me, it came during the Pacific Northwest heat wave of June 2021, which sent temperatures soaring above 49 degrees Celsius (120 degrees Fahrenheit) and set boreal forests ablaze.

I had spent years studying ocean circulation and Earth's carbon cycle but not marine carbon dioxide removal (mCDR)—techniques for reducing CO_2 in the oceans so they, in turn, can draw more CO_2 from the air. Nevertheless, just before the heat wave began, I offered to help organize a virtual panel discussion on mCDR for an

ocean research conference. Most of the questions that arose during the session were about fears that such research could create a moral hazard, allowing people to claim that drawing down CO_2 lessens the urgency of reducing fossil-fuel emissions.

During the panel, a First Nations scholar from the University of British Columbia, Candis Callison, talked about how to involve local shoreline communities where ocean field trials might be conducted. Callison was a brilliant voice, helping the scientists understand more about public discourse on climate change. Just days later wildfires flared up and damaged several First Nations reserves—including the home, Callison informed me, where her relatives lived. This tragic event vividly reminded me of the dangers we already faced after one degree C of global warming. The tragedies could become much worse, given that even optimistic scenarios indicated the world would warm by at least another degree. I decided mCDR research was important. If it ultimately showed that the methods were futile or hazardous, the research could prevent prolonged investment in a false hope. If the work revealed safe ways to stimulate the ocean to take up more CO_2, then those could be new tools to help stabilize the climate.

Starting in the 1950s, scientists began analyzing air bubbles trapped in ice cores drilled from the Greenland and Antarctic ice sheets to understand climate history. By the 1980s they realized that the world's oceans could inhale or exhale enough CO_2 to substantially contribute to Earth's long-term cycles of ice-sheet expansion and retreat across continents. The leading hypothesis at that time for the seesawing of carbon concentrations in the ocean over thousands of years was that the surface water contained iron, which blew in from arid landscapes during cold periods, and its levels regulated phytoplankton growth across the seas. More iron would cause more growth, which would pull more CO_2 from the air. Oceanographer John Martin of Moss Landing Marine Laboratories in California proposed that artificially fertilizing the

ocean with iron could influence climate. At a 1988 meeting at the Woods Hole Oceanographic Institution in Massachusetts, Martin voiced what would become one of the most memorable quotes in oceanography: “Give me half a tanker of iron, and I will give you an ice age.”

Martin’s iron hypothesis prompted more than a dozen artificial iron-enrichment experiments between 1992 and 2009. Researchers released iron on the ocean’s surface and tracked for days or weeks how the area’s water chemistry and organisms changed. Results confirmed that iron enrichment could lead to a phytoplankton bloom when other conditions were favorable. Whether or not oceanographers considered these experiments “geoengineering,” the studies yielded extraordinary insight into the interacting biological and chemical processes that could alter climate on long timescales.

Serious concerns about interfering with nature grew, however, and nations worldwide signed a 2008 amendment to the London Convention. It prohibited further ocean-fertilization experiments beyond “small-scale, scientific research studies within coastal waters,” which chilled enthusiasm for such work. For the next decade researchers conducted studies mostly in virtual oceans, using models.

Several events started to thaw scientists’ cold views. The 2015 Paris Agreement’s goal of limiting warming to 1.5 degrees C set off a slew of studies about how much worse two degrees C of warming would be for ecosystems and for society. The research revealed that every fraction of a degree of avoided warming offers protection from serious dangers, including increasingly extreme heat, drought, and loss of terrestrial and marine biodiversity. Even though breakthroughs in renewable energy had slowed emissions’ tremendous rise, carbon removal would also be needed to stabilize the global climate.

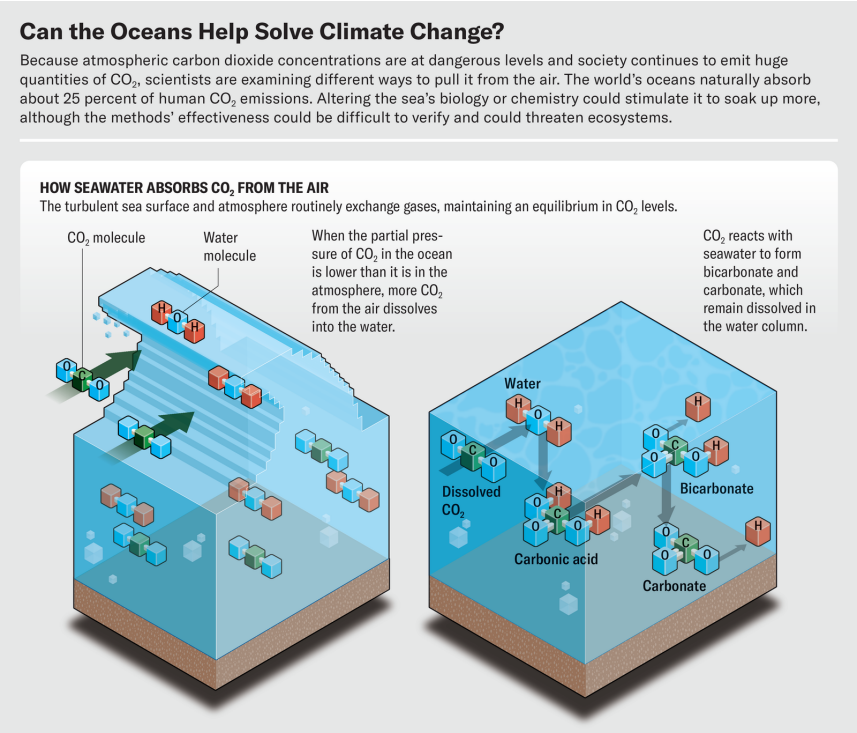
> Oceanographers are still debating how to prove whether any ocean strategy can effectively remove CO_2 from the atmosphere.

Against this backdrop, the National Academies of Sciences, Engineering, and Medicine released a report on mCDR in 2022 that outlined six major strategies and the research required to evaluate them. The document provided social acceptance for marine scientists to pursue such work. Companies were looking for ways to buy credible carbon credits on a large scale, adding to the urgency. In 2022 financial services company Stripe and several large corporations committed to buying $1 billion of credits for carbon removal and permanent storage, on land and in the sea, to help guarantee demand that could accelerate the development of carbon-reduction technologies.

Progress has begun in earnest. The National Oceanic and Atmospheric Administration and the U.S. Department of Energy have both held competitions for proposals on mCDR science. Research is underway across the world. In June 2024 a company called Vesta spread 8,200 metric tons of crushed olivine—rock dust—on the ocean just offshore of North Carolina to try to absorb CO_2 directly from the water. Vesta was the first company with a federal permit to test carbon removal from U.S. seas. Also in June, start-up Equatic began engineering, in Quebec, for a demonstration-scale plant that alters seawater chemistry to absorb more CO_2.

Water at the ocean's surface routinely exchanges gases with the atmosphere. Nitrogen, oxygen, CO_2, and other trace gases each exert a part of the atmosphere's overall pressure. In the ocean, CO_2 also exerts a partial pressure, along with water and other molecules. When the partial pressure of CO_2 in the ocean is lower than its partial pressure in the atmosphere, CO_2 dissolves in seawater as wind pushes air against the waves. The air and water seek an equilibrium in their CO_2 levels. As society's carbon emissions

intensify, the atmospheric CO_2 partial pressure increases, and more of the gas is moved into the ocean. Most of the incoming CO_2 reacts with seawater to form bicarbonate and carbonate, which—like salt in the ocean—remain dissolved in the water column for millennia. Since the industrial revolution more than 150 years ago, the ocean has absorbed approximately 25 percent of human CO_2 emissions, a great service that has significantly slowed the pace of climate change.

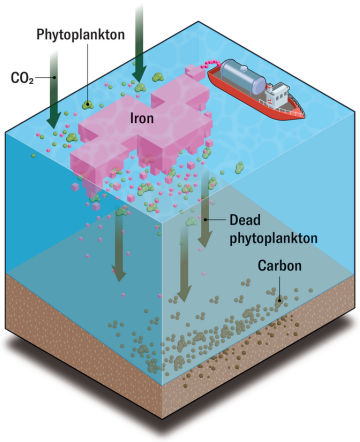


Ben Gilliland

BIOLOGICAL METHODS

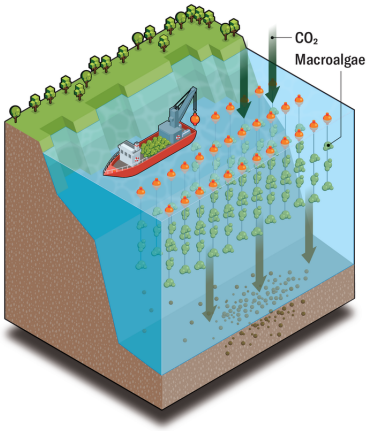
MICROALGAE FERTILIZATION

Phytoplankton take in sunlight, CO_2 and nutrients to grow. Fertilizing surface water with nutrients such as iron can enhance growth and therefore CO_2 consumption. As phytoplankton die, they sink to the seafloor, sequestering the carbon there.



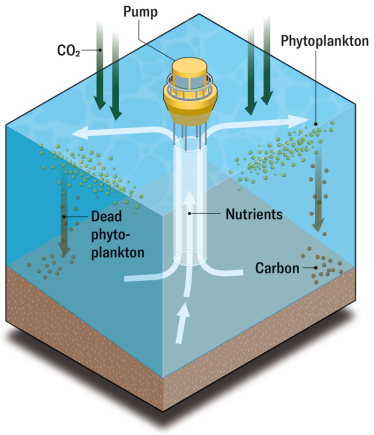
MACROALGAE CULTIVATION

As marine plants grow, they store carbon in their tissues. Cultivating macroalgae such as seaweed could draw more CO_2 from the ocean, allowing it to extract more from the air. Dead algae sink and take the carbon with them.



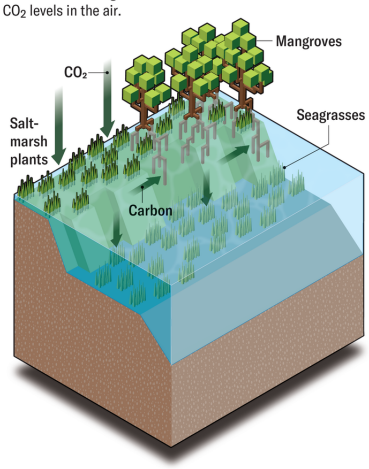
ARTIFICIAL UPWELLING

Instead of fertilizing surface water, pumps can bring nutrients there from deep water, stimulating algae growth and CO_2 absorption.



BLUE CARBON RESTORATION

Mangrove trees, salt-marsh plants and seagrasses breathe in CO_2 and can store carbon in their roots and surrounding sediment. Restoring these "blue carbon" habitats can reduce CO_2 levels in the air.



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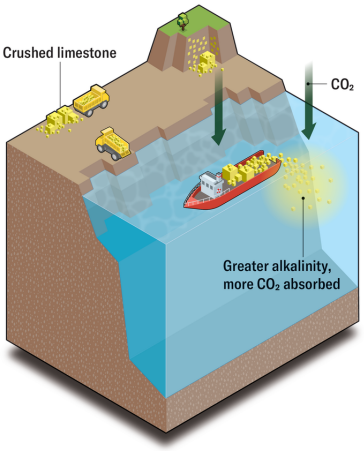
CHEMICAL METHODS

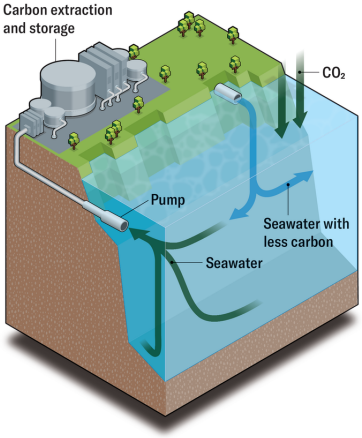
OCEAN ALKALINITY ENHANCEMENT

Spreading alkaline material such as crushed limestone can raise the water's alkalinity (the ability to neutralize acids), allowing it to convert more dissolved CO_2 into bicarbonate and subsequently draw more from the air.



DIRECT OCEAN REMOVAL

Pumps can bring seawater into an onshore (or floating) facility that extracts CO_2 and stores it. The deficient water is sent back to the ocean where it can absorb more airborne CO_2.



The goal of all the mCDR strategies is to lower the partial pressure of CO_2 in the ocean's surface layer, using either chemical or biological means. One category of chemical mCDR has the wonky name "ocean alkalinity enhancement." Alkalinity is the water's ability to neutralize acids. About 99 percent of the atmospheric CO_2 the ocean absorbs becomes bicarbonate or carbonate, and this percentage can go higher when the water is more alkaline. Therefore, when an alkaline substance dissolves in seawater, the reaction reduces the partial pressure of CO_2, allowing the water to absorb more from the air. Spreading pulverized alkaline rock such as limestone or olivine across the ocean or on beaches, as Vesta did in June, can raise alkalinity.

In a second category of chemical mCDR, called direct ocean removal, seawater is pumped into a floating or onshore facility that extracts CO_2 and transports it for commercial use or stores it underground. The water is then pumped back into the sea, ready to absorb more CO_2 from the air. Researchers are trying a variety of technologies to extract the carbon, such as electrodialysis, which forces water through a membrane, similar to how desalination plants operate. Captura is one company that is pursuing this approach.

Biological techniques depend primarily on plant life, large and small. One approach is to cultivate macroalgae such as kelp—often compared with planting trees on land. As the plants grow, they store carbon in their tissues. For sequestration, the plants would be sunk to the seafloor, where the carbon might settle in sediment or remain dissolved in deep ocean waters.

Some scientists are continuing to experiment with the original fertilization approach to boost microalgae—the tiny, single-celled phytoplankton that are ubiquitous in the sea. Nutrients such as iron, phosphorus or nitrogen would be added to the sea surface, where

they could prompt phytoplankton to photosynthesize and therefore grow faster than they otherwise would. The hope is that when these phytoplankton die and sink, the carbon stored within their cells will remain in the deep ocean. Another biological approach is artificial upwelling: pumps would move nutrient-rich water from the ocean's interior toward the surface to try to boost macroalgae or microalgae growth.

Oceanographers are still debating how to prove whether any mCDR strategy can effectively remove CO_2 from the atmosphere. With enough boats, sensors and people, we can measure the effect of an mCDR deployment on the surface water and then calculate the increased ocean uptake of CO_2 while the effect is still detectable. For any longer period, we would need to rely on models because the water that was initially altered would be stirred by ocean currents over a wide region and diluted below the level of detectability. The ocean already stores 50 times as much CO_2 as the atmosphere, but it is highly variable in space and time, so directly measuring the total additional carbon from an mCDR intervention is nearly impossible. Ironically, the same traits mean some mCDR methods could move a substantial amount of atmospheric CO_2 into the ocean while barely perturbing the ocean's background state.

The work to track these effects has become known as monitoring, reporting and verification. The goal is to try to monitor the carbon removed over time and report those results to a third party for independent verification. In direct ocean removal, for example, instruments at the extraction facility would measure the CO_2 removed from seawater, and water samples collected from the nearby ocean, along with models, would track the additional carbon uptake at sea. Quantifying the carbon inside dead phytoplankton sinking to the sea bottom would be much harder.

Of course, rigorous monitoring, reporting and verification would also be needed if companies and organizations are to pay for

carbon credits—say, $300 for a metric ton of sequestered CO_2. The first issue is that we need to be sure the CO_2 would not have been removed from the atmosphere without the intervention. We call this property an intervention's additionality. For example, if kelp cultivation creates a thick mat of seaweed at the surface, but that growth creates a sunshade that slows photosynthesis in phytoplankton that would have lived a bit deeper, then the net change in ocean uptake of CO_2—the additionality—might be zero.

The second issue is durability: how long captured carbon remains safely sequestered from the atmosphere. Phytoplankton enriched by iron might bloom, and a portion of their carbon-rich biomass may sink below the surface. But if microbes consume that carbon or it returns to its dissolved form, the carbon may again enter the atmosphere in a matter of months or years, lowering the durability of the intervention.

This past May I attended a meeting of scientists, engineers, philanthropists and government representatives to discuss every angle of ocean alkalinity enhancement. We eagerly scrutinized the first results from a field trial in Halifax Harbor off Nova Scotia, led by a company called Planetary Technologies and academic partners at Dalhousie University in Halifax. The trial involved water that a shoreline power plant was discharging into the harbor after it had been used for cooling, a routine practice. Researchers added alkaline compounds to the outflow pipe and measured the added alkalinity in the inner harbor. But because the signal was diluted beyond that area, they could only estimate the total carbon removal, using a tested ocean model. The early results suggest the trial successfully removed carbon that would have remained dissolved in the water without the work. And because that carbon is now stored in the ocean largely as bicarbonate, it should be stable for thousands of years—a highly durable result.

To assess additionality and durability in the vast and turbulent ocean, the research community will have to depend on a blend of direct observations and modeling because the complete impact of any mCDR deployment will play out over months or years. It will occur over areas of ocean too extensive to be directly observed and at levels too small to detect. A whole new generation of “applied ocean biogeochemists” is needed for this task.

Scientists must also assess whether a technique would endanger ecosystems or communities and weigh risks against any potential benefits. Large offshore kelp farms, for example, could disrupt local ecology or interfere with fisheries. For direct ocean carbon removal, companies would need plans to safely store or sell the CO_2 produced as a waste product. Electrochemical technologies would filter and pump large volumes of seawater, and the machinery could suck in and destroy small plants and animals. Every approach has trade-offs, but so does leaving CO_2 in the atmosphere to cause ongoing warming.

Researchers considering biological methods have the difficult challenge of proving that large-scale manipulation of the ecosystem is safe. The history of humans tinkering with ecosystems is littered with failures. Consider the importation of South American cane toads to Australia. The toads were brought to eat beetles feeding on sugar cane but became a toxic pest and national menace. It is difficult to predict every potential pitfall in open environments. Some of the basic problems we might look for when considering unintended consequences of biological mCDR are the accidental stimulation of harmful algal blooms that can poison shellfish, the expansion of oxygen-poor “dead zones” that can suffocate fish, and ecosystem effects on the food web, including fisheries.

> Not emitting CO_2 is the most reliable solution, but if the last 10 percent of reductions is difficult, ocean removal could help.

We would also have to assess whether biological methods pursued in one place could cause problems in another. If we spread iron on the ocean surface, more phytoplankton will also consume other nutrients they need to grow, such as nitrate and phosphate. Across the Southern Ocean encircling Antarctica, strong westerly winds create upwellings of vast nitrate and phosphate reservoirs from the deep ocean, which suggests that is where iron fertilization could be most effective. Ocean currents carry those upwelled nutrients across the globe, however, sustaining up to 75 percent of ocean photosynthesis in low latitudes. If iron fertilization prompts phytoplankton to consume these nutrients in the Southern Ocean, marine ecosystems throughout the rest of the world would be robbed of this nutrition—a serious ecological issue. And reduced growth worldwide would probably mean less CO_2 drawn naturally from the air; in the end, there might be little additionality.

An mCDR technique that removes additional carbon, stores it durably and is safe must also pass one other test: Can it scale? The world emits more than 37 billion metric tons of CO_2 annually. If we don’t want to bail out a sinking ship with a teacup, we should look for strategies that can remove about a billion metric tons a year. How might the options stack up?

Ocean alkalinity enhancement could hypothetically reach tens of billions of metric tons a year, if evaluated solely on the availability of appropriate rock that could be ground into alkaline powder. Logistically, however, it would be most efficient if the rock were spread by ships already sailing along existing maritime transport routes, and models suggest this approach would cut the potential to approximately one billion to three billion metric tons of CO_2 drawdown per year.

Moreover, the mining and grinding of huge volumes of rock requires substantial energy and comes with its own social and ecosystem impacts on land. Nearly seven billion metric tons of

limestone (an alkaline rock) are mined and crushed for agricultural and other applications every year, so the world would need a new industry equally as large to clean up a fraction of our CO_2 pollution problem.

An evaluation of biological methods starts with the estimate that, worldwide, less than 10 billion metric tons of CO_2 in the surface ocean naturally ends up sinking to the bottom every year within macroalgae and microalgae that die—deep enough to remain in the ocean for at least 100 years. To remove an additional billion tons of CO_2 that won't quickly reenter the atmosphere, a biological method would have to increase the total amount of biological material sinking into the planet's deep seas by about 10 percent. It is hard to imagine that such a big increase would not have any major unintended consequences.

Answering the scaling question cannot be left to oceanographers alone. We must evaluate all the engineering, energy and economic challenges associated with deployment. Community engagement is needed to understand whether society is willing to interact with the ocean in this way. And, ultimately, if mCDR passes all the tests and has social acceptance, some entity or market would have to pay for it.

What can we reasonably ask of the ocean? The 37 billion metric tons of CO_2 we emit every year constitutes a tiny percentage of Earth's voluminous atmosphere, yet it has an outsize impact on our climate. Not emitting the gas in the first place is a far simpler, cheaper and more reliable solution than finding a technology to pull this trace gas out of the atmosphere.

But even if we could halve emissions within the coming decade and slash emissions by 90 percent just 20 years later, we will still face roughly 50–50 odds of overshooting 1.5 degrees C of global warming, the goal that almost every nation agreed to in the Paris

Agreement. If the last 10 percent of emissions remained difficult to eliminate, warming would proceed indefinitely on a slower but still risky trajectory toward ice-sheet collapse and tens of meters of sea-level rise. We are researching mCDR so strategies might someday help society solve the final few percent of problems.

We must be honest when assessing promises and perils. At the Ocean Sciences Meeting—a leading conference of oceanographers from around the world—held last February in New Orleans, it seemed to me that everyone was talking about mCDR. Many scientists expressed cautious hope that further research might prove ocean alkalinity enhancement is safe and cost-effective; it is the most likely to be scalable and durable. Many researchers were skeptical that biological methods could be proved safe, verifiable or scalable. Still, with the need to slow climate change feeling increasingly urgent and given how much these studies might teach us about the ocean itself, interest in further research remains high.

Engaging in mCDR research requires a tremendous amount of hope. The techniques matter only if all our other efforts to mitigate climate change—from renewable energy to more walkable cities—reduce carbon emissions to a small fraction of what they are today. Only if we slow the gushing faucet of emissions to a trickle can mCDR possibly open the drain enough to stop the buildup of CO_2 in the atmosphere.

Jamie B. Palter is an oceanographer and associate professor at the University of Rhode Island's Graduate School of Oceanography.

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https://www.scientificamerican.com/article/could-ocean-engineering-pull-carbon-from-the-atmosphere-as-a-last-resort-against-climate-change

Hypochondria Is a Real and Dangerous Illness, New Research Shows

Intense health anxiety is a true mental illness and threatens lives. The good news is that it's treatable

By Joanne Silberner

Deena So'Oteh

To describe the destructive effects of intense health anxiety to his young doctors in training at Columbia University Irving Medical Center in New York City, psychiatrist Brian Fallon likes to quote 19th-century English psychiatrist Henry Maudsley: "The sorrow which has no vent in tears may make other organs weep."

That weeping from other parts of the body may come in the form of a headache that, in the mind of its sufferer, is flagging a brain tumor. It may be a rapid heartbeat a person wrongly interprets as a brewing heart attack. The fast beats may be driven by overwhelming, incapacitating anxiety.

Hal Rosenbluth, a businessman in the Philadelphia area, says he used to seek medical care for the slightest symptom. In his recent

book *Hypochondria,* he describes chest pains, breathing difficulties and vertigo that came on after he switched from a daily diabetes drug to a weekly one. He ended up going to the hospital by ambulance for blood tests, multiple electrocardiograms, a chest x-ray, a cardiac catheterization and an endoscopy, all of which were normal. Rosenbluth's worries about glucose levels had led him to push for the new diabetes drug, and its side effects were responsible for many of his cardiac symptoms. His own extreme anxiety had induced doctors to order the extra care.

> Recent medical research has shown that hypochondria is as much a real illness as depression and post-traumatic stress disorder.

Hypochondria can, in extreme cases, leave people unable to hold down a job or make it impossible for them to leave the house, cook meals, or care for themselves and their families. Recent medical research has shown that hypochondria is as much a real illness as depression and post-traumatic stress disorder.

This work, scientists hope, will convince doctors who believed the disorder was some kind of character flaw that their patients are truly ill—and in danger. A study published just last year showed that people with hypochondria have higher death rates than similar but nonafflicted people, and the leading nonnatural cause of death was suicide. It was relatively rare, but the heightened risk was clear.

The research has also shown that the condition is actually two syndromes. One is illness anxiety disorder, Fallon says, in which the general idea of a sickness prompts excessive fear and preoccupation. The second syndrome is somatic symptom disorder, in which people worry about actual symptoms—a rapid heartbeat, say, or high blood pressure. The leading psychiatry handbook, the *Diagnostic and Statistical Manual of Mental Disorders*, now uses these two more specific diagnoses. (When referring to aspects that

both conditions have in common, I use the word “hypochondria,” which is widely used by doctors and many patients, or the phrase “intense health anxiety.”) In addition, a new feature of hypochondria has garnered attention: cyberchondria, in which people spend an inordinate amount of time on the web researching medical conditions they think they might be suffering from.

Studies have also pointed to more effective treatments. Short-term cognitive-behavioral therapy (CBT) provides people with techniques to more rigorously evaluate the causes of their concerns —particular physical responses, in the case of somatic symptom disorder, or general fears about contracting a disease, for illness anxiety—and quell their spiraling sense of terror. Antidepressant drugs also help. Dismissing a patient with comments such as “it’s all in your head,” however, only makes things worse.

Estimates of hypochondria’s frequency range from as high as 8.5 percent to as low as 0.03 percent in medical settings. The COVID pandemic, which combined a real health scare with isolation and more time to ruminate, may have pushed the incidence up. In Australia, it jumped from 3.4 percent before the emergency to 21.1 percent during it.

The ancient Greeks thought hypochondria originated in a region of the body just under the rib cage that produced “black bile,” an ill-defined substance that caused a variety of physical ailments. Eventually hypochondria came to be associated with the nervous system, and in the early 20th century Sigmund Freud termed it an “actual” neurosis. He tied it, as he did many things, to feelings of guilt and sexual repression. It wasn’t until the 1990s, after clinical treatment studies with talk therapy and drugs, that psychiatrists stopped linking hypochondria to guilt about sexual and aggressive feelings.

Despite the pain and anguish it causes, “for centuries, hypochondria was deemed a fashionable, even a desirable

disorder," perhaps as a sign of an intellectual, thoughtful disposition, according to hypochondria reference material from the Wellcome Collection.

Some of the most revered minds have claimed to have the disorder, complete with mournful descriptions. There's this from James Boswell, 18th-century biographer of English writer Samuel Johnson: "A Hypochondriack [sic] fancies himself at different times suffering death in all the various ways in which it has been observed and thus he dies many times before his death." Avowed hypochondriac and 18th-century German philosopher Immanuel Kant noted that hypochondria was not a "really existing disease" but an apprehension. Twentieth-century French philosopher Jacques Derrida, convinced throughout his life that his death was imminent, used to say, "Life will have been so short." He died of pancreatic cancer at 74.

Much of the more modern research was done by Arthur Barsky, now a professor of psychiatry at Brigham and Women's Hospital in Boston. In the 1970s he was doing his psychiatry training at Massachusetts General Hospital. Primary care doctors would stop him in the hallway or at lunch to ask him about patients with headaches, dizziness, fatigue, palpitations or shortness of breath. "They keep coming back," Barsky remembers the doctors complaining, "but I've done everything I can."

> "It's not so much death that's often feared," says patient Annalisa Barbieri, "but being ill, being dependent, the loss of control."

Barsky searched the medical literature and couldn't find much to guide clinicians. He decided to dig in, and eventually he published a series of defining papers on the nature and epidemiology of hypochondriasis and treatments for the illness that, along with work by Peter Tyrer of Imperial College London, provided a more accurate scientific basis for treating the disease. The American

Psychiatric Association eventually decided to divide the condition into illness anxiety disorder and somatic symptom disorder. Fallon, who was a consultant to the committee of psychiatrists behind the renaming, says a major reason for jettisoning the old category was that it focused on the absence of medical explanations for symptoms, and that enhanced the stigma when such a label was attached to a patient's chart. The two new descriptions are about actual symptoms, such as unusual thoughts and behaviors related to a person's medical concerns. Fallon estimates that about 20 to 25 percent of hypochondria cases are illness anxiety disorder, and the rest are somatic symptom disorder.

Hypochondria may, at first glance, seem to be a version of a related problem: obsessive compulsive disorder, or OCD. Both are marked by intrusive thoughts and distressing fears. There are differences, however. Some people with OCD may have intrusive thoughts about *getting* an illness, but these individuals usually also have other manifestations of OCD, such as an extreme need for order or symmetry. Among people with hypochondria, their fear is primarily of *having* an illness.

Cyberchondria, the latest manifestation of the disorder, has been the topic of more than 100 medical publications. (The *Diagnostic and Statistical Manual* hasn't officially recognized it yet.) This version involves more than opening a laptop and checking Dr. Google—it interrupts people's lives, taking away from time with their families or work and increasing their anxiety. In 2016 Fallon and his colleagues asked 731 volunteers about "online symptom searching" and about their level of health anxiety. Those at the lower end of the illness anxiety scale tended to feel better after checking their symptoms online, but not so for those with higher anxiety. "Contrary to their belief," Fallon says, "checking the Internet for answers only makes them feel worse."

In one study of cyberchondria in Germany, half the people who used symptom-checker apps qualified as having hypochondria.

Frequent users of such apps, if they had the disorder, were likely to be unsettled by what the apps told them. A study of nurses in Turkey showed that cyberchondria coincides with an obsession with healthy eating, and a study of medical students in Egypt revealed an association with smartphone addiction.

Treating any kind of hypochondria is a challenge for doctors. They've got to rule out organic disease, and if they do but the patient keeps coming back, it can be frustrating. Back in 1991 Barsky and several of his colleagues asked patients in a large medical clinic what they thought of their physicians, and they also asked those physicians what they thought of their patients. The patients with hypochondria were less satisfied with their physicians than were other patients in the clinic. And perhaps not surprisingly, their physicians reported that those patients were more frustrating to care for and less likely to listen to them.

Clinical trials have shown that hypochondria as a whole, and somatic symptom disorder in particular, can be successfully treated with CBT or with antidepressants that improve the availability of the neurotransmitter serotonin (known as SSRIs). A combination of the two also works. More than 30 years ago, soon after the first SSRI, Prozac, went on the market, Fallon tried it on a patient who was very unhappy about being sent to a psychiatrist. "He had a dramatic improvement," Fallon says, which inspired the psychiatrist to test it in a small trial. Just over 60 percent of the patients improved. Subsequent larger, double-blind studies by Fallon and others showed Prozac's benefits, though at somewhat lower rates.

CBT for hypochondria can take different forms, all of which rely on identifying ways that health anxiety limits a patient's ability to function and developing a plan the person can put into action when the disabling thoughts hit. A therapist might get a patient ready with stress-reducing breathing techniques to apply when needed. Another option is being prepared to recognize bad thoughts and

practicing good replacement thoughts. If a woman is convinced the pain in her leg is cancer, for example, she can restructure the worry into a plan that includes contacting her doctor if pain continues. A therapist may also suggest she stop asking other people to share their symptoms with her.

Barsky and Fallon teamed up to compare Prozac alone, CBT alone, the two together and a placebo medication. They were aiming for an improvement of 25 percent or more on two scales that measure the disorder. After about six months the combination of Prozac and CBT came out on top with 47 percent improvement. Results for the groups that received a single treatment type were about equal, averaging a 42 percent improvement—12 percentage points better than the placebo group.

> When someone with hypochondria hears they have a one-in-100 or even a one-in-1,000 chance, they may end up convinced that they are that one unlucky person.

After hypochondria was divided into two diagnoses, Fallon went back to this study. He found that patients he could classify as having somatic symptom disorder appeared to do noticeably better with Prozac than with CBT. For those with illness anxiety disorder, results tentatively suggested that CBT worked better than Prozac. That may be, Fallon says, because people in the group with somatic symptom disorder had substantially more depression and anxiety than those in the group with illness anxiety disorder.

The cause (or causes) of either condition remains a mystery. A slew of genes have been associated with depression, but this discovery hasn’t happened for hypochondria. If there is a genetic cause, it isn’t likely to be a simple one. When a trait appears more often in identical twins (who share a genetic profile) than in fraternal twins, it’s reasonable to think genes rather than environment are to blame. A Canadian study published nearly 20 years ago compared rates of health anxiety in fraternal and identical twins. Earlier studies had

suggested that genes can explain about a third of the burden of health anxiety, but these researchers found that some of the hallmarks of health anxiety (treatment seeking and fear of illness, pain and death) were at most “modestly heritable.”

Experts in the field suggest that vulnerable people may be lured into full-bore illness by commercialism in our medical system. “Every symptom is significant if you listen to television,” Barsky says. “Pharmaceutical companies are telling us every day when we turn on the television that we should go to our doctors and check things out.” Rosenbluth blames his switch to a heavily advertised drug and his subsequent hyperanxiety on having repeatedly watched a promising advertisement.

Whatever the cause, hypochondria is associated with a certain level of innumeracy, or trouble grasping risk levels—difficulty perhaps compounded by anxieties about those risks. Tobias Kube, a psychologist currently at the University of Kaiserslautern-Landau in Germany, found this out when he was working with Barsky at Harvard Medical School. In a study, they compared 60 people with hypochondria and related disorders to 37 volunteers without the conditions. The researchers asked the participants how worried they’d be if they were told they had a certain chance of having or not having a particular medical condition. If told to consider a one-in-10 or a one-in-100 or a one-in-100,000 chance of having something, people with intense health anxiety disorders reported greater concern than did volunteers without the conditions. “Patients still think, okay, it may be unlikely, but it’s still possible,” Kube says.

People with intense health anxiety also were more worried than the other group if they were told they had a 90 percent chance of not having a disease, although this more positive framing of risk prompted less concern. And people with hypochondria-related disorders were also more concerned by frequency numbers—say,

one in 100—than by the same value presented as a percentage, such as 1 percent.

So does innumeracy cause hypochondria, or do the fears and anxieties associated with hypochondria make understanding odds difficult? “I suppose that both directions are possible,” Kube says. “But I consider it more likely that hypochondria causes the difficulties with interpreting likelihoods of medical diagnoses.” He reasons that finding out there is a low likelihood of having a disease diverges so much from the patient’s fears that the person hears only that a chance does exist. Instead of being relieved, they figure something must be wrong.

> “Expressing empathy first and then offering to help the person connect with resources can be a good approach.” —Jessica Borelli, clinical psychologist

This inability to take comfort was supported by a second study. The same team asked 129 people—some with hypochondria and related issues, some with depression and some without either condition—to watch a videotape of a doctor being reassuring about gastroenterological complaints. After watching the talk, people with hypochondria still reported more concern than those in the other groups.

These challenges in evaluating information have implications for doctor-patient discussions. “Doctors can’t rely on simply explaining that it’s unlikely and then expecting patients to be fine,” Kube says. When someone with hypochondria hears they have a one-in-100 or even a one-in-1,000 chance, they may end up convinced that they are that one unlucky person. Kube and his co-authors suggest that doctors emphasize to their worried patients their high chances of not having a particular disease rather than their low chances of having it.

Effective treatments could be lifesaving, as indicated by a study in Sweden. The research started when, several years ago, psychologist David Mataix-Cols of the Karolinska Institute wondered just how far the consequences of hypochondria could go. “These people suffer enormously over many, many years,” he says. “And yet no one had actually looked—do they die?” He realized he had a powerful database to help him answer the question.

Sweden has detailed health and demographic records that include whether a patient has ever been diagnosed with hypochondria by a specialist. Mataix-Cols and his colleagues checked the death rate among all 4,129 people with a diagnosis of hypochondria between 1997 and 2020 (an undercount, he says; he suspects doctors in Sweden are reluctant to label their patients with a stigmatized condition). They compared that number with the rate among 41,290 demographically matched control subjects and reported their results last December in *JAMA Psychiatry*.

They found a hazard ratio for death of 1.69, meaning a nearly 70 percent increase in the probability of death in the hypochondria group from both natural and unnatural causes over the course of the study. Suicide was the primary cause of unnatural death. Mataix-Cols emphasizes that although the fourfold increased suicide risk they found is alarmingly high, the absolute risk in the population with hypochondria was still quite low. Suicide occurred, in fact, in fewer than 1 percent of people with the condition. “People should not be panicking like, ‘Oh, my God, I’m going to die because of my hypochondria’—this is not the message they should get,” he says. Rather the message he would like repeated is that hypochondria is a serious condition that should be treated.

The results of Mataix-Cols’s study startled Fallon and Barsky—neither has lost a patient with hypochondria to suicide. Barsky notes that people with hypochondria are hunting for a disease to match their symptoms so the disease can be treated; they’re not looking to die.

Annalisa Barbieri, a 58-year-old woman in England with hypochondria, has feared she had Parkinson's disease, liver cancer, and other illnesses. "It's not so much death that's often feared but the dying, the being ill, the being dependent, the unknown, the loss of control," she says. After CBT, Barbieri learned to reframe and replace these terrifying thoughts with more realistic assessments of her body. Today, she says, the monstrous anxiety inside her mostly sleeps. It does reawaken during times of stress, such as the kind she felt recently after her mother and several other people died in a short period. She rolls out what she learned during her CBT: to separate out assumptions from facts and to make a plan. It takes work, she says, and it does work.

Rosenbluth found writing his book about his condition cathartic, and the antianxiety medication he reluctantly takes has helped. He says he's able to think things through with the help of a new doctor, who often spends 45 minutes per visit hearing out Rosenbluth's concerns. Finding the best way for doctors to talk with patients who have hypochondria will improve their lives, according to experts in the field. Kube, in Germany, is exploring optimal approaches to these conversations. He plans to study in more detail how doctors can best frame "likelihood" statistics and how they can better communicate probabilities. He also wants to test the effect of a physician's demeanor by asking volunteers to watch videotapes of doctors demonstrating varying levels of warmth and competence.

Some of the researchers in the Swedish early-death study plan to train medical personnel on how to recognize cases of hypochondria earlier and how to get those patients into treatment. Other scientists in Sweden have already shown that computer-based information on health anxiety combined with telehealth sessions with therapists can help as much as face-to-face therapy encounters. They looked at how 200 patients did with either face-to-face sessions or online self-help modules and occasional e-mail check-ins. In both groups,

hypochondria dropped about 13 points on a 0- to 54-point scale after 12 weeks of treatment.

Family members and friends can also help someone they know and love who is overcome by obsession and fear about health. “Expressing empathy first and then offering to help the person connect with resources can be a good approach,” says clinical psychologist Jessica Borelli of the University of California, Irvine. “That might look like, ‘I’ve noticed that you have a lot of worries about your health, and that sounds really hard. I’d like to help you find some support. Is that something you are open to?’”

Borelli saw her first patient with hypochondria about 20 years ago and has seen many since. If you know someone who has hypochondria, she says, it might be helpful to offer them a suite of options—perhaps assistance in scheduling an appointment with a therapist or medical doctor or help organizing errands or cooking if an illness obsession has driven them to let things slide. Sometimes making life seem more manageable can help people begin to function in a healthier way.

When a person has been doctor hopping for years, looking in vain for a medical diagnosis, a therapist might be where to start. There also may be real but unexamined medical issues at the root of a patient’s anxiety, Borelli notes. If a person has not seen a primary care doctor—some people’s fear of hearing bad news keeps them away, for instance—helping them to find a physician, schedule a visit, and even offering to go with them would be a good first step away from unreasonable fear.

IF YOU NEED HELP

If you or someone you know is struggling or having thoughts of suicide, help is available.

Call the 988 Suicide & Crisis Lifeline at 988 use the online Lifeline Chat at 988lifeline.org/chat or contact the Crisis Text Line by texting TALK to 741741.

Joanne Silberner, a freelance journalist, has been covering medicine since the start of the HIV epidemic. A co-founder of the Association of Healthcare Journalists and a former NPR health reporter, she lives near Seattle.

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https://www.scientificamerican.com/article/why-hypochondria-can-be-deadly-and-how-newer-treatments-help

Should Offshore Oil Rigs Be Turned into Artificial Reefs?

Oil rigs around the world are habitats for marine species. When they stop producing oil, should they be removed or allowed to stay?

By Asher Radziner

The steel “jackets” that support California’s offshore oil platforms are covered in millions of organisms and provide habitat for thousands of fishes.
Joe Platko

Even before I could make out the silhouette of Platform Holly on the foggy horizon, I could see and smell oil. Ripples of iridescent liquid floated on the sea’s surface, reflecting the cloudy sky. But the oil wasn’t coming from a leak or some other failure of the rig. Milton Love, a biologist at the Marine Science Institute at the University of California, Santa Barbara, explained that it was “kind of bubbling up out of the seafloor.” Our boat, less than two miles from the central California coast, was sailing above a natural oil seep where the offshore energy boom first began.

For thousands of years the Chumash, an Indigenous group native to the region, identified these oceanic seeps and their naturally

occurring soft tar, known as *malak*, which washed up on the shore. Sixteenth-century European explorers noted oil off the coast of modern-day Santa Barbara, and in the 1870s the U.S. oil boom reached California. In the late 1890s the first offshore oil wells in the world were drilled from piers off of Summerland Beach; 60 years later the state's first offshore oil platform was deployed to drill the Summerland Offshore Field.

Since then, 34 other oil platforms have been installed along the coast, and more than 12,000 have been installed around the world. These hulking pieces of infrastructure, however, have finite lifetimes. Eventually their oil-producing capacities tail off to the point where it is no longer economically viable to operate them—that, or there's a spill. Today 13 of California's 27 remaining offshore platforms are what's known as shut-in, or no longer producing oil.

Platform Holly is among the dead platforms awaiting their afterlives. At the time of its installation in 1966, everyone knew a platform situated directly over a natural oil and gas seep was going to be a success. And for nearly five decades it was. Then, in 2015, a corroded pipeline near Refugio State Beach owned by Plains All American Pipeline cracked, spilling 142,800 gallons of crude oil into the Santa Barbara Channel. The spill killed sea lions, pelicans and perch, among other creatures; closed fisheries and beaches; and permanently severed Platform Holly from its market.

Venoco, the oil company that owned Holly at the time, was not responsible, but it was bankrupted by the event. Because Holly is positioned within three miles of the coast, it was transferred into the hands of the California State Lands Commission (SLC) in 2017. The SLC is now responsible for managing the process of decommissioning the platform and determining its fate.

> Because Holly is already owned by the state, not an oil company, its transition could illuminate how to evaluate the

fate of rigs worldwide based on science, not politics.

According to platform-decommissioning consultant John Bridges Smith, a former leasing specialist with the Bureau of Ocean Energy Management who counts ExxonMobil, ConocoPhillips and Chevron among his clients, Holly and the eight other platforms whose leases are terminated or expired will be decommissioned by the end of the decade. Based on the original contracts between the oil companies and the state and federal governments, which date to the 1960s, this means the structures will have to be fully removed. In December 2023 the Bureau of Safety and Environmental Enforcement recommended that all 23 California platforms standing in federal waters be fully removed.

Doing so will incur a great expense. That's true everywhere but especially in California, where some of the platforms are in very deep water. According to one conservative estimate, completely removing all of California's platforms would cost the responsible oil companies $1.5 billion. Smith says these companies would prefer to delay that process for as long as possible. Some environmental groups in California, meanwhile, are pushing to hold them to the speediest timeline.

Platform Holly, located off the coast of Santa Barbara, Calif.
Milton Love

Love, who has spent the past three decades studying the aquatic life that now calls southern California's oil platforms home, would prefer a third alternative.

In the decades since they were installed, the steel support structures of California's oil platforms have become vibrant ecosystems isolated from fishing pressures—de facto marine sanctuaries. Rather than being removed, aging fossil-fuel infrastructure and its serendipitously associated habitats can be salvaged in the ocean as state-managed artificial reefs. The entire topside—the above-water portion of steel, offices and cranes—and shallow section of a rig are removed, but part of the submerged base may remain. A

pathway for doing so already exists in the U.S. and has been successfully followed 573 times in the Gulf of Mexico. Similar examples can be found around the world, from Gabon to Australia. Because Holly is already owned by the state, not an oil company, its transition could illuminate how to evaluate the fate of rigs worldwide based on science, not politics.

When an oil platform is decommissioned, the process goes like this: First, in a phase known as plugging and abandoning, its oil wells are filled with concrete and sealed. Next, scientists conduct an environmental review and consider the various merits and risks of different removal strategies. The results determine a platform's final resting place, which in most cases has been in a scrap metal yard. A platform's support structure is called its jacket—hundreds of vertical feet of woven steel that is affixed to the bottom of the ocean. Most of the time engineers will use explosives to sever a platform jacket from the seafloor. The steel is then hauled to shore for disposal and recycling. Decommissioning is considered complete when a platform has been removed down to 15 feet below the mud line and the seafloor has been returned to preplatform conditions.

Most of the offshore oil platforms that have ever been built were installed in the Gulf of Mexico—more than 7,000 since 1947. More than 5,000 of those have since been removed. In the 1980s oil companies and recreational fishing associations pushed for an alternative outcome that would both be cheaper and help to bolster struggling fish populations. In 1984 the U.S. Congress passed the National Fisheries Enhancement Act, providing for the creation of the National Artificial Reef Plan, which allowed oil platform operators to donate decommissioned rigs to states as "artificial reefs."

In the following years Texas, Louisiana, Mississippi, Florida and Alabama each passed the necessary legislation and established their own State Artificial Reef Programs. These were, and still are,

funded by oil and gas contributions and the interest earned on those payments. The program hasn't replaced full removals; between 1987 and 2017 only 11 percent of all decommissioned oil platforms off Louisiana were partially removed. But in deeper waters, the story is different: of the 15 structures decommissioned in depths greater than 400 feet, 14 have been partially removed, or "reefed."

Offshore oil infrastructure in California acts as a nursery for certain fish species.
Bob Evans

When a platform is partially removed, its topside is taken to shore. To avoid creating a navigational hazard, the first 80 to 85 feet of its jacket closest to the surface are either brought ashore or laid along the sea bottom. Finally, the remaining jacket—whether it is 15 feet of steel or hundreds—is either left in place or severed from the seafloor and towed to an approved reefing site. Liability for the reefed structure gets transferred from the oil company to the state, and the oil company donates 50 percent of its cost savings (from doing a partial removal versus a full removal) to the state. This process, colloquially referred to as rigs-to-reefs, has successfully bolstered fish populations in the Gulf.

Ann Scarborough Bull, a U.C.S.B. biologist who studies the ecology of offshore oil platforms and renewable energy installations, worked in the Gulf of Mexico on offshore oil and gas regulation for 14 years. She arrived in 1975, when her husband

took a job in the highly profitable offshore oil industry. When it came to oil platform ecology, “the Gulf of Mexico hadn’t been studied,” Bull says. She took a job as a chief scientist for the U.S. Minerals Management Service, which has since been reorganized into the Bureau of Ocean Energy Management, and received funding to research the communities of fish and invertebrates dwelling underneath the platforms. On her frequent trips offshore, it became clear to her that the rig jackets provided habitat that was vital to the region’s economy.

Lutjanus campechanus, commonly known as the northern red snapper, is one of the most frequently caught species in the Gulf’s recreational fishing industry. A long-lived apex predator, it is mostly sedentary in its adult phase and restricted to reef habitats. Until the mid-20th century, the primary fishing grounds for red snapper were off the western coast of Florida and in the waters south of the Florida Panhandle.

Just as populations in the fish’s historical range were being depleted by overfishing and trawling, red snapper began to shift and expand west across the entirety of the Gulf. Thousands of oil platforms were being installed across the northwestern and north-central Gulf. Decades of research have shown that with natural reefs few and far between, red snapper were using the oil platforms as a kind of outpost, which allowed their population size to expand significantly.

> Imagine the Empire State Building extending up from the ocean floor, blossoming with mussels and scallops and sea anemones, providing food to legions of fish.

As drilling operations multiplied, commercial and recreational reef-fishing industries grew in tandem. Surveys from the early 1980s indicated that one quarter of fishing trips were associated with oil and gas structures. “This whole society in the Gulf of Mexico grew

up with two ways to make a living: one, be a fisherman, and the other, be connected with oil and gas," Bull says.

In 2001 Bull moved back to her native California, and she arrived at U.C.S.B. in 2016. Her experience studying the state's platforms and coming to understand the surrounding politics has shown her that the differences in platform strategy between California and Louisiana are multifold. "There are factions, especially in Santa Barbara, that absolutely despise oil and gas companies," Bull says. This animosity, she explains, makes the rigs-to-reefs process a harder sell.

It's not unwarranted. On January 28, 1969, a blowout at Union Oil's Platform A in the Santa Barbara Channel spilled 100,000 barrels of crude oil into the Pacific Ocean. Black tar covered beaches for dozens of miles and killed thousands of birds and marine mammals. At the time, it was the largest oil spill in U.S. history.

The spill prompted the first Earth Day and the creation of the U.S. Environmental Protection Agency. It also spawned numerous environmental nonprofits in the Santa Barbara region, including Get Oil Out! and the Environmental Defense Center. Development of new oil fields off the coast of California halted and didn't resume until 1982.

Then California's first decommissionings began. In 1988 Texaco successfully removed Platforms Helen and Herman. In 1996 Chevron removed Platforms Hope, Heidi, Hilda and Hazel from the Santa Barbara coast—but not completely. The cuttings piles—gigantic mounds of rock debris, mud, and other hydrocarbon detritus discharged by the drilling process—underneath all four platforms were allowed to remain.

Linda Krop, now chief counsel for the Environmental Defense Center, was then a law clerk with the organization. The group

wasn’t too happy that Chevron had seemingly gotten around the obligations of its original contracts, which required full removal of its platforms and restoration of the local environment to its natural condition.

> “I just think it’s criminal to kill huge numbers of animals because they settled on a piece of steel instead of a rock.” — Milton Love, biologist

In the nearly three decades since, Krop has worked as an attorney holding oil companies accountable for their environmentally destructive actions. She had her greatest court victory in 2016, achieving the termination of 40 federal oil leases offshore. Krop is firmly against the prospect of reefing off California. “The fish are going to be fine if the platforms go away,” she says. “They’re not going to disappear.”

In July 2023 I visited Holly with Milton Love on an especially foggy morning. After a 30-minute boat trip from the Santa Barbara Harbor, its skeletal outline began to emerge from the mist. From a distance Holly resembled a skull with barred teeth and low, hollow eyes, but up close it was an eight-story scaffolding of steel beams, pylons and old shipping containers.

Holly hasn’t produced oil for a decade, but the whirring and beeping of generators and cranes was still too loud to speak over. People in construction vests milled about the upper decks, ostensibly monitoring the wells’ recent plugging procedure and shoring up the platform. Brown sea lions were flinging themselves from the ocean onto the platform’s lower decks, howling and jostling for space. Love told me that what we were seeing was only a small piece of the action. The real story, he said, was hidden below the waterline, where the mechanical noise dims and is replaced by the crackle of shrimp and fish nibbling at the reef.

The platform jackets are covered in millions of organisms and provide habitat for thousands of fish. Some of California's 27 platforms are relatively small; Holly stands in only 211 feet of water. Others, such as the Exxon-built Harmony, stand in depths up to 1,198 feet. Imagine the Empire State Building extending up from the ocean floor, blossoming with mussels and scallops and sea anemones, providing food to legions of fish. According to a 2014 paper co-authored by Love, these platforms are among the most productive marine fish habitats in the world and, per cubic meter of seafloor, are more productive than any natural reef.

In 2019 the Gulf recreational fishing community took more than 50 million trips and caught 332.5 million fish. But recreational fishing off the coast of California is nowhere near as big. And because of the more than 120,000 acres of natural rock reef along the state's coast and Channel Islands, the amount of habitat area generated by the rigs does not significantly alter the total regional habitat area or increase the carrying capacity of the fish population. In contrast, the Gulf platforms contribute 30 percent of their region's total "reef" habitat area.

Love argues that California's platform ecosystems are vital for different reasons. After finishing his Ph.D. and landing at U.C.S.B. as a research biologist, Love received funding from the National Biological Survey; he wrote a book called *The Rockfishes of the Northeast Pacific* and set out to study how oil platforms functioned as fish habitats. "Most of the money has always been from the federal government," Love says. But a "small percentage" came from Chevron and ExxonMobil.

Love's early work laid the foundations for others to research the structures as well. In a 2014 study, quantitative marine ecologist Jeremy T. Claisse, now at California State Polytechnic University, Pomona, and his colleagues revealed that along the coast of southern California, jacket habitats don't just support millions of tunicates, barnacles, rock scallops and shrimp; they can be sites of

fish production. That means many fishes living on and around the legs grow up there and may either spend the entirety of their lives at one platform or travel elsewhere, bolstering fish populations nearby.

Sea anemones live on the shell mounds that form under the platform legs.
Bob Evans

Bocaccio and cowcod rockfish of southern California's natural reefs are economically important and at one point were considered overfished. In 2006 Love found that California's offshore oil platforms contribute 20 percent of the young bocaccio rockfish that survive each year across the species' entire geographic range, which stretches from Alaska to Baja California. The platforms operate essentially as nurseries, he says, incubating the next generation.

Mussels dominate the platform jacket in the first 40 feet of water, forming three-inch crusts around the submerged legs and beams. Barnacles and bivalves extend even deeper. When these creatures die or are dislodged by a storm, they sink to the feet of the gargantuan structures and form shell mounds up to 220 feet in diameter and rising upward of 20 feet from the seafloor. Both among the decaying shell mounds and throughout the crisscrossing beams of the platforms' midwater sections, juvenile rockfish of the region proliferate.

Trapped within these shell mounds, however, are the piles of toxic drill cuttings. Until the late 1970s, regulation to properly dispose of cuttings was fairly loose, and operators would often deposit the debris on the seafloor. In a 2001 study, surface sediments from the shell mound of Platform Hazel, installed in 1958, were found to be lethal to 50 percent of tested shrimp within 96 hours of exposure. Recently installed platforms don't appear to have the same problem, perhaps because most cuttings must be hauled to shore. In one study, cuttings piles below platforms installed before stricter regulation were found to contain 100 times more volatile organic compounds than a newer platform, Gina, installed in 1980.

Love and his colleagues wanted to know if the contamination from cuttings extended to the water column around the shell mound. In 2013 they published a paper that found California's platforms—regardless of age—were not contaminating their associated fish populations. "We looked at fishes that live around platforms—not just Holly but throughout southern California—and compared the heavy metal concentrations with fishes of the same species on nearby natural reefs," he says. "There was no statistical difference between what we saw."

Still, people like Krop at the Environmental Defense Center are not convinced any oil infrastructure should be allowed to stay in the ocean. "If we need to build some [more] artificial reefs, then let's do it the right way," she says. California has been building its own artificial reefs since 1958, when the state's Department of Fish and Wildlife placed 20 automobile bodies in the waters of Paradise Cove off Malibu. Such artificial reefs tend to be spread over many acres in relatively shallow waters. Platform jacket reefs, in contrast, are not even technically artificial reefs and exist as habitats of extreme vertical complexity and dimension. They are smaller in area yet more productive on average.

In 2003 Mark Carr of the University of California, Santa Cruz, wrote that there are few natural rock reefs at the depths of the

California oil platforms and none with comparable physical characteristics. If the goal is to contribute to overall reef area, their value is “minuscule.” If, however, the intent is to preserve their unique habitats, their value is “100 percent.”

Love has a more irreverent perspective on their value. “As a biologist, I just give people facts,” he says. “But I have my own view as a citizen, which is: I just think it’s criminal to kill huge numbers of animals because they settled on a piece of steel instead of a rock.”

Many countries around the world are coming up on the decommissioning of their platforms for the first time. According to Amber Sparks of Blue Latitudes, a company that consults for governments worldwide regarding the environmental effects of their platform-decommissioning practices, there is no international standard for how an oil platform should be reefed.

Globally, the process is often ad hoc. Off the coast of Gabon, for instance, high-biodiversity habitats underneath more than 40 active oil platforms are included in a system of marine national parks. In Malaysia, an oil platform has been converted into a resort for scuba divers. With the assistance of Chevron, Thailand established an artificial reef program and reefed seven platforms near Koh Pha-Ngan in 2020. In waters off the U.K., five platforms have been approved for partial removal, but no full platform jacket has been reefed, and no rigs-to-reef program exists. A 2017 study evaluated the possibility of transforming one U.K. rig into a hub for harvesting wave energy.

When a decommissioned platform is removed, so, too, goes habitat area for sea lions and certain fish species.
Joe Platko

According to Francis Norman, managing director of the nonprofit Center of Decommissioning Australia, there is large demand from recreational fishing communities for artificial reefs—at least off the coast of Western Australia, where more than 40 platforms are stationed in shallow waters. But in the eastern state of Victoria, 23 Exxon platforms in the Bass Strait are in depths up to 525 feet—these structures are too far from land to be seen over the horizon and are not fished because of rough water conditions.

Norman says Australia does not have an official rigs-to-reef program, but in 2023 Exxon applied for permits to partially remove 13 of its platforms. The company, he says, withdrew its application this summer after a wave of media reports featured criticism of partial removal.

As of August 2024, all of Holly's 30 wells were fully plugged and abandoned. Jennifer Lucchesi, executive director of the California State Lands Commission, says the facility is being "hardened" so it won't need 24-hour staffing as it moves into "caretaker" status. Now studies of Holly's subsurface biology are looking at the platform's effects on its local marine environment to inform the creation of an environmental impact report, which will review the

likely net outcomes of full removal versus partial removal versus no action. The “biological study” component is being prepared by Love, Bull and their colleagues at U.C.S.B.

Oil companies are interested in platform reefing because of money, not fish. Partial removal is far cheaper than full removal. Reefing the California platforms instead of eradicating them would net the companies a savings of $150 million and generate $600 million for the state. (Actual costs and savings for removal are likely to exceed these projections by at least a factor of four.) Still, not a single California platform operator has applied to begin the rigs-to-reef process. Smith believes the hesitancy results from differences in policy. Legislation in the Gulf States asks for 50 percent of an oil company’s cost savings to be paid to a state in most cases; in California, it’s 80 percent. And whereas in the Gulf liability transfers to the state, in California it essentially stays with the responsible oil company. Previous attempts, in 2015 and 2017, to amend the legislation in California failed. Krop says groups like hers “would not support making the state liable,” and Smith says that would make reefing “unworkable” for the oil companies. When approached for a comment, Chevron wrote: “We are still finalizing our decision on this issue.”

Smith believes the most likely outcome for California’s aging offshore infrastructure will be not full removal or partial removal but indefinite delays. Operators are supposed to submit decommissioning plans two years before a lease ends, but operators for six offshore platforms whose leases ended in 2015 still have not followed through.

Oil platforms were designed to be productive for 20 to 30 years, but some are still producing oil after 45 years. No one knows how long they might stand. In one scenario, maintenance may not be properly kept up. This isn’t hard to imagine: Platform Holly fell into a state of disrepair following its operator’s bankruptcy, and ExxonMobil, a prior operator, paid millions to refurbish the

platform so it could support the equipment required to plug and abandon its dormant wells.

In a soon-to-be-published paper on the topic of delay, Smith discusses a worst-case scenario in which poor maintenance and corroded steel cause a platform to collapse during an earthquake or storm. A pile of steel legs, crossbeams and submerged topside offices would rest like a shipwreck on the seafloor. Most of the midwater organisms would be gone, as would those associated with the lengthy vertical water column. But Love says organisms associated with complex bottom habitats would perhaps flourish. Rockfish and lingcod would swim around the jagged, anemone-covered pieces of broken platform legs and rusted steel, past scurrying crabs, exploring their reconfigured home.

In another world, you could see oil companies keeping up with maintenance indefinitely. To prevent the steel legs from rusting and collapsing, they could continue applying zinc anodes to the steel bars, allowing the zinc to rust instead of the legs. “The marine habitat will change with climate change, of course, as everywhere will,” Love says. But the sea lions would stick around on the lower decks, as would the blacksmith damselfish in the shallow waters. The platforms’ topsides, steadfast off the Santa Barbara coast, would be a reminder of an oil-ridden past.

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https://www.scientificamerican.com/article/should-offshore-oil-rigs-be-turned-into-artificial-reefs

Hitting the Curiosity Sweet Spot Speeds Up Learning

Understanding curiosity can help people—and robots—learn faster

By Lydia Denworth

Peter Ryan

The world is full of things to learn. Where to start? How to choose what to pay attention to? What motivates someone to seek new knowledge?

The desire to learn is partly a preference for novelty: we tend to seek out new information and experiences, and that adds to what we know. We also like to reduce uncertainty. Information can bring food, safety, relationships, and other physical rewards. But scientists now believe these drives combine into a more complicated urge that can be critical to learning, even when—perhaps especially when—there's no immediate payoff. We are just curious.

We're often curious in a particular way: we want to learn more about things we already know a little bit about. "You can think of

curiosity as the process that guides the acquisition of knowledge," says neuroscientist Celeste Kidd of the University of California, Berkeley. We internally track how well we are learning, or our learning progress, and learning comes more easily and is more enjoyable when curiosity is high. Following our instincts appears to be a particularly rewarding way to explore the world. "If you feel positive after learning something, then you now understand the joy of learning, which motivates you to learn next time," says educational psychologist Kou Murayama of the University of Tübingen in Germany.

Kidd and Murayama are among many investigators, in fields as diverse as neuroscience, education, psychology and computational science, who are curious about curiosity. This new research focuses less on curiosity as an individual trait—one that many scholars and artists possess, as do you, the reader of an article on curiosity—and more on the variable state of being curious. Each of us is capable of curiosity, but what sparks and sustains it?

Scientists are piecing together the brain processes that underlie the wide-eyed wanting-to-know we generally think of as being curious. They are identifying how the brain homes in on novelty, copes with uncertainty, triggers reward networks and solidifies memory. Researchers are also beginning to see why curiosity can be so consequential.

> "It becomes obvious that what we should value is learning."
> —Jacqueline Gottlieb, cognitive neuroscientist

The instinct can be dangerous on occasion—curiosity famously killed the cat—but overall, it seems to encourage exploration in ways that promote survival. Gathering information even when its purpose is unclear allows us to build more accurate mental models of our world, says comparative psychologist Victor Ajuwon of the University of Cambridge, who studies elements of curiosity in rats,

goldfish and cuttlefish. “That is going to be useful for you in the future,” he says.

This link between curiosity, which occurs moment to moment, and the longer timescales of development and evolution is a new way of thinking, says Pierre-Yves Oudeyer of French research institute Inria in Bordeaux. Setting your own goals seems to increase motivation and let learning blossom in a sweet spot between challenge and frustration. Russian educational psychologist Lev Vygotsky called it “the zone of proximal development.” But until recently, little attention has been paid to what might be happening cognitively to make curiosity’s sweet spot so, well, sweet.

All humans know what it is to be curious, and we generally think of it as a positive trait, associating it with intrinsic motivation, creativity and open-mindedness. Influential early thinkers captured important aspects that are still thought to hold true. In 1966 psychologist Daniel Berlyne recognized that curiosity could relate to perception, such as when we notice a visual incongruity like a zebra among horses, and it could be specific or wide-ranging. In 1994 behavioral economist George Loewenstein theorized that curiosity was caused by the need to fill an information gap.

Comprehending how curiosity works, Kidd says, means understanding “how people form their beliefs about the world and how they change their minds.” A deeper analysis of the neural underpinnings and role of curiosity could potentially show teachers how to reach students more effectively, enable computer scientists to program artificial-intelligence systems to learn efficiently, and alleviate suffering from some mental disorders. Knowing how to facilitate curiosity about other kinds of people and cultures may even help make the world a kinder place.

Curiosity didn’t get a lot of scientific attention until now, because it is difficult to define. Are all urges to know driven by curiosity? In a review published earlier this year, Jamie J. Jirout of the University

of Virginia and her co-workers posit that curiosity “must arise from an internal desire for information” for its own sake. So, for example, a child asking why a rainbow happens is probably driven by curiosity if they just saw one—but not if the question is prompted by a science exam the next day. (Nor is curiosity the craving to know the outcome of a biopsy, which can be more like dread.) Some researchers study information seeking as a whole without trying to separate out curiosity.

Curiosity can on occasion be disconcerting, even distressing. People desperate to know, for example, the secret behind a magic trick have been willing to accept mild electric shocks as the price of satisfying their curiosity sooner. And arguments in pubs led an executive at the Guinness brewery to create the company’s eponymous book of records and then distribute its first copies in drinking establishments, the better to settle future disagreements immediately. (Have you ever wondered what a beer company and the world’s largest ball of string had to do with each other?)

"Curiosity in Children across Ages and Contexts," by Jamie J. Jirout, Natalie S. Evans and Lisa K. Son, in *Nature Reviews Psychology*, Vol 3; August 2024; restyled by Jen Christiansen

More often, though, curiosity is delicious. Studies show we happily avoid spoilers so as not to lose out on the fun of an unfolding drama. If you missed the Super Bowl or the series finale of *Succession*, you probably went well out of your way to keep from finding out what happened too soon. Nowadays we all carry digital reference libraries in our pockets, and we have a hard time resisting the need to use them as soon as a nagging question arises. Researchers measure the tip-of-the-tongue feeling, which heightens curiosity, by assessing the strength of the urge to google an answer. (Appropriately, they also liken the feeling to "mild torment.")

It's probably the anticipation of an answer that feels delectable. Higher levels of curiosity lead to higher levels of activity in areas such as the striatum, which is involved in the release of dopamine, the neurotransmitter most associated with feelings of reward. The

dopamine link “seems to resonate with this idea that curiosity is an internal reward, and then definitely it’s a motivator,” says cognitive neuroscientist Jacqueline Gottlieb of Columbia University’s Zuckerman Institute.

To work out that information itself is rewarding, neuroscientists have had to show how the brain distinguishes between physical rewards and information. Such work started in monkeys, the first other species in which scientists, who fear anthropomorphic overreach, have felt confident claiming curiosity exists. (No surprise to fans of Curious George.) Neuroscientist Benjamin Hayden of the University of Minnesota and his colleagues set up an experiment in which monkeys got water as a treat, and the researchers gave them the opportunity to find out ahead of time whether that reward was coming. The monkeys chose to get a heads-up 80 to 90 percent of the time and were even willing to lose out on larger rewards to know. They are saying, in effect, “I’m so curious that I want this information now,” Hayden says**.**

Mice appear to show the same tendencies, according to a study by psychologist Jennifer Bussell, a postdoctoral researcher at the Zuckerman Institute. Moreover, in both monkeys and mice, neurons in the orbitofrontal cortex (OFC), which is involved in an early stage of decision-making, responded differently to water rewards and to cues—information—that predicted those rewards. The OFC neurons encode details such as the amount of water as independent variables to be compared later, rather like raw material that will feed into their choice.

“There’s probably a drive that evolved to learn new stuff and gather information because 99 percent of the time in the natural world, for an animal, information is useful,” Bussell says. “Evolutionarily, you have to nudge the creature to come out of its burrow, even if it’s afraid that there’s a predator coming.” If the brain builds a system that regards gathering information and reducing uncertainty as rewarding, “that kind of solves the problem,” she says.

Reflecting the evolutionary significance of curiosity, the work of taking the raw material encoded by the OFC neurons and integrating the two different kinds of values—information and physical rewards—occurs in a small, ancient structure in the midbrain called the lateral habenula, according to a 2024 study by neuroscientist Ilya Monosov and others at Washington University in St. Louis. The lateral habenula, which exists across many species, assesses the relative importance of possible motivations, Monosov says. “In your daily life, you rarely make decisions based on either physical reward or secondary rewards, like money alone or information seeking alone,” he says. Instead our brains do the complicated work of comparing our concrete needs and our curiosity—Should I go to bed now and get enough sleep or finish reading the whodunit?—and weighing one against the other.

Other parts of the brain also grapple with uncertainty. In a 2024 study, Gottlieb and her colleagues explored perceptual curiosity by having participants view sets of images of animals and inanimate objects, such as a walrus and a hat. The brain clearly distinguishes animate from inanimate objects with neuronal signals that Gottlieb calls the equivalent of “barcodes,” a feature the researchers wanted to use. The images also varied in their clarity from easily identifiable to completely mysterious. When people were confident about what they were looking at, the barcodes in the visual parts of their brains flashed clear signals: animate or inanimate. But when people weren’t sure, the signals fell somewhere in between. And when the signals from the vision area reached the frontal cortex, where decisions get made, they triggered either confidence or curiosity. “The more uncertain this visual part of their brain was, the more curious people said they were,” Gottlieb explains.

Curiosity also primes memory circuits, the better to retain the new information. Presented with trivia questions—What Beatles single lasted longest on the charts? What is the only known place on Earth where trees have square trunks?—participants in a 2014 study rated their curiosity about the answers. (Don’t worry, I’ll share them at

the end.) Then, in a functional magnetic resonance imaging machine, they had to wait 14 seconds to get those answers. While waiting, they were shown neutral images of faces. Later, people were better able to remember answers to questions that had stoked their curiosity—and, oddly, they were also more likely to recall faces that were paired with those questions. The brain imaging revealed increased activity in the hippocampus, critical to creating memories. Matthias Gruber of Cardiff University in Wales, lead author on that study, has called curiosity “a vortex” that pulls in not just what you wanted to know about but incidental information around it.

Anyone who’s been subjected to their barrage of “why” questions knows that children possess powerful curiosity. The rudimentary elements of their curious brain circuits seem to be present early. Studying curiosity in babies shows how these circuits are already poised to guide knowledge acquisition throughout life, according to Kidd. Babies are driven to maximize learning from their environment and seem to recognize that surprising events represent an opportunity. They show a strong preference for highly informative stimuli—a human face is more appealing than a toy truck, and infant-directed speech is more alluring than nonhuman sounds. Babies are also intrigued by anything new. Even babies who can’t speak yet are aware of gaps in their knowledge. And Kidd has found that when children are uncertain, they continue to try to learn more and to store what they learn. Once they feel they understand something, they lose interest.

In an influential 2012 study, Kidd and her colleagues showed seven- to eight-month-old infants animated scenes of objects popping out of boxes. She used an eye tracker to measure how long the scenes engaged the babies’ attention and found they preferred to look at scenes with an intermediate level of complexity. Not too predictable and a little bit surprising proved to be just right. (The researchers called it the “Goldilocks Effect.”) In a 2022 paper,

Kidd and her colleagues observed the same preference for intermediate complexity in monkeys, suggesting it is widespread.

The appeal of information of intermediate complexity—carrying just the right level of intrigue—makes sense as grist for the learning mill. It seems to represent an opportunity to add to what we know in accessible ways. To test the idea that learning progress is a piece of the curiosity puzzle, Oudeyer took the unusual step of bringing curiosity to computers. “Building machines that are curious was exotic and strange 20 years ago,” he says. But it can be an efficient way to tackle big challenges, maybe even as big as getting to another planet someday.

Computers, of course, are not curious beings; they are compilations of wires, motors and sensors. In 2016, when Google DeepMind made headlines by building a computer that beat an 18-time world titleholder at the complex Chinese game Go, that computer still relied on a cutting-edge search capability and data fed into it about possible moves. But as people improved at building AI, they started asking whether there was a better way to have computers learn complicated things. One answer would be to give them curiosity—or programming that mimics the thought patterns behind curiosity-driven exploration. That’s just what Oudeyer and his colleagues did.

Torso the robot has a blue head, blue arms and a blue upper body attached to a wood base, and it is programmed to explore its surroundings as a child would. It learns how objects interact by playing with them. Two joysticks are mounted to Torso’s base. On a coffee table, a circular, rimmed arena ringed with lights contains a tennis ball and a smaller robot called Ergo, which looks like a chunky desk lamp.

Unlike humans and other animals, robots can be programmed to model the behavior of an ideal agent and test popular theories of how we explore. Do we keep track of prediction errors—that is,

how right or wrong our guesses about outcomes are? Yes, but a robot programmed to do only that was distracted by its own movements in irrelevant ways (imagine waving repeatedly in front of a window to learn how each arm movement relates to the color of the cars going by outside). Do we zero in on novelty or uncertainty? Yes, but absent other motivations, those led to random and disorganized behavior in machines.

Torso learned fastest and most efficiently when programmed to pursue curiosity. The robot could produce movements and perceive its environment and was instructed to find correlations between the two, though without specific aims. Instead Torso was to search for opportunities for learning and follow where they led. “He’s basically told, your only goal is to try to find goals for which you are making progress,” Oudeyer says. In effect, as Torso gains knowledge, it is saying something like, *Hmm*, *that’s interesting*, *let’s build on that*. It is the algorithmic version of reinforcement learning, or practicing. “A child needs to practice to be able to learn,” Oudeyer says. “What makes it practice? Its motivational system. Curiosity is one of the fundamental dimensions of motivational systems that push organisms to explore and to learn new things.”

When programmed this way, Torso first moved its left hand—a lot. Then it discovered the left joystick and moved it forward, backward, left and right. Eventually it made the connection between moving the joystick and moving Ergo, which moved the ball. Moving the ball changed the color of the lights from blue to yellow to pink. After 15 to 20 hours of exploration, Torso worked out how to move Ergo in every direction, how to move the ball and how to light up the arena. To the researchers’ surprise, the robot even worked out that the cup at the end of Ergo’s lamplike arm could cover the ball and effectively hide it, which Torso proceeded to do, looking an awful lot like a shell-game hustler working a crowd on the sidewalk.

Such experiments are evidence for a positive feedback loop between curiosity and learning. “Focus on learning activities that are neither too easy nor too difficult, the ones where you have maximum improvement in speed, which will progressively get you to more and more complicated and yet learnable activities,” Oudeyer says.

Torso’s progress closely mirrored the developmental trajectories children use as they learn about tools or language. As the brain continues to develop, so does the sophistication of its approach to curiosity. A 2024 study of more than 100 four-year-olds found that they relied on learning progress as well as novelty to explore during a touchscreen game. And Gruber has found that compared with younger children, adolescents are better able to process cognitive conflict (that is, uncertainty) and appraise incoming information in the higher-order areas of the prefrontal cortex.

As for adult humans, we hang out in a sweet spot, Kidd says. “We’re much more invested in watching more episodes of a show where we know the characters [and] understand something about the plot than starting something entirely new,” she says. Even in studies where participants get paid to be curious, their brains aren’t very curious about things that fall outside this satisfying mental place. But when they are deeply engaged, in what’s sometimes called a state of flow, learning progress is guiding them. It clearly feeds their curiosity.

In a 2021 experiment published in *Nature Communications*, Oudeyer and Gottlieb, who are frequent collaborators, and their colleagues created a set of four online games. Each game had families of monsters that varied in size, color, number of eyes, and so on. The goal? Discover the hidden rules that dictate which of eight foods each family of monsters likes to eat. The easiest game had a one-dimensional rule: tall family members like pizza, and short ones like broccoli. Two more games had progressively more complicated rules that were harder to pick up on: with two

dimensions, for instance, tall monsters with three eyes like pizza, and short monsters with two eyes like broccoli. The fourth game had no rule; it was entirely random and unlearnable.

The question was how the nearly 400 players would organize their exploration as they worked out the rules. How could they be both curious and efficient? Correct guesses are rewarding, and errors are instructive, but do people monitor how much they are learning and use that information to decide what to do next? In this case, yes, they did. Participants monitored both their percentage of correct responses and their improvement over time. “It becomes obvious that what we should value is learning,” Gottlieb says. In other words, high certainty alone is less useful than the transition between high and low uncertainty. Curiosity is what helps us make that shift.

But curiosity also shifts over time. Although conventional wisdom says people get less curious as they grow older, studies show that it’s more accurate to say curiosity adapts to what people know about the world. When you walk into the Louvre in Paris, are you more likely to swing through all the galleries, making sure to hit the most popular exhibits? Or do you prefer to lose yourself for an hour in one wing? Your choice most likely will depend on your age, Tübingen’s Murayama says. In an experiment conducted with almost 500 visitors to the London Science Museum who were aged 12 to 79, he found younger people took a broad approach and older people a narrower but deeper approach, viewing more facts on fewer topics in a citizen science exhibit. “Older adults have more knowledge, and knowledge is really a driver of curiosity.”

As scientists come to understand curiosity better, they may also better understand some mental health disorders in which its circuits may be disrupted. In depression, for example, curiosity is dampened, whereas in obsessive-compulsive disorder the desire to reduce uncertainty is overwhelming.

The research has more immediate implications in the classroom. It's well known that curiosity has a positive influence on learning outcomes and student enjoyment. Multiple efforts are underway to leverage the new findings to strengthen both things. In 2024 the French government began giving primary school students a peer-reviewed educational technology based on Oudeyer's work. The program generates personalized questions driven by what each child wants to learn. Compared with material that teachers created by hand, the AI-designed material led to more efficient learning and higher student motivation because they built on a child's own interests.

There may be useful ways to boost adult curiosity, too. Several researchers are working on programs based on learning progress that help older adults hone their attentional skills. But anyone can take advantage of the sweet spot, Kidd says. "Just even understanding that having some knowledge will make it easier to acquire more knowledge can be helpful," she says. It can get you to "sit and try to focus more on that first book that lets you break in" to a new subject.

And understanding that confidence and curiosity are related probably affected your level of curiosity about the nuggets of trivia I sprinkled through this story. Maybe you knew that the most popular exhibit at the Louvre is the *Mona Lisa* or guessed that the Beatles' most durable hit was *Hey Jude*. But I suspect you were very curious about those odd-shaped trees. Yes, there really are trees with square trunks—in Anton Valley in Panama.

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of *Friendship* (W. W. Norton, 2020).

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https://www.scientificamerican.com/article/how-the-science-of-curiosity-boosts-learning

Animals

- **Mystery of Deep-Ocean ‘Biotwang’ Sound Has Finally Been Solved**
  A strange sound dubbed “biotwang” was first heard bouncing around the Mariana Trench 10 years ago, and scientists have finally figured out where it comes from
- **Birds Are Goofy Runners—And Dinosaurs Might Have Been, Too**
  Looking silly when they run saves birds energy—and some dinosaurs may have done the same

Mystery of Deep-Ocean ‘Biotwang’ Sound Has Finally Been Solved

A strange sound dubbed “biotwang” was first heard bouncing around the Mariana Trench 10 years ago, and scientists have finally figured out where it comes from

By Melissa Hobson

The elusive Bryde’s whale produces an artificial-sounding “biotwang.”
Nature Picture Library/Alamy Stock Photo

Recorded by underwater microphones, the unexplained sound—a low, sonorous grunting followed by a squeaky, mechanical echo like a frog burping in space—first rumbled through a computer speaker about a decade ago. Baffled researchers called it the “biotwang.”

“You’ve got this low-frequency portion, like a moan,” says Lauren Harrell, a data scientist at Google’s AI for Social Good team, adding her own impression of a hearty groan. “Then you have the higher-frequency component that sounds, to me, like the original *Star Trek Enterprise* ship—the ‘bip boo, bip boo’ sound.”

Autonomous underwater gliders first encountered the odd noise in 2014 echoing near the miles-deep Mariana Trench in the western Pacific Ocean. Researchers couldn't identify its source, but they had a theory. "There are enough other *Star Wars*–sounding whale calls that they guessed it was made by a baleen whale," says Ann Allen, a research oceanographer at the U.S. National Oceanic and Atmospheric Administration. But, she adds, "anybody who's not familiar with whales would never think this was made by an animal."

Hear the biotwang for yourself:

Confirming which marine creature makes a particular unusual noise isn't easy: it requires a person on a boat to see and identify the source at exactly the same time the sound is heard. "It takes a lot of time, a lot of effort and a fair amount of luck," Allen says.

That's how Allen, Harrell and their colleagues finally solved the biotwang mystery, which they describe in *Frontiers in Marine Science*. While surveying whales off the Mariana Islands, an archipelago near the trench of the same name, noaa researchers saw an enigmatic baleen species called the Bryde's whale (*Balaenoptera edeni*) 10 times. These rarely observed whales have a vast range spanning much of the ocean, making them hard to study. On nine of the occasions when Bryde's whales turned up, the researchers also heard the biotwang. "Once, it's a coincidence," Allen says. "Twice is happenstance. Nine times, it's definitely a Bryde's whale."

After identifying the source, the scientists reviewed years' worth of audio data from underwater hydrophones to figure out where this specific whale sound had previously been heard. But according to Allen, noaa's growing database has more than 200,000 hours of such recordings. "It's so much data that it's simply impossible to analyze [manually]," says Olaf Meynecke, who studies baleen

whales as a research fellow at Griffith University in Australia and wasn't involved in the study.

> "We seem to be so detached from, or simply have no access to, this amazing acoustic underwater world. I think it's about time that we change that." —Olaf Meynecke *Griffith University*

When analyzing audio data for another project, Allen had been "flabbergasted" by the huge volumes of information to slog through. At one point, she says, her dad suggested, "Just get Google to do it for you." So Allen reached out to company staff, and, to her surprise, they agreed. Google provided AI tools that helped to speed up her analysis by transforming audio data into an image called a spectrogram and then training algorithms to look for certain frequencies using image recognition.

The new study lays out the evidence associating biotwangs with Bryde's whales in the western North Pacific. The data suggest that the animals the researchers studied are members of a distinct Bryde's whale population and showed where in the ocean they were found during different seasons and years—something that had previously been challenging to discern because scientists couldn't easily tell different populations of the elusive whales apart. In 2016, after a strong El Niño led to a shift in the location of the whales' food (largely krill, sardines and anchovies), there were lots of biotwangs—even in the northwestern Hawaiian Islands, an area these whales ventured into only under certain climate conditions. This correlation could mean that their movements are at least partially determined by their prey's distribution, which changes with environmental conditions.

Once scientists know where and when these whales travel, Harrell says, AI models could "connect those data to climate and environmental factors" and thus support protection efforts. As climate change worsens and El Niño and its cold-water counterpart,

La Niña, potentially undergo changes,“these whales will have to travel farther—and they may have to work a little harder to find food,” Allen says.

The data-processing technology isn’t perfect. “These algorithms can only search for a frequency they know,” Meynecke says. Baleen whale vocalizations change over time and between populations. But because the tools are open source, other scientists can use them to discover more about whale language. “We seem to be so detached from, or simply have no access to, this amazing acoustic underwater world,” he says. “I think it’s about time that we change that.”

[Audio credit: “A Complex Baleen Whale Call Recorded in the Mariana Trench Marine National Monument,” by Sharon L. Nieukirk et al., in *Journal of the Acoustical Society of America*, Vol. 140, No. 3; September 2016]

Melissa Hobson, doing business as The Ocean Writer Ltd., is a marine science and conservation writer based in Hastings, U.K. She has written about the ocean for outlets including *National Geographic*, *New Scientist*, the *Guardian* and the *Sunday Times*. Visit Melissa’s website at https://www.melissahobson.co.uk/ or follow her on LinkedIn.

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https://www.scientificamerican.com/article/mystery-of-deep-ocean-biotwang-sound-has-finally-been-solved

Here’s Why Birds Look So Goofy When They Run

Looking silly when they run saves birds energy—and some dinosaurs may have done the same

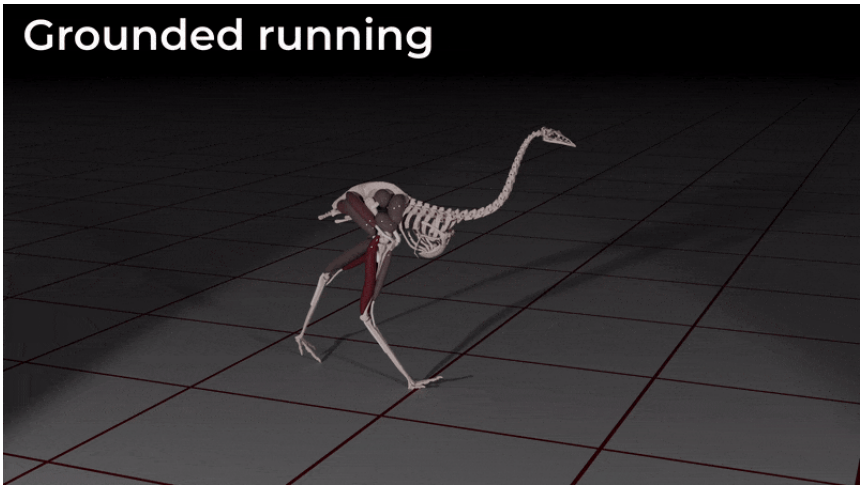
By Meghan Bartels

Ken Griffiths/Alamy Stock Photo

When humans want to move fast—barring speed-walking races—we pick up our feet. But when birds need to get somewhere quickly without flying, they tend to always keep one foot on the ground, leading to a strange-looking gait that scientists call “grounded running.”

“Most people won’t even probably realize that they’ve seen a bird use grounded running,” says Pasha van Bijlert, an evolutionary biomechanics graduate student at Utrecht University and Naturalis Biodiversity Center in the Netherlands. “Some of the times that you see a bird walking in a weird way, they’re actually not walking; they’re running—you can tell from the fact that they’re bouncing.”

Grounded running in birds has puzzled scientists because humans mimicking the behavior use quite a bit more energy to achieve a running pace than we do with our habitual rapid movement style, called aerial running. But research by van Bijlert and his colleagues in *Science Advances* finds that birds aren't foolish for using grounded running—even though they may look silly.



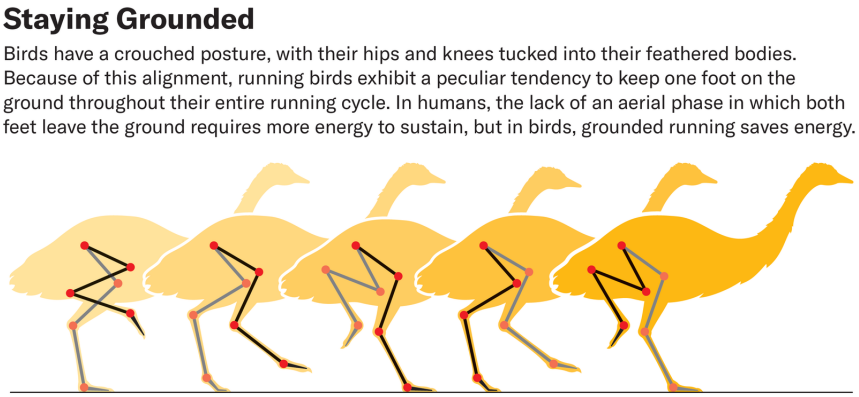
A virtual model of an emu used to study bird locomotion.
Pasha van Bijlert

For the study, the scientists used a computer model of a Common Emu (*Dromaius novaehollandiae*) to show that the bird's posture makes grounded running more efficient than aerial running at certain speeds. Researchers built the model because they expected two factors to influence the birds' movement: their highly elastic leg tendons and their crouched stance, with hips and knees tucked into their feathered body.

Neither factor lends itself to physical experiments. "You can't really change a bird's anatomy and see how that affects its running styles," van Bijlert says. "I can't train an emu to stand up straight." Hence the simulation approach, which allowed the researchers to adjust emus' leg anatomy and prevent the tendons from storing energy as they tested what gaits were most efficient for moving at certain speeds.

The simulation alone is impressive work, says Armita R. Manafzadeh, a biomechanist at Yale University, who was not

involved in the new research. “Physics-based simulations with locomotion has come such a long way,” she says. “When this kind of methodology first started out, there were so many simplifications being made and the algorithms were so simplistic that the outputs on the computer really didn’t look like a living animal at all.”



Brown Bird Design

The simulations showed two strategies for reducing energy expenditure during faster movement: either keeping legs relatively straight during the running cycle or keeping one foot on the ground as much as possible. Humans take the first route, but birds can’t—so they use grounded running instead. (Humans asked to run in a crouched position will instinctively switch to grounded running as well; give it a try if you’re interested.)

“If we think about bird locomotion through a human lens, then [grounded running] seems like a really weird and kind of dumb thing to do because it seems really energetically costly,” Manafzadeh says. “It’s actually a pretty smart thing to do when you have the anatomy of a bird.”

Van Bijlert says the research may also inform scientists’ understanding of birds’ long-lost ancestors: dinosaurs. He suspects that especially dinosaurs that are closer relatives of birds, such as the petite velociraptors, might have chased down their prey like nightmare agents of the Ministry of Silly Walks. But more

simulations are needed to determine whether bipedal dinosaurs, including the fearsome *Tyrannosaurus rex*, also might have practiced grounded running, Manafzadeh says. She adds that she hopes the new research reminds scientists to be curious about how other species experience life on Earth. “If we try to interpret the diversity of animal locomotion through a human-centric lens,” she says, “we’re going to miss out on lots of really cool and equally viable ways of moving around the world.”

A version of this article entitled “Goofy Running” was adapted for inclusion in the December 2024 issue of Scientific American. *This text reflects that version, with the addition of some material that was abridged for print.*

Meghan Bartels is a science journalist based in New York City. She joined *Scientific American* in 2023 and is now a senior news reporter there. Previously, she spent more than four years as a writer and editor at Space.com, as well as nearly a year as a science reporter at *Newsweek*, where she focused on space and Earth science. Her writing has also appeared in *Audubon*, *Nautilus*, *Astronomy* and *Smithsonian*, among other publications. She attended Georgetown University and earned a master’s degree in journalism at New York University’s Science, Health and Environmental Reporting Program.

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https://www.scientificamerican.com/article/birds-are-goofy-runners-and-dinosaurs-might-have-been-too

Arts

- **Poem: ‘The First Bite’**
  Science in meter and verse

Poem: ‘The First Bite’

Science in meter and verse

By Gillian Neimark

Masha Foya

Edited by Dava Sobel

It’s been a billion years since blue green algae sequined
lakes and—like a python swallowing a pig—a protist ate one.
I see that pale hunter orbiting gloomy coves
tail whipping mellow waters, then guzzling a necklace
of cyanobacteria—
awareness tuned only
to that earthen, exquisite taste
not knowing that algae eat sunlight
and pluck electric arcs from water
exhaling long tongues of odorless oxygen
that suffocate anaerobes all over this earth.
It waits for its meal to die.
But one green bloom burns on
inside, spits flame, survives.

Night ebbs, day breaks
And now the protist feels pregnant
with a tiny sun god.
Together they tumble over the ocean
drunk with the liquors of light
each trying to cough up the other
to be alone again and just float sated.
Hundreds of millions of years of wrestling
until the captive, now a chloroplast
packed with pigments,
is fully formed
and engineers a biosphere:
A garden in the east, just shy of Eden
an apple, another reckless bite, exile
across the jeweled earth

Gillian Neimark is a science journalist who also writes poetry and fiction. She launched her children's imprint, Blue Jasper Editions, in 2023 with *Forest Joy and Nature Explorers*.

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https://www.scientificamerican.com/article/poem-the-first-bite

Astronomy

- **Epic Gravity Lens Lines Up Seven-Galaxy View**
  A galaxy cluster bends light from seven background galaxies around it, letting astronomers peer into space and time

Epic Gravity Lens Lines Up Seven-Galaxy View

A galaxy cluster bends light from seven background galaxies around it, letting astronomers peer into space and time

By Tom Metcalfe

The Carousel Lens (*center*) bends the light of seven background galaxies.
DESI Legacy Imaging Surveys/LBNL/DOE & KPNO/CTIO/NOIRLab/NSF/AURA

An almost impossible alignment of galaxies that forms a giant magnifying lens could give astronomers an unprecedented deep view of the universe.

The Carousel Lens—named for its concentric circular patterns, like the reflections in a fun-house mirror—incorporates a cluster of galaxies about five billion light-years from Earth whose gravity is so intense that it magnifies the light of seven galaxies behind it, between 7.6 billion and 12 billion light-years away. This

phenomenon, called gravitational lensing, occurs only when galaxies line up precisely from our perspective.

As seen from Earth, the massive gravitational lens creates multiple images of six of the seven background galaxies, each of whose light arrives to us by a slightly different path. If a “transient” event, such as a supernova, occurs in any one of those galaxies, astronomers here will have up to four views of it at slightly different times.

“If we had a supernova exploding, we would have as many images of the supernova as we have images of the source,” says cosmologist Nathalie Palanque-Delabrouille, director of Lawrence Berkeley National Laboratory’s physics division, which took part in the lens’s discovery. “That would provide just amazing information.”

Careful observations of both the foreground cluster—which may itself be made up of hundreds of galaxies—and the background galaxies can help astronomers better understand how dark matter and dark energy behave, as well as more about the universe’s ancient past. The farthest background galaxy is so distant that it must have developed in an early phase of the universe, which most scientists think is around 13.7 billion years old.

Researchers used artificial-intelligence systems to find potential gravitational lenses by sorting through millions of galactic survey images. They then arranged for the Hubble Space Telescope to image the location, revealing the Carousel Lens at high resolution.

William Sheu, an astrophysics graduate student at the University of California, Los Angeles, and lead author of a new study about the discovery in the *Astrophysical Journal*, says analysis of the Hubble images could reveal even more background galaxies that have been magnified by the gravity of the same foreground galaxy cluster.

Gravitational lensing follows Einstein’s 1916 general theory of relativity, which predicted that gravity would bend light; the first such lens was found in 1979. Boston University astronomer Tereasa Brainerd, who was not involved in the discovery, says the lenses have become powerful tools for studying many of the open questions of the cosmos.

“This is an especially remarkable object,” Brainerd says. “It’s the result of outstanding good luck that the lens and the seven background galaxies are almost perfectly lined up along our line of sight.”

Tom Metcalfe is a freelance journalist who is based in London. Metcalfe writes mainly about science, space, archaeology, Earth and the oceans. He has also written for Live Science, the BBC, NBC News, *National Geographic*, *Air & Space* and many others.

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https://www.scientificamerican.com/article/epic-gravity-lens-lines-up-seven-galaxy-view

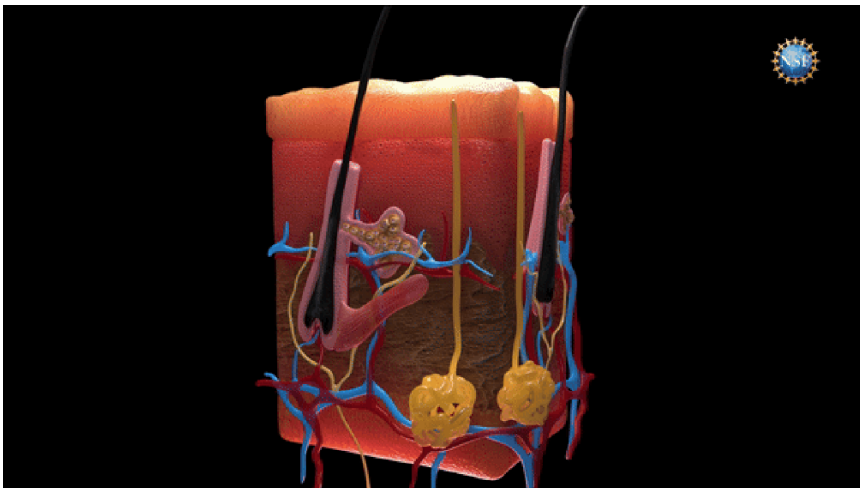
Basic Chemistry

- **Scientists Make Living Mice’s Skin Transparent with Simple Food Dye**
  New research harnessed the highly absorbent dye tartrazine, used as the common food coloring Yellow No. 5, to turn tissues in living mice clear—temporarily revealing organs and vessels inside the animals

Scientists Make Living Mice’s Skin Transparent with Simple Food Dye

New research harnessed the highly absorbent dye tartrazine, used as the common food coloring Yellow No. 5, to turn tissues in living mice clear—temporarily revealing organs and vessels inside the animals

By Lauren J. Young



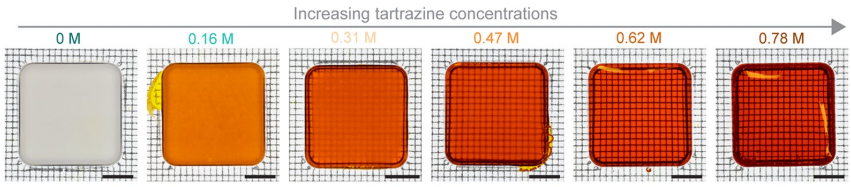
Skin normally scatters light, a phenomenon represented by white lines in the beginning of this clip. When the food, drug and cosmetic dye Yellow No. 5 is absorbed by skin, however, it reduces scattering and allows light to penetrate deeper, making the tissue transparent. (This technique has not been tested on humans. Dyes may be harmful. Always exercise caution with dyes and do not consume them directly, apply them to people or animals or otherwise misuse them.)
Keyi “Onyx” Li/U.S. National Science Foundation

In mere minutes, smearing mice with a common food dye can make their skin almost as transparent as glass.

For a study in *Science*, researchers spread a solution of tartrazine, a common coloring for foods, drugs and cosmetics, onto living mice to turn a portion of their tissues clear—creating a temporary window that revealed their blood vessels, muscles and internal organs. The procedure has not yet been tested in humans, but it may someday offer a way to view and monitor injuries or diseases

without the need for specialized imaging equipment or invasive surgery.

Skin, like most mammalian tissue, is highly opaque because its mix of water and densely packed lipids, proteins, and other essential molecules scatters light in all directions. “The concept is similar to bubbled water,” says the study’s lead author, Zihao Ou, a physicist at the University of Texas at Dallas. Water and air are transparent separately, but mixed together they form cloudy microbubbles, Ou adds. Think of a rushing river or a crashing wave. The clarity changes because water and air molecules have different refractive indexes—the amount of light bent while passing through an object or substance. The fats and proteins in rodent or human skin typically have higher refractive indexes than the water, creating a contrast that you can’t see through.

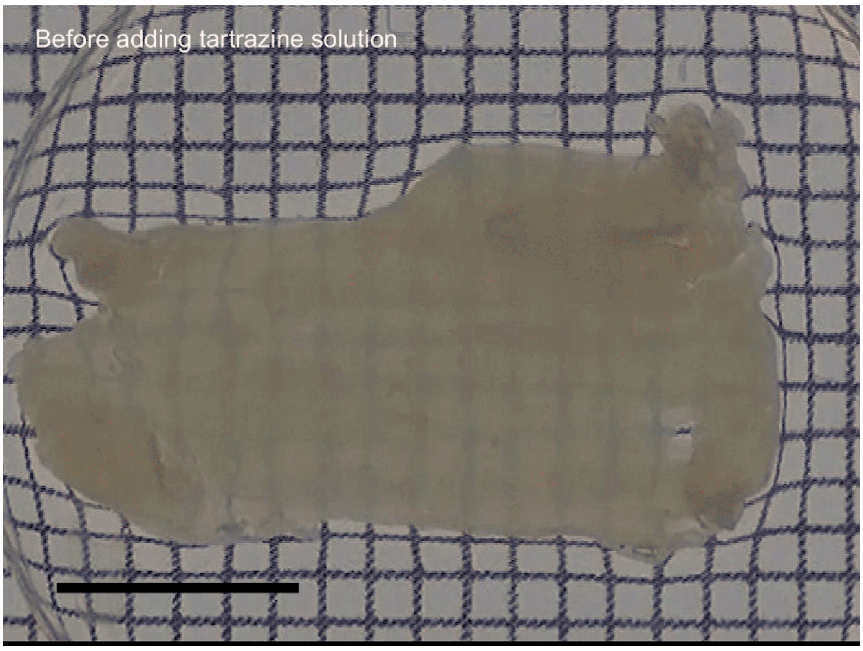


Hydrogel samples that mimic human tissues' optical distribution showing increasing tartrazine concentrations.
Guosong Hong/Stanford University

In the new study, Ou and his colleagues looked for light-absorbing molecules that could make the various refractive indexes within the layers of skin more similar, essentially reducing the amount of scattered light.

The team investigated 21 different synthetic dyes before landing on the highly absorbent tartrazine, more commonly known as Yellow No. 5. The zingy lemon-yellow coloring is approved by the U.S. Food and Drug Administration for use in limited quantities and is commonly found in chips, sodas, candies, butter, vitamins and drug tablets. Tartrazine in solution increases the refractive indexes for red and yellow light, and it absorbs most light at wavelengths in the near-ultraviolet and blue spectra. When the dye is applied to mouse

skin, these combined effects reduce the scattering of light that gives the tissue its usual opacity.

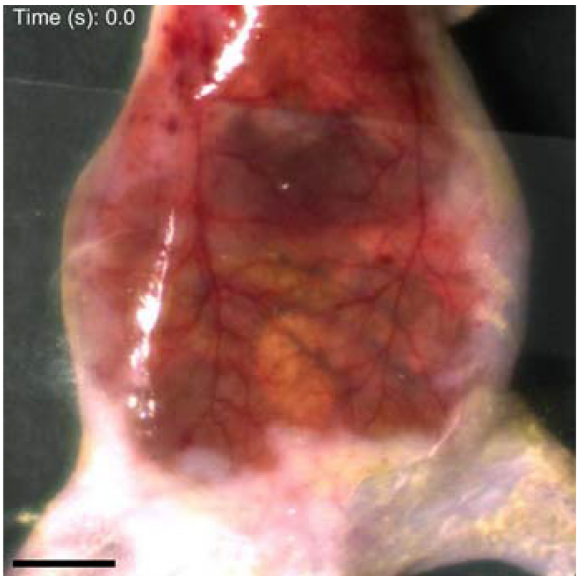


Animated stills from a real-time imaging video show the dynamic process of a chicken breast tissue that transitions from opacity to transparency after immersion in a 0.6-molar solution of tartrazine (Yellow No. 5). The progression begins before the tartrazine solution's application and then shows a range of 0.2 to 60 seconds after. The scale bar represents 5 mm.
Guosong Hong/Stanford University

"The higher the absorption, the more efficient the molecule is," Ou explains. The FDA's limits on chemicals and additives have caused the food industry to look "for chemicals that are extremely efficient," even in small amounts, he says.

The researchers tested various concentrations of the dye on hydrogel samples that mimic human tissues' optical distribution and on slices of raw chicken breast. They then gently massaged the dye into the skin of anesthetized mice until it was absorbed. In less than 10 minutes the team began to see internal features underneath the top layers of tissue. Under visible light, tartrazine rubbed onto the animals' abdomens revealed their digestive tracts in action; spreading it onto a leg exposed muscles. Using high-resolution laser imaging, the scientists also saw details of nerves in the gastric system, small units in muscles called sarcomeres and, when the dye was applied to the scalp, even structures of the brain's blood

vessels. If the tartrazine wasn’t washed off, the effect lasted about 10 to 20 minutes before the skin returned to its original state.



A still image of a real-time video demonstrates the optical transparency in a mouse abdomen, enabling the visualization of the animal’s abdominal organs. The scale bar represents 5 mm. (The red hue is from the dye.)
“Achieving Optical Transparency in Live Animals with Absorbing Molecules,” by Zihao Ou et al., in *Science*, Vol. 385. Published online September 5, 2024

Related research has focused on using already transparent materials that absorb into the skin, including glycerol and fructose solution. Those molecules can also reduce light scattering but are “not as efficient [as tartrazine] because they are not ‘colored’ enough,” says study co-author Guosong Hong, a materials science engineer at Stanford University. Other approaches that remove essential molecules in tissues rather than adding new ones produce similar effects but can be done only in nonliving animals or biopsied tissue.

Although it is far from human trials, the new process may someday have helpful medical applications. Hong proposes that related techniques could potentially assist in early skin-cancer detection and make laser-based tattoo removal more straightforward. They could also make veins more visible for drawing blood or administering fluids via a needle, he says—especially in older people with veins that are difficult to locate.

The strategy may also be a more compelling option than the use of imaging technologies such as magnetic resonance imaging (MRI) and ultrasound for some experiments, including live-animal studies. So says Oregon Health and Science University dermatologist Rajan Kulkarni, who worked on a 2014 study in which researchers replaced the lipids in whole organs and animals with clear hydrogel to see inside. “It would give you the ability to visualize at light-microscopy resolution, whereas other methods of MRI, CT [computed tomography] and ultrasound are not as finely resolved,” Kulkarni adds. “In terms of a proof of concept, it’s really fantastic. Clinically, it remains to be seen.”

The study authors didn’t observe any adverse side effects in the mice after the tartrazine was removed, although Ou says it could cause temporary damage to skin tissue. He adds that this dye and similar, more efficient molecules must be further tested for human safety. Tartrazine can cause allergic reactions. And although the coloring is FDA-approved, the agency has strict limits on amounts used in products. In the study, the mice were able to tolerate the highest concentration used, 0.6 molar, during the short testing periods. But “human skin is about 10 times thicker than [that of] mice, which means that the time required for diffusion is probably much greater—a few minutes for mice is going to be hundreds of minutes for humans,” Ou says. “We hope that with our initial work, there will be more follow-up proposing new molecules that are going to be more efficient and safer for human application.”

Lauren J. Young is an associate editor for health and medicine at *Scientific American*. She has edited and written stories that tackle a wide range of subjects, including the COVID pandemic, emerging diseases, evolutionary biology and health inequities. Young has nearly a decade of newsroom and science journalism experience. Before joining *Scientific American* in 2023, she was an associate editor at *Popular Science* and a digital producer at public radio’s *Science Friday*. She has appeared as a guest on radio shows, podcasts and stage events. Young has also spoken on panels for the Asian American Journalists Association, American Library Association, NOVA Science Studio and the New York Botanical Garden. Her work has appeared in *Scholastic MATH*, *School Library Journal*, *IEEE Spectrum*, Atlas Obscura and *Smithsonian Magazine*. Young studied biology at California Polytechnic State University, San Luis Obispo, before pursuing a master’s at New York University’s Science, Health & Environmental Reporting Program.

https://www.scientificamerican.com/article/scientists-make-living-mices-skin-transparent-with-simple-food-dye

Behavior

- **These Bird Nests Show Signs of an Architectural ‘Culture’**
  Culture may play a role in how birds build collectively in the Kalahari Desert

These Bird Nests Show Signs of an Architectural ‘Culture’

Culture may play a role in how birds build collectively in the Kalahari Desert

By Gennaro Tomma

White-browed Sparrow-Weaver nests and roosts.
Wolfgang Kaehler/Alamy Stock Photo

From long and winding migration flights to intricate songs and clever tool use, many bird behaviors are known to be transmitted socially and persist across generations—what scientists define as animal “culture.” Now a study suggests culture might play a role in avian architecture, too.

Researchers analyzed more than 400 structures built by 43 different groups of White-browed Sparrow-Weavers in the Kalahari Desert in southern Africa. These birds live communally, and the entire cohort works together to build a nest and multiple roosts from grass. The group’s dominant female then lays eggs in the nest, which has a long, tubelike entrance. Individual birds slumber

nearby in the U-shaped roosts, which have both an entrance and an exit.

The scientists found that different gatherings of birds, even those living only a few meters from one another, built very different tube structures. The biggest difference was in “how short or long the structures are,” says study lead author Maria C. Tello-Ramos, a cognitive ecologist at the University of Hull in England. Tube width also varied between groups. Furthermore, each group maintained the same architectural style over time—and when outsiders joined, they adapted to this style.

To examine why the groups built differently, the team analyzed factors that can determine a nest’s size and shape for a given bird species: weather conditions, tree height, individuals’ body size and genetic relatedness. (If closely related birds build similar structures, for instance, one might assume a genetic element.) Yet none of these factors seemed to play a relevant role in shaping how the Kalahari sparrows built their nests, the researchers report in *Science*.

“Then we say, ‘Okay, so what is left?’” Tello-Ramos explains. She and her colleagues proposed that cultural transmission might be key to nest building. “In our paper, we haven’t gotten there yet with experiments, but we have very good clues that that might be it,” she says.

“These are important questions that are understudied,” says Christina Riehl, an evolutionary biologist at Princeton University. She’s not convinced the study’s data are enough to fully rule out genetic influence. “They can’t actually look at the effect of, say, genetic differences, because they don’t have really good genetic information on all the individuals in these groups,” she says. “I think there’s a lot left to be done, and I think this paper will inspire future research in a really good way.”

Gennaro Tomma is a freelance science journalist. Follow him on X (formerly Twitter) @gennaro_tomma

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https://www.scientificamerican.com/article/these-bird-nests-show-signs-of-an-architectural-culture

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Book Reviews

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  Oak trees have genetic flexibility that allows them to solve ecological problems. But even they will need our help to survive climate change
- **Book Review: An Expansive New Translation of a Haruki Murakami Classic**
  In End of the World and Hard-Boiled Wonderland, the title is flipped, but cyberpunk pleasures remain

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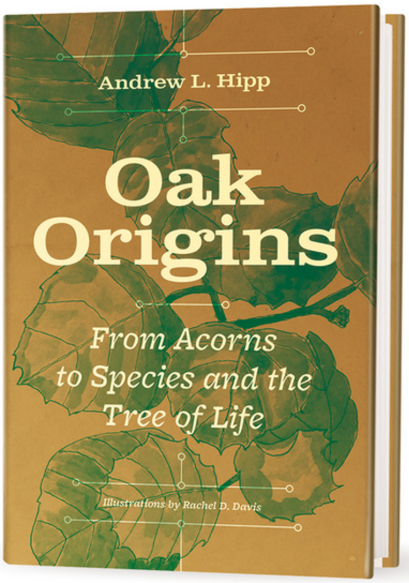
Book Review: How Oak Trees Warn Us about the Limits of Adapting to Climate Change

Oak trees have genetic flexibility that allows them to solve ecological problems. But even they will need our help to survive climate change

By Dana Dunham



Oak Origins: From Acorns to Species and the Tree of Life
by Andrew L. Hipp. Illustrated by Rachel D. Davis.
University of Chicago Press, 2024 ($35)

In many parts of the world, if you take a walk in the woods, you are likely to encounter an oak tree. With 425 species worldwide, their collective abundance may lead one to believe these trees are somewhat unremarkable—a fixture we take for granted. But Andrew L. Hipp, a botanist and research director at the Morton Arboretum in Illinois, reveals that oaks are a dynamic and essential part of the forest.

Oaks have been on naturalists' radar for some time. In *On the Origin of Species*, Charles Darwin highlighted European oaks as an example of species variation. The advent of DNA technology, though, offered a sharp new lens on what Hipp calls one of oaks' "superpowers": their ability to breed with other oak species while still maintaining some of their original genetic qualities.

After oaks first appeared—56 million years ago—they expanded their range, adapting to diverse environments through natural selection. They began to diverge into distinct species at least 45 million years ago. Yet a California scrub white oak can reproduce with an Engelmann oak. Hipp contrasts this knack with humans' inability to procreate with chimpanzees, even though our evolutionary split was far more recent.

Oaks' capacity to hybridize without merging brings out fascinating nuances in the so-called Tree of Life. This visual metaphor separates species into distinct branches. But look closely at the oaks' section, Hipp says, and "you will find strands of gossamer trailing between the branches, genes moving between lineages."

He gently guides readers through these complexities, laying the groundwork for lucid explanations about the trees' evolution and biology. In one analogy, he compares oaks' prodigious potential for genetic recombination with the extensive postproduction tape-splicing that created Miles Davis's song "Pharoah's Dance."

Oaks are primed with genetic flexibility that allows them to solve ecological problems. But the current rise in global temperatures far outpaces its fastest previous climb, posing a problem even these "protean" adapters cannot solve without human intervention. Hipp's work shows that conserving oak species will preserve invaluable nodes in our genetic web.

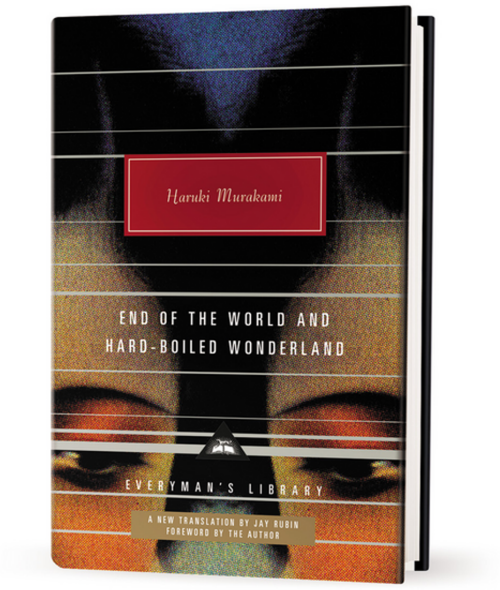
Dana Dunham is a writer and editor based in Chicago.

https://www.scientificamerican.com/article/book-review-how-oak-trees-warn-us-about-the-limits-of-adapting-to-climate-change

Book Review: An Expansive New Translation of a Haruki Murakami Classic

In End of the World and Hard-Boiled Wonderland, the title is flipped, but cyberpunk pleasures remain

By Matt Bell



End of the World and Hard-Boiled Wonderland: A New Translation
by Haruki Murakami. Translated by Jay Rubin.
Everyman's Library, 2024 ($30)

First translated from the Japanese in 1991 by Alfred Birnbaum, Haruki Murakami's award-winning 1985 novel is a tale of two worlds. One is a clever pastiche of cyberpunk and detective tropes where rival syndicates secretly vie for dominance; the other is a surreal fantasy where "old dreams" are read from the skulls of mysterious one-horned creatures. In a new translation, longtime Murakami translator Jay Rubin restores, at the author's request, roughly 100 pages of previously excised material.

This new material noticeably lengthens the novel but doesn't significantly increase its pleasures—pleasures one reaches only by wading through too much juvenile erotica and misogyny, including a novel-length depiction of a 17-year-old character termed the "fat girl," whose body composition and sexual possibility are central preoccupations. Still, Murakami fans will enjoy the chance to read the novel in a form closer to the author's original intent and make comparisons between the familiar Birnbaum and Rubin's newer effort. Rubin nonetheless keeps many of Birnbaum's choices intact, including the names of the secretive Calcutecs and their criminal rivals, the Semiotics.

Rubin has chosen to revert the title's order in English to that of the original Japanese, giving primacy to the better of Murakami's settings, the mysterious walled town called End of the World. Here the translator's decisions matter considerably, with Rubin choosing "heart" (instead of Birnbaum's "mind") for the apparently difficult-to-translate *kokoro*, which Rubin explains actually "straddles the full territory" of mind, heart and morality.

Although the relative limitations of English occasionally risk reduced complexity, the resulting language often still moves, as when one narrator pledges his emergent dream-reading skills to help his romantic interest recover her lost heart, her missing *kokoro*: "The heart is not like raindrops," he promises. "It doesn't fall from the sky, indistinguishable from other things ... I'll find it for sure. Anything and everything is here, and anything and everything is not here." As it is when Murakami's two storylines finally come together, it's where mind, heart and morality converge that *End of the World and Hard-Boiled Wonderland* is at its best.

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https://www.scientificamerican.com/article/book-review-an-expansive-new-translation-of-a-haruki-murakami-classic

Books

- **The Universe in 100 Colors Provides a Stunning Tour through Science**
  A science photo book probes the colors we can see—and even “forbidden” colors we can’t

The Universe in 100 Colors Provides a Stunning Tour through Science

A science photo book probes the colors we can see—and even "forbidden" colors we can't

By Sarah Lewin Frasier

A simulation of Vantablack on half of a cicada.
Tyler Thrasher; From *The Universe in 100 Colors*, by Tyler Thrasher and Terry Mudge (Sasquatch Books, 2024)

Humanity is lucky to reside on a planet circling a star with plentiful radiation, illuminating the world around us in reflected wavelengths of light. These wavelengths—a portion of which we experience as color—have long warned us of danger and enticed us to closely inspect the objects we encounter.

In a new photo book, *The Universe in 100 Colors*, science enthusiasts Tyler Thrasher and Terry Mudge take readers on a tour of color across scientific disciplines—from things most people will never see in day-to-day life (such as the black color of the brain's dopamine precursors, a lack of which can lead to Parkinson's disease) to ubiquitous backdrops (for instance, the green porcelain

that gives chalkboards their color). Some are fanciful: the drab color routinely used to paint rental apartments is called “landlord white,” for example. Still others are profound—such as the peachy orange that would have been the universe’s first visible color if humans had been around to see it.

“It’s a story of light and all the creative paths that it can take in its journey to your eyeball,” says Mudge, who curates a science subscription box called Matter. And then there are the paths it *can’t* take: one section of the book details views our visual systems can’t naturally perceive, including the “forbidden” colors you’d get by processing red and green wavelengths simultaneously.

Above you can see a simulation of Vantablack, a paint containing tiny carbon nanotubes that squirrel away 99.6 percent of the light that touches them, removing details of shape and shadow and rendering 3D objects into indistinct blobs. The paint was invented by a materials scientist but exclusively licensed to a particular artist, so it’s “forbidden” in a much more prosaic way—one reason the book’s authors had to digitally edit the cicada pictured here to demonstrate the effect themselves.

In art and science, “the goal of both is to make observations about the world around us and communicate something,” says Thrasher, who describes himself as a “mad scientist artist.” And “when you combine the two, when you start to bring creative expression to science, I think you get closer to what a lot of people call alchemy.”

Sarah Lewin Frasier is *Scientific American*'s assistant news editor. She plans, assigns and edits the Advances section of the monthly magazine, as well as editing online news. Before joining *Scientific American* in 2019, she chronicled humanity's journey to the stars as associate editor at Space.com. (And even earlier, she was a print intern at *Scientific American*.) Frasier holds an A.B. in mathematics from Brown University and an M.A. in journalism from New York University's Science, Health and Environmental Reporting Program. She enjoys musical theater and mathematical paper craft.

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https://www.scientificamerican.com/article/the-universe-in-100-colors-provides-a-stunning-tour-through-science

Culture

- **Curiosity, Horses and Hypochondria**
  Discovering weird new shapes, turning oil rigs into reefs and making the ocean absorb more greenhouse gases
- **Contributors to Scientific American's December 2024 Issue**
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Curiosity, Horses and Hypochondria

Discovering weird new shapes, turning oil rigs into reefs and making the ocean absorb more greenhouse gases

By Laura Helmuth

Scientific American, December 2024

Did you grow up around horses? If not, your parents or grandparents or greats probably did. Until very recently, horses were our main means of transportation and labor. Humans have been hunting horses since around 300,000 years ago, but when did our relationship with them change from predator-prey to partner? New archaeological and genetic discoveries have changed the understanding of horse domestication. Rather than a gradual process that began around 6,000 years ago, domestication seems to have happened quickly, around 4,000 years ago, and it abruptly changed trade routes, technology and conquest. Archaeozoologist William T. Taylor shares his own research and pulls together evidence from burial sites, bits, genes and human history to show how horses made the modern world.

Don’t you love it when mathematicians figure out a problem and then realize nature beat them to it? In a fun and beautifully illustrated story, science writer Elise Cutts shows how three-dimensional shapes with minimal corners can fit together to fill a space. It’s another new insight from the field of tessellation, which has been on a tear recently. (You may remember our story in the January 2024 issue about newfound Einstein tiles, shapes that can fit together infinitely without repeating a pattern.) The iridescent wash on our illustrations may remind you of nautilus shells, which contain the newly defined shapes.

The ocean has absorbed about 25 percent of the carbon dioxide released by fossil-fuel burning since the industrial revolution began. This has slowed the pace of global warming—giving us enough time to fix it, we hope. Scientists have speculated for decades that it could be possible to increase the rate of absorption, and now marine carbon dioxide removal efforts are beginning at scale. Oceanographer Jaime B. Palter describes strategies being tested or implemented now to absorb more of the CO_2 in the ocean so it can pull more CO_2 from our atmosphere, with helpful, elegant graphics.

Hypochondria is a serious health condition that is starting to get more respectful, insightful and effective treatments. The term can refer to excessive fears about getting an illness or anxiety that some symptom is a sign of a catastrophic health condition. People affected by a new type of hypochondria called cyberchondria spend inordinate amounts of time studying medical conditions online or visiting multiple doctors. Like other anxiety disorders, hypochondria can be disruptive and tormenting. It can frustrate physicians who can’t find a “real” condition to diagnose and treat. Health reporter Joanne Silberner covers the latest findings on how to diagnose and treat hypochondria, including advice for people who want to help someone with the condition.

Offshore oil rigs have become havens for fish, shrimp, mussels, anemones, and more, serving as artificial reefs in otherwise open water. In the Gulf of Mexico, they've allowed red snapper and other species to expand their ranges and populations. When it's time to decommission an oil rig, the platform and upper part of its support structure can be removed, leaving the bottom part to the fishes. California now faces a difficult decision over whether to "rig-to-reef" some of its aging offshore rigs. Freelance writer Asher Radziner explains the stakes, the science and the controversy.

Curiosity has been challenging to study because it's hard to define exactly what it is. It's a desire to gain knowledge and reduce uncertainty, sure, but it's also something delicious and stimulating and fun. I suspect all of you would score high on any curiosity scale—learning about the world through science is one of the best ways to satisfy curiosity ... and encourage even more of it. *Scientific American* Science of Health columnist Lydia Denworth explores how curiosity influences memory and learning, what brain states underlie it, and how to help young people develop it.

Laura Helmuth was formerly editor in chief of *Scientific American*. She previously worked as an editor for the *Washington Post*, *National Geographic*, *Slate*, *Smithsonian* and *Science*. She is a former president of the National Association of Science Writers. She is currently a member of the National Academies of Sciences, Engineering, and Medicine's standing committee on advancing science communication and an advisory board member for SciLine and The Transmitter. She has a Ph.D. in cognitive neuroscience from the University of California, Berkeley. She recently won a Friend of Darwin Award from the National Center for Science Education. Follow her on Bluesky @laurahelmuth.bsky.social

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https://www.scientificamerican.com/article/curiosity-horses-and-hypochondria

Contributors to *Scientific American*'s December 2024 Issue

Writers, artists, photographers and researchers share the stories behind the stories

By Allison Parshall

Thomas Fuchs.
Thomas Fuchs

Thomas Fuchs

Advances

Illustrator Thomas Fuchs (*above*) says the weirder the assignment, the better. For more than a decade his illustrations for *Scientific American* have depicted strange scientific discoveries that can't be captured in photographs. This month he was challenged to come up with visuals for quantum entanglement, fungal robots and seeing

with sounds. Advances, the magazine's news section, "is so un-illustratable, and I love it for that reason," he says. "If there's no image in your head, it frees you up a lot, and you can go completely wild." Also see the drawing Fuchs did for our Science Agenda about book bans.

Fuchs has long been artistically inclined. "I was always the guy in school who would paint the AC/DC logo on jean jackets—I was like, I can draw a straight line," he jokes. He started art school for graphic design but soon realized he could focus on illustration instead. "Straight lines look good and all, but every once in a while [you can] put a curve in it." For Fuchs, illustration is about looking deeper into the science behind the story and choosing imagery that "opens up another question" beyond what is in the article itself.

> "The way we think about our ancient relationships to horses is very much the on-the-ground reality for folks today." — William T. Taylor, archaeozoologist, author

William T. Taylor
When Horse Became Steed

Growing up in Montana, William T. Taylor lived in a house that was "adorned with every trapping of cowboy culture you could imagine," he says. "On a fancy occasion, you'd put on your cowboy boots, your bolo and your hat." His grandfather was a rancher, but his own father was a lawyer, so they didn't have any animals. Then, after graduating from college, Taylor spent a summer doing archaeology research in Mongolia, another place with "very vibrant horse culture." While helping to excavate a 2,500-year-old horse burial, "I had so many questions about the interactions between people and horses that I couldn't really get an answer to."

Taylor ultimately became an archaeozoologist and recently published a book called *Hoof Beats* (University of California Press,

2024). In this issue, he tells the story of horses' domestication and spread across the ancient world. These findings inform our understanding of both the past and the present, shaping conservation strategies for the planet's last wild horse species, native to Central Asia, and supporting Indigenous peoples' long histories with horses on America's Great Plains. "The way we think about our ancient relationships to horses," Taylor says, "is very much the on-the-ground reality for folks today."

Violet Frances
Tessellation Revelation

As an assistant art director at *Scientific American* in the 1990s, Violet Frances became enchanted by older issues from the 1950s and 1960s. "The design was so clear, so laser-focused," she says. In what was an era of busy, 3D illustrations, she became fixated on simplicity. Her favorite illustration she produced was a two-page spread for a 1998 story about fundamental particles called gluons: a single, eye-catching Feynman diagram. These pared-down graphics "look kind of like scientific hieroglyphics," she says. "I was struck by how beautiful they are."

Today Frances still aims to find the simplest way to represent abstract scientific truths. For this issue's feature on a class of new shapes by science writer Elise Cutts, "I tried approaching the illustrations to just let the geometry sing," she says. Frances is also a fine artist, and her multimedia work often focuses on the human form. Since she came out as a trans woman five years ago, her art has completely transformed. "Along with the disorienting joy of that time, I realized that so much of my fine art was me trying to make a golem of myself," she says. After that, "I became way more interested in just the mess of existence." In 2023 she had her first solo art exhibition since coming out as trans. "For me, life is an experiment," Frances says. "That's how I want to live it."

Allison Parshall is an associate news editor at *Scientific American* who often covers biology, health, technology and physics. She edits the magazine's Contributors column and weekly online Science

Quizzes. As a multimedia journalist, Parshall contributes to *Scientific American*'s podcast *Science Quickly*. Her work includes a three-part miniseries on music-making artificial intelligence. Her work has also appeared in *Quanta Magazine* and Inverse. Parshall graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

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https://www.scientificamerican.com/article/contributors-to-scientific-americans-december-2024-issue

Readers Respond to the July/August 2024 Issue

Letters to the editors for the July/August 2024 issue of Scientific American

By Aaron Shattuck

Scientific American, July/August 2024

CURBING HUNGER PANGS

I enjoyed “Turning Down the Food Noise” [The New Science of Diet, Health and Appetite], Lauren J. Young’s article on the influence of satiety pathways on food intake and how glucagonlike peptide 1 (GLP-1) receptor agonists such as Wegovy can intervene successfully. In 2002 I took part in a phase 3 trial of Axokine, a drug candidate from Regeneron that also acted to suppress the desire to overeat. Axokine was never approved by the U.S. Food and Drug Administration because it failed to meet the trial’s endpoint for weight loss across all the participants.

It had a dramatic effect on me when I was in the active arm of the trial, however: I lost about 90 pounds within around nine months. For whatever reason, I was a superresponder. Hence, I have followed the development of other appetite blockers with great interest, although I have not found it necessary to use them. Satiety drugs truly can be life changers.

JOHN P. MOORE *WEILL CORNELL MEDICINE AND* SCIENTIFIC AMERICAN*'S BOARD OF ADVISERS*

I recognized the sensations people reported in Young's article—not from GLP-1 drugs but from my gastric bypass surgery 19 years ago. I was first aware of a change at Thanksgiving. I had a small portion, then noticed everyone at the table was going for seconds and thirds. I was surprised that I had no desire to do that. I went on to lose almost 200 pounds, and I've kept it off without feeling I needed to use my willpower. Have the researchers in the article investigated possible GLP-1 changes in my cohort?

ALAIN MORIN *VIA E-MAIL*

> "Thank you for writing about ticker-tape synesthesia and giving me a name for my mental closed-captioning!" — Schuyler V., *Kentucky*

In discussing the search for longer-lasting structures of GLP-1, Young says that success was found in the saliva of the Gila monster. I am certain that saliva was not tested because someone said, "Well, let's test the Gila monster; we've tested everything else." Could you kindly explain how in heaven or through what scientific method this finding was made?

STEPHEN M. ZELMAN *NEW YORK CITY*

YOUNG REPLIES: *Morin's observation came up during my interview with Giles Yeo of the University of Cambridge. Yeo*

explained that gastric bypass makes the stomach smaller and the gut shorter in length to reduce food absorption, which leads to weight loss. But the rearrangement of sections of the small intestine, a primary source of GLP-1, also changes gut hormone production. "Suddenly food is delivered further down the gut in a less [digested] form than it would normally be," Yeo said. "As a result, different hormones are released, including GLP-1." Several studies show that GLP-1 levels increase almost immediately after gastric bypass surgery—sometimes nearly 10 times higher—before the recipient has lost any weight. These findings suggest that GLP-1's influence on satiety may play an important role in the surgery's weight-loss effects.

In response to Zelman: Scientists have long investigated ways to develop drugs from potent chemicals of various venomous creatures, such as snakes, cone snails and lizards like the Gila monster. Research in the 1980s suggested that Gila monster venom stimulated the pancreas, later inspiring endocrinologist John Eng to break down the molecular recipe of the saliva. That's how he discovered exendin-4, a peptide that was similar in structure and function to GLP-1 but much more durable and longer-lasting. Exendin-4 served as the template for the new class of GLP-1 drugs, first as diabetes drug exenatide and more recently semaglutide.

SEEING SPOKEN WORDS

I was thrilled to read "Speech Transforms into Text I 'See' " [Mind Matters], Emily Makowski's article on ticker-tape synesthesia. Since childhood, I have seen the words I and others speak appear and scroll before my eyes, much like a ticker tape. I remember being surprised that not everyone experienced this. My parents were always amused by my ability to recite the spellings of words backward.

As mentioned in the article, I find it difficult to concentrate on reading if there are conversations, TV or music with lyrics in the background. Like Makowski, I won spelling bees in primary school—so often that my third grade teacher revised the rules to allow for multiple winners. To my knowledge, I have never met anyone else with ticker-tape synesthesia.

ANNE PRUCHA *WINTER SPRINGS, FLA.*

I've experienced this same speech-to-text conversion for as long as I can remember. I thought everyone experienced this until a conversation with friends in college let me know that, nope, I was fairly unique. This was the first time I'd ever stumbled across something written about the phenomenon. Thank you for writing about ticker-tape synesthesia and giving me a name for my mental closed-captioning!

SCHUYLER V. *KENTUCKY*

ASTEROID BENNU

"An Asteroid's Secrets," by Robin George Andrews, describes the material sampled from the near-Earth asteroid Bennu as having much in common with the geology of our own planet. That makes me wonder whether the asteroid could actually be from Earth, a relic of the huge collision that created our moon. The article says that "some of the sample's microscopic grains reveal" that Bennu is older than the sun, which is of course older than the moon. But how do those ancient grains confirm Bennu's age? Couldn't they be material accreted over the billions of years the asteroid has spent roaming our solar system?

STEVE WISE *CHARLOTTE, N.C.*

ANDREWS REPLIES: *For Bennu to have come from Earth, scientists would expect the sample to have chemical signatures that*

are a very, very close match to those of Earth or even the moon—and that's not what they're seeing. Water-rich objects are actually very common in the solar system, so Bennu being hydrated isn't that strange. But getting pristine asteroid material from an ancient water world is very exciting.

The sample of Bennu was taken from below its surface. And these grains have clear chemical traces that show they weren't forged by our sun.

ROUND AND ROUND WE GO

"There Is Too Much Trash in Space," by the Editors [Science Agenda], discusses the problem of orbital debris. Half a century ago my colleagues and I had a small NASA contract to look at ways to get rid of such debris. We took the unusual step of not asking for follow-on funding because we could not think of anything that would work. Shortly after that I also managed a contract called Space Industrialization, in which we wrestled with that same problem and devised only a partial solution. In our plan, an entrepreneur could lease a "pad" and pay for provided utilities at a space-based facility. If they went broke, management would safely deorbit their hardware.

CHARLES GOULD *LAS VEGAS, NEV.*

ERRATA

"March of the Mangroves," by Michael Adno, should have described William "Ches" Vervaeke and Scott F. Jones as using a GPS device, not a GPS transmitter.

In the November issue, the credit for the cover image should have read, "John Gurche/Created for the Institute of Human Origins/Arizona State University."

Aaron Shattuck is a senior copy editor at *Scientific American*.

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https://www.scientificamerican.com/article/readers-respond-to-the-july-august-2024-issue

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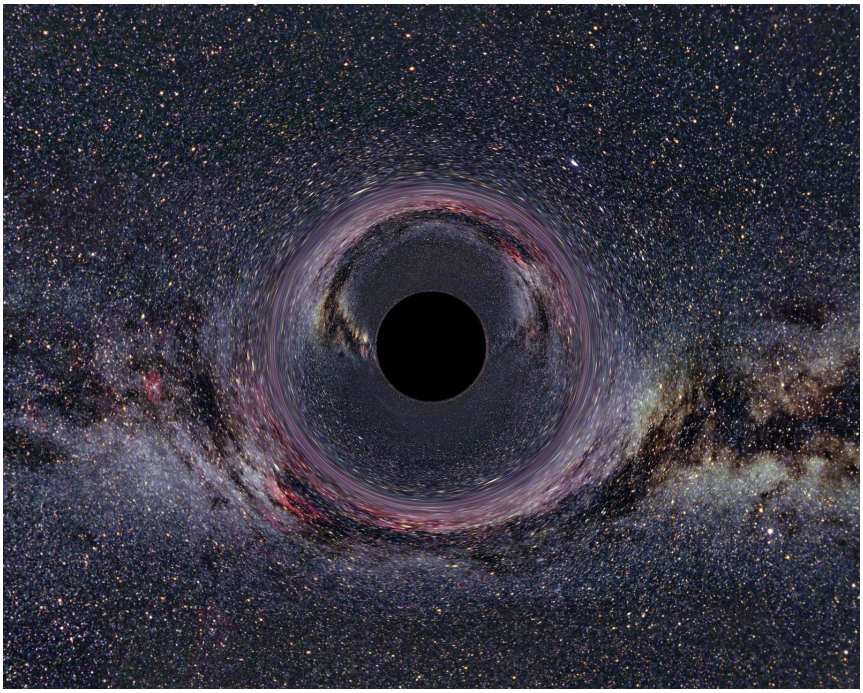
Dark Matter

- **Dark Matter Black Holes Could Fly through the Solar System Once a Decade**
  The universe’s hidden mass may be made of black holes, which could wobble the planets of the solar system when they pass by

Dark Matter Could Be Hiding Out as Atom-Sized Black Holes

The universe's hidden mass may be made of black holes, which could wobble the planets of the solar system when they pass by

By Clara Moskowitz



Tiny black holes may regularly streak through our solar system.
Photo 12/Getty Images

Black holes the size of an atom that contain the mass of an asteroid may be flying through the inner solar system about once a decade. Theoretically created just after the big bang, these examples of so-called primordial black holes could explain the missing dark matter thought to dominate our universe. And if they sneak by the moon or Mars, scientists should be able to detect them, a new study shows.

Such black holes could have arisen easily right after the universe was born, when space is thought to have expanded hugely in a fraction of a second. During this expansion, tiny quantum fluctuations in space's density would have grown larger, and some

spots might have become so dense that they collapsed into black holes scattered throughout the cosmos. If dark matter were fully explained by such black holes, their most likely mass, according to some theories, would range from 10^{17} to 10^{23} grams—about that of a large asteroid, packed into the size of an atom.

If primordial black holes are responsible for dark matter, one probably zips through the solar system about every 10 years, according to a recent study in *Physical Review D*. And if such a black hole comes near a planet or a large moon, it should nudge the body off course enough for the change to be measurable by current instruments. “As it passes by, the planet starts to wobble,” says study co-author Sarah R. Geller, a theoretical physicist now at the University of California, Santa Cruz. “The wobble will grow over a few years but eventually it will damp out and go back to zero.”

Study lead author Tung X. Tran, then an undergraduate student at the Massachusetts Institute of Technology, built a computer model of the solar system to see how the distance between Earth and nearby objects would change after a black hole flyby. He found that such an effect would be most noticeable for Mars, whose distance from Earth scientists know within about 10 centimeters. A black hole in the middle of the predicted mass range weighing, 10^{21} grams, would produce one meter of variation in 10 years, Tran says —“way above the threshold of precision that we can measure.” The Earth-Mars distance is particularly well tracked because scientists have been sending generations of probes and landers to the Red Planet.

If scientists detect a disturbance, they must determine whether the planet was pushed by a black hole or just a plain old asteroid. By tracking the wobble pattern over time, they can trace the culprit’s trajectory and predict where it will head in the future. “We actually get really rich information from the pattern of perturbations,” says study co-author Benjamin V. Lehmann of M.I.T. “We’d need to convince ourselves that it’s really a black hole by telling observers

where to look.” If the object is an asteroid, telescopes should be able to see it. Plus, most asteroids come from within the solar system and therefore orbit on the same plane as the planets. A primordial black hole, in contrast, would be coming from far away and would likely have a different trajectory than that of an asteroid.

Another potential way to look for primordial black holes in the solar system would be to analyze the fine movements of asteroids such as Bennu, which has been tracked very precisely by the ongoing space mission OSIRIS-REx (Origins, Spectral Interpretation, Resource Identification, and Security-Regolith Explorer). After reading the new study, “I think we can try to dig into OSIRIS-REx data to see if we can see this effect,” says Yu-Dai Tsai, a particle physicist at Los Alamos National Laboratory. “I think it’s a promising direction to look at.” Tsai and his colleagues studied how the probe’s Bennu measurements could be used to look for other forms of dark matter in a paper published on September 20 in the journal *Communications Physics*.

Primordial black holes are an increasingly appealing solution to the puzzle of dark matter, an invisible form of mass that physicists think makes up most of the matter in our universe. Because they can “see” this substance only through its gravitational effects on regular matter, its identity has remained elusive as many favored theories have failed to pan out. For decades physicists thought dark matter was likely to take the form of so-called weakly interacting massive particles (WIMPs). Yet generations of ever more sensitive experiments meant to find these particles have come up empty, and particle accelerators have also seen no sign of them. “Everything is on the table because WIMPs have been put in such a corner, and they were the dominant paradigm for decades,” says astrophysicist Kevork N. Abazajian of the University of California, Irvine, who wasn’t involved in the *Physical Review D* study. “Primordial black holes are really gaining popularity.”

Physicists are also recognizing that dark matter may not interact with regular matter through any force other than gravity. Unlike WIMPs, which could also touch regular matter through the weak nuclear force, black holes would be detectable only through their gravitational pull. “Given that we are still searching for the correct way to detect dark matter interacting with ordinary matter, it is particularly important to explore probes based on the gravitational force it produces, which is the only interaction of dark matter whose strength is already known and the only interaction we are sure exists,” says theoretical physicist Tim M. P. Tait of U.C. Irvine, who was also not involved in the M.I.T. team’s new research. “This is a really interesting idea and one that is timely.”

That same issue of Physical Review D also happened to include a paper about a different team’s search for signs of primordial black holes flying near Earth. The researchers’ simulations found that such signals could be detectable in orbital data from Global Navigation Satellite Systems, as well as gravimeters that measure variations in Earth’s gravitational field. The two papers are complementary, says David I. Kaiser of M.I.T., a co-author of the study on interplanetary distance measurements.

Although these black holes could be passing relatively nearby, the chances that one could move through a human body are incredibly low. If that were to happen to you, though, it wouldn’t be fun: as the tiny black hole moved through you, it would tug everything toward it, crushing cells together in a deadly fashion. Its minuscule volume, however, would at least prevent you from getting sucked in.

A version of this article entitled “Mini Monsters” was adapted for inclusion in the December 2024 issue of Scientific American. *This text reflects that version, with the addition of some material that was abridged for print.*

Clara Moskowitz is a senior editor at *Scientific American*, where she covers astronomy, space, physics and mathematics. She has been at *Scientific American* for a decade; previously she worked at

Space.com. Moskowitz has reported live from rocket launches, space shuttle liftoffs and landings, suborbital spaceflight training, mountaintop observatories, and more. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science communication from the University of California, Santa Cruz.

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https://www.scientificamerican.com/article/dark-matter-black-holes-could-fly-through-the-solar-system-once-a-decade

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Education

- **Book Bans Harm Kids**
  Censoring what children read deprives them of reality and the chance to feed their curiosity and develop empathy

Book Bans Harm Kids

Censoring what children read deprives them of reality and the chance to feed their curiosity and develop empathy

By The Editors

Thomas Fuchs

Books are a gift, opening a door to the wide world. But not if you live in one of the U.S. communities where local school boards or state officials have cast certain books as scary monsters that harm children with words and ideas.

Organized conservative groups in many communities are censoring books from school and public libraries, claiming that some themes aren’t age-appropriate for children, never mind the context. They target books on health, climate change, psychology, and other science they find distasteful or antithetical to their way of thinking. They try to criminalize teachers and librarians who dare to give

kids a chance to indulge their curiosity. Under the guise of protecting children from harm, they vow to defund public libraries and alter school curricula.

> In 2023 the American Library Association documented more than 1,200 cases of efforts to ban library books.

But it's the book bans themselves that cause the most harm, robbing youngsters of opportunities to think critically, explore ideas and learn about experiences different from their own. The people responsible for moving books from classrooms and library shelves are trying to limit the flow of information. Their efforts aim to undermine democracy; they would create an electorate of young people who will not question authority, build alliances with people who have less political power, or challenge the status quo. Knowledge is power. Book bans go against the very nature of an open, civil society. Whether through the legal system, the ballot box or our voices, we must uphold educational freedom and support knowledge. We must stop the censoring of books.

Censorship has a shameful history in the U.S. The infamous 1873 Comstock Act made it illegal to mail works considered to be obscene, such as pamphlets about birth control. James Joyce's *Ulysses* was banned in the country in the 1920s, and the U.S. Postal Service burned copies. More recently, conservatives have bowdlerized the history and science children learn in schools, altering depictions of slavery, rejecting textbooks that reference climate change and challenging evolution.

In 2023 the American Library Association documented more than 1,200 cases of efforts to ban library books. Petitioners targeted more than 4,200 books for removal from schools and libraries. The most contested books of 2023 include classics such as Toni Morrison's *The Bluest Eye*, modern novels and graphic novels about growing up LGBTQ+, a book about teen health, and another about human trafficking. PEN America, a nonprofit that advocates

for free expression in literature, noted more than 3,300 efforts to ban books in schools during the 2022–2023 academic year. In some places, books on cancel alert have included works by Judy Blume and Margaret Atwood and, in one case, a book about body positivity aimed at preschoolers.

Why is it so scary to just let kids read?

Education researchers Gay Ivey of the University of North Carolina at Greensboro and Peter Johnston of the University at Albany studied four classrooms where teachers let teens choose what they wanted to read from a long list of books. The students' reading scores improved, they say, but teachers saw even more positive outcomes. The students talked to one another about themes in the books they read, developed compassion and empathy for the characters and their struggles, and thought about choices and consequences. In addition, their mental health improved.

In one survey, nearly 40 percent of children, especially those from underrepresented ethnic backgrounds, said reading about characters they could identify with boosted their confidence. Yet nearly half of children ages eight to 11 said they had trouble finding such books.

In some states, book-banning efforts are nestled into other bills with seemingly virtuous goals. In Missouri, for example, Senate Bill 775, enacted in 2022, looks to protect children from sexual abuse and trafficking, but embedded within the law is a passage that criminalizes teachers and librarians for giving students "explicit sexual material," with wording so broad that it could include books on health or sex education.

Rebecca Wanzo, a professor at Washington University in St. Louis who studies graphic novels, which are some of the most frequently banned books, says denying children and teens access to the panoply of ideas in books creates people who "don't know what they don't know." She says some students who take her classes are

shocked by the alternative explanations her lectures and reading lists provide for different aspects of human existence.

So where does this leave us?

Some teachers are keeping canceled books in secret drawers. Some schools in more open districts are introducing the idea of reading clubs focusing on banned books. Librarians are questioning what they are allowed to put on shelves instead of promoting what's there. Parents who want their kids to have a thorough education are trying to fight back against well-funded and politically motivated advocates of book bans.

The kids who can are speaking up for books and libraries. It is up to us to help them, as well as the ones who can't. Book bans are antithetical to free speech and free thought. They are antidemocratic, antiscience and antievidence. Reading this editorial with no one looking over your shoulder is your fundamental right. Our children deserve the same.

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https://www.scientificamerican.com/article/book-bans-harm-kids

Evolutionary Biology

- ## Learning from Great Tits' Urban Adaptability
  One of Europe’s most common birds, the Great Tit, shows an amazing adaptability to human-made habitats. There seem to be no limits for this species when it comes to inventing new ways of acquiring food from people

Great Tits Show How Animals Can Thrive in Cities

One of Europe's most common birds, the Great Tit, shows an amazing adaptability to human-made habitats. There seem to be no limits for this species when it comes to inventing new ways of acquiring food from people

By Anders Brodin

Great Tit.
Mike Lane/Alamy Stock Photo

Although its name might be unknown (and blush-inducing) to some Americans, the Great Tit is one of the most familiar bird species in Europe and Asia—and one of the most intriguing. The species shows a cognitive capacity that is amazing for a slight bird weighing only 18 grams. It produces false alarms to scare other birds off seed feeders and knocks on kitchen windows to get feeders refilled. On cold winter days Great Tits drum on beehives, whereupon the bees will come walking out, easy prey for the hungry birds. In combination with the bird's broad food preferences, its cleverness has resulted in an unusual response to urbanization.

By “unusual,” I mean that Great Tits not only get by but thrive. And their success at city living offers some lessons on how we humans can better get along with not just Great Tits but also our other urban animal neighbors.

Urbanization, which involves land development, is an increasing problem for wild animals the world over. Stressors such as pollution, noise, artificial light and the lower-quality food found in cities are considered unhealthy for animals. Studies of urbanization in birds, including my research, are usually designed to elucidate its detrimental effects, with some interesting exceptions. Together with Hannah Watson, a colleague at Lund University in Sweden, I measured levels of corticosterone, or CORT, a common stress hormone in birds, in 188 urban and rural Great Tits. Contrary to expectations, the urban birds had consistently lower levels of CORT than forest birds. This finding is even more remarkable when you consider that urban populations are denser than forest ones, which should increase competition for territories and food and hence ramp up stress.

> Understanding animal cognition is important because of the concern about keeping wild animals in captivity.

Such exceptions may be more common than one would think. Another forest bird, the European Blackbird, a close relative of the American Robin, has successfully colonized suburban habitats in Europe in a similar way as the Great Tit. A study at 10 pairs of urban and rural sites across Europe showed that levels of stress hormones were consistently lower in the urban blackbird populations than in forest ones.

Great Tits belong to the family Paridae and are relatives of North American chickadees but almost twice their size. They are colorful and perky, and they frequently become tame when rewarded with treats. Not surprisingly, they have been the subject of the highest number of scientific studies among all wild birds.

Adaptability has also allowed Great Tits to colonize a habitat that is in stark contrast to an urban one. Originating in the temperate deciduous forests of Eurasia, the little bird is now common in boreal coniferous forests at northern latitudes. The species colonized northern Sweden in the early 1900s during the construction of railroads. Bird feeding has a long tradition in this country, and the rail builders took a liking to the birds, nailing up their leftover pork fat at the entrances to the huts where they slept. As the railroads extended northward, the Great Tits followed. Nowadays they are common in this habitat, but when the cold winter takes hold, they leave the forests and emerge at bird feeders in nearby towns and farms.

Great Tit (*Parus major*) adult and Blue Tit (*Parus caeruleus*) adult foraging for insects on crabapple fruit Suffolk England.
FLPA/Alamy Stock Photo

Cognition in the Paridae family is interesting, and not only because of the achievements of that single species. In general, members of this family possess the largest relative brain sizes of all small birds. Different species practice one of two entirely different wintering strategies. All American species, such as chickadees, and their close relatives in the Old World, such as Willow and Marsh Tits, are large-scale food hoarders. These species are spatial-memory specialists that store many thousands of food items, all in separate locations, as winter food. The Great and Eurasian Blue Tits, in

contrast, do not store food at all. Curious and innovative, they instead obtain food in all possible and seemingly impossible ways, especially from humans.

The cognitive skills of the Great Tit have been important for its successful colonization of new habitats. And understanding animal cognition has become important because of the growing concern about the ethics of keeping wild animals in captivity. Scientists disagree on many questions involving the awareness of animals: Is it justifiable, for example, to keep cognitively advanced animals such as apes and dolphins in captivity for our own entertainment?

The more we learn about animal cognition, the better we will be able to answer such questions. Considering the cognitive ability of a small bird such as the Great Tit, there should be room for much reflection when we think about the confined spaces in zoos where we keep animals that we consider to be even more cognitively advanced.

If you aren't sold yet on the incredible cognitive skills of the Great Tit, here's another piece of evidence: they are masters of vocal mimicry. Compared with well-known mimics such as mockingbirds and European Starlings, Great Tits have an ability so rare that it may pass unnoticed. It is the way they use their mimicry that is impressive. Whereas other species mimic with the sole purpose of making their songs more impressive, the Great Tit will mimic other birds only when it might offer some advantage and never in its own song. For example, it may imitate the sounds of almost any other songbird in a neighboring location to expand its own territory. The neighbor bird will then avoid the Great Tit's range, believing that it is already occupied by a competitor of its own kind.

Great Tits may also strategically mimic a call that warns of predators. The most significant peril for small birds at a feeder is an airborne predator that attacks at high speed, such as a falcon or

hawk. When one is nearby, all small birds talk the same language. A high-pitched seeee will make all birds at a feeder take off in panic. In Aesop's fable about the boy who cried wolf, a shepherd boy gives false alarms by repeatedly screaming, "Wolf!" when there is no wolf present, just to fool the villagers into rushing to his rescue. When a wolf eventually does attack the sheep, no one comes to help because the villagers believe the cry is just another false alarm. The boy did not benefit from his trickery. The clever Great Tit, however, does precisely this, sounding false alarms and actually gaining from it: by scaring the other birds off, the Great Tit gains exclusive access to the feeder.

What can we learn from this? Birds as intelligent as the Great Tit and other urban-survivor species will find food we leave for them and places to make our acquaintance if we give them just a little room to use their smarts.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Anders Brodin is professor in ecology at Lund University in Sweden. He has studied cognition in parids for more than 40 years, having been first intrigued by an article in *Scientific American* in 1983 about food hoarding and memory in them. He is systematically collecting observations from the public of interesting or unusual behavior by foraging birds. Please submit them here.

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https://www.scientificamerican.com/article/learning-from-great-tits-urban-adaptability

Fossil Fuels

- **Fossil Fuels Are Not Essential**
  The fossil-fuel industry argues that we can’t live without its deadly products. It is wrong

We Can Live without Fossil Fuels

The fossil-fuel industry argues that we can't live without its deadly products. It is wrong

By Naomi Oreskes

Scott Brundage

The final results are not yet in, but it's pretty certain that 2024 is going to be the hottest year on record. Practically every week this year, we heard of some new daily or monthly record being broken, some extreme weather event made more extreme than it would have been by human-caused climate change. In July exceptional rainfall led to flooding that triggered deadly landslides in the Kerala region of India, killing hundreds of people. In September, Hurricane Helene became one of the biggest storms to hit the U.S. Fueled by record-high ocean temperatures, the storm brought torrential rains and massive storm surges to the Southeast. At press time, the death toll from the hurricane had surpassed 230.

Sadly, reports of these events often provoke not shock, sadness or outrage but rather a sense of déjà vu, if not ennui. If 2024 does prove to be the hottest year ever measured, it will be the fifth time in less than a decade that we have faced such a grim fact. Perhaps for this reason, the response of the fossil-fuel industry is to shrug its shoulders and insist that, despite all the climate damage that fossil fuels cause, we just can't live without them. In a white paper published earlier this year, KinderMorgan, which owns and operates pipelines, put it this way: "There is an enduring economic and social need for fossil fuels that will continue to play a central role in our lives." ExxonMobil's 2024 Global Outlook declares that "oil and natural gas remain vital" because they are "needed for modern life."

> What is essential to civilization is that we dramatically reduce our use of coal, oil and gas.

Everyone involved in the energy and environment conversation knows any transition away from fossil fuels and toward renewable energy will take time. Indeed, this is why it's so consequential that the oil and gas industry has worked for decades to delay the transition, which even it now acknowledges is necessary.

The argument that we can't live without a dangerous, even deadly product is an old one. In their new book on the history of health disparities in the U.S. (and the role of corporate America in creating and reinforcing many of those disparities), historians David Rosner and Gerald Markowitz recount an argument made 99 years ago, when the fossil-fuel industry defended an activity that would soon kill large numbers of people: putting lead in gasoline.

By the 1920s many people, most notably American physician and Harvard University professor Alice Hamilton, had become concerned about occupational exposure to toxic materials, such as lead, asbestos and mercury. Hamilton was an expert on lead poisoning, and some states had passed laws to limit exposure to

toxic substances in the workplace, in part based on her work. When the oil industry decided to add lead to gasoline, Hamilton was concerned. The situation pitted her against some of the biggest names in American business, including industrialists Charles F. Kettering and Alfred P. Sloan and oil magnate John D. Rockefeller.

General Motors engineer Thomas Midgley, Jr., had discovered that adding tetraethyl lead to gasoline solved the problem of knocking —the noise caused by fuel burning unevenly or incompletely in an engine. Midgley worked under Kettering—GM's head of research —who reported directly to Sloan, GM's CEO. GM quickly contracted with Rockefeller's Standard Oil to put tetraethyl lead into gasoline. By 1923 the product was on the market.

But there was a catch. It had been known since classical antiquity that lead is highly toxic; Midgley himself had suffered a bout of lead poisoning as a result of his research. Many workers in industrial settings where lead was used became ill or died. So GM and DuPont—which would manufacture the tetraethyl lead—agreed the product would be marketed simply as "ethyl."

It didn't take long for scientists to voice concerns. According to Rosner and Markowitz, the U.S. surgeon general wrote to the chair of DuPont asking whether the companies had taken public health impacts into account. Midgley admitted that neither DuPont nor GM had collected any relevant data, but he nonetheless insisted that the amounts that an ordinary person would be exposed to would be harmless.

In 1925 the surgeon general organized a conference of businesspeople, union leaders, scientists, doctors and government officials to consider the matter. Given what Midgley told the surgeon general, one might expect the representatives of American industry to have insisted that lead in gasoline was safe. Instead they argued it was essential for the U.S. economy, for industrial progress, for the American way of life.

Kettering contended that because oil supplies were limited, anything that improved efficiency had to be viewed as indispensable. Standard Oil's lawyers and engineers stated at the conference: "Our continued development of motor fuels is essential in our civilization."

In later years, industry representatives and defenders would repeatedly reprise this theme. True, some workers got sick or even died, but this was the price of progress. The editor of the journal *Chemical and Metallurgical Engineering* asserted that "casualties" from lead "were negligible compared to human sacrifice in the development of many other industrial enterprises."

In 1965 California Institute of Technology geochemist Clair C. Patterson estimated that the blood lead level of many Americans was more than 100 times what it would be from natural causes and well above what was known to cause at least low-level lead poisoning. Meanwhile other scientific studies were proving that even low levels of lead exposure could cause neurotoxicity, with alarming effects on intelligence and behavior. In 1973 the U.S. began a gradual phaseout of leaded gasoline. In 2021 Algeria became the last country to ban it.

When lead was removed from gas, the positive effects were dramatic. One study found that between 1976 and 1995, mean American blood lead levels dropped 90 percent. Moreover, the scaremongering predictions of Midgley and Co. did not come true. Not only did the American economy not collapse when leaded gasoline for cars was phased out, but it took only a few short years for car manufacturers to redesign engines to operate with unleaded gas. Leaded gasoline was not essential to civilization, and neither are fossil fuels. What is essential to civilization is that we dramatically reduce our use of coal, oil and gas—the largest contributors to the existential threat of global climate change—and thereby set our planet on a path toward a safer future.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Naomi Oreskes is a professor of the history of science at Harvard University. She is author of *Why Trust Science?* (Princeton University Press, 2019) and co-author of *The Big Myth* (Bloomsbury, 2023).

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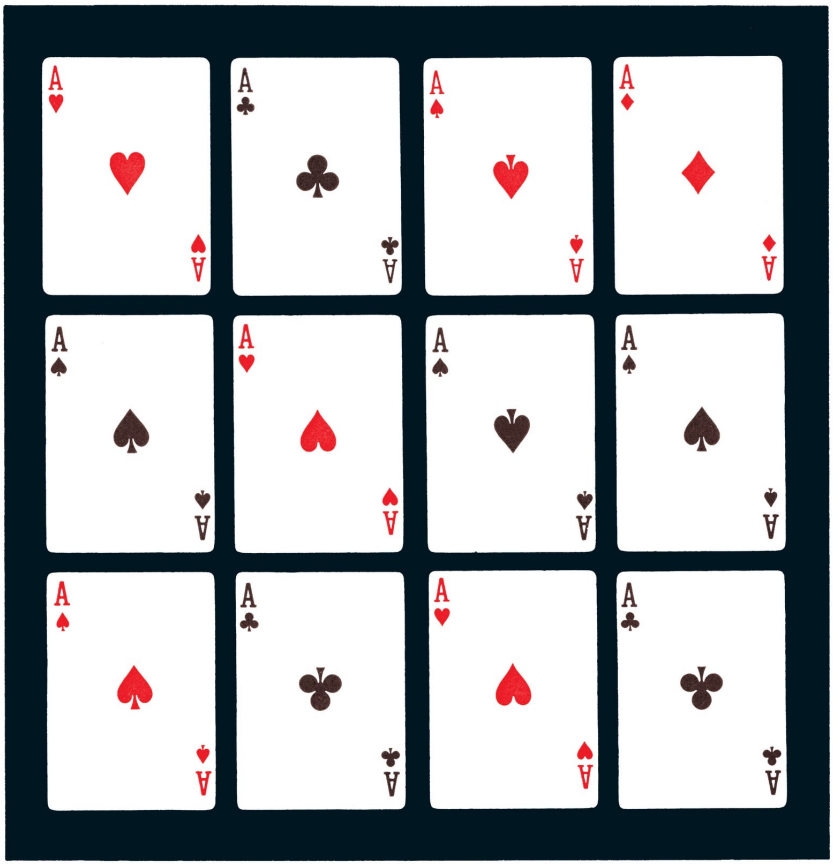
History

- **December 2024: Science History from 50, 100 and 150 Years Ago**
  Alcohol in space; basking in the limelight

December 2024: Science History from 50, 100 and 150 Years Ago

Alcohol in space; basking in the limelight

By Mark Fischetti



1974, How Many Aces of Spades?: “After a brief glance at this display most people report seeing three. Actually there are five. Because people expect aces of spades to be black, they tend to miss the atypical red ones. Thus do prior conditioning and experience influence perception.”
Scientific American, Vol. 231, No. 6; December 1974

1974

More Alcohol Found in Space

“Is there intelligent life elsewhere in the universe? Positive evidence facetiously adduced was that whereas methyl alcohol had

been discovered in interstellar space, ethyl alcohol (the potable kind) had not. Clearly someone had consumed the stuff. But in October a group of [researchers] used a highly sensitive spectrometer to investigate the dense cloud of gas and dust designated Sagittarius B2, a rich source of most of the known molecules in space. They discovered weak radio emission at the wavelength of 3.3 millimeters [and] identified it as radiation from ethyl alcohol. Ethyl alcohol, composed of nine atoms (C_2H_5OH), is one of the largest and most complex molecules now known to exist in interstellar space. The substance is spread in a thin vapor throughout Sagittarius B2, which is some 50 light-years in diameter. One calculation shows that, if the ethyl alcohol were condensed, it would come to 10^{28} fifths of a gallon at 80 proof. Potability, however, might be a problem; the alcohol is heavily contaminated with substances such as hydrogen cyanide, formaldehyde and ammonia. The discovery brings the total number of different kinds of molecules detected in space to 32."

1924

"Methanol" Is a Safer Name

"Some time ago attention was called to the coinage of this word to designate methyl alcohol, commonly called wood alcohol. The purpose was to provide a trade designation which would not involve the word 'alcohol' and consequently detract from the use of this material as a beverage. In one year in one of our larger cities there were 54 deaths traceable to the internal use of wood alcohol. As soon as the word 'methanol' had been accepted by the trade and users, the number of deaths in the same locality dropped to less than 20 in a year. It is believed that a great deal more has been accomplished by this ingenious device than would have been possible by any campaign of education or legal enforcements."

Chromosomes, Not Jelly

“With the microscopic study of the cell and its constituent parts, and the rediscovery of Mendel’s law in 1900, two formerly independent lines of investigation have reinforced each other. We now know that living cells are not mere drops of jelly; each contains a complexity of parts, one of which is the easily dyed speck called the nucleus. The nucleus in turn contains a number of highly important microscopic constituents called chromosomes, of which each species of plant or animal possesses a characteristic number. Although the nature and behavior of these little chromosome particles are not fully understood, it is quite evident that they have very much if not everything to do with determining the great facts of heredity.”

1874

Paintings Bask in the Limelight

“The new and celebrated painting ‘Roll Call’ [by Lady Elizabeth Butler] is now nightly exhibited in London to large audiences, by means of the oxyhydrogen light, or lime light, and all the colors of the picture are brought out with marvelous brilliancy, in fact with the same perfection as by daylight. The idea of illuminating art galleries in the evening by the lime light is an excellent one. The yellow color of the ordinary gas flame reveals only a portion of the colors of the paintings. The reds and yellows are seen well enough, but the blues and greens, and their various tints, are sadly distorted, and the artistic effect lost. Lime light obviates such difficulties.”

Levett Ibbetson is credited with pioneering the use of limelight in photography. An oxyhydrogen flame (a mixture of oxygen and hydrogen) heated a piece of quicklime until it became white-hot, creating incandescence.

Sanitary Hospital Walls

“A writer in the *London Builder* suggests that thick glass might be easily and cheaply cemented to the walls of hospitals. It would be non-absorbent, imperishable, easily cleaned, readily repaired if damaged by accident, and unlike paper and paint, would always be as good as at first. Glass can be cut or bent to any required shape. If desired, the plates may be colored any cheerful tint. The non-absorbent quality is the most important for hospitals and prisons, and, we should think, is worthy the consideration of architects.”

Mark Fischetti has been a senior editor at *Scientific American* for 17 years and has covered sustainability issues, including climate, weather, environment, energy, food, water, biodiversity, population, and more. He assigns and edits feature articles, commentaries and news by journalists and scientists and also writes in those formats. He edits History, the magazine's department looking at science advances throughout time. He was founding managing editor of two spinoff magazines: *Scientific American Mind* and *Scientific American Earth 3.0*. His 2001 freelance article for the magazine, "Drowning New Orleans," predicted the widespread disaster that a storm like Hurricane Katrina would impose on the city. His video *What Happens to Your Body after You Die?*, has more than 12 million views on YouTube. Fischetti has written freelance articles for the *New York Times*, *Sports Illustrated*, *Smithsonian*, *Technology Review*, *Fast Company*, and many others. He co-authored the book *Weaving the Web* with Tim Berners-Lee, inventor of the World Wide Web, which tells the real story of how the Web was created. He also co-authored *The New Killer Diseases* with microbiologist Elinor Levy. Fischetti is a former managing editor of *IEEE Spectrum Magazine* and of *Family Business Magazine*. He has a physics degree and has twice served as the Attaway Fellow in Civic Culture at Centenary College of Louisiana, which awarded him an honorary doctorate. In 2021 he received the American Geophysical Union's Robert C. Cowen Award for Sustained Achievement in Science Journalism, which celebrates a career of outstanding reporting on the Earth and space sciences. He has appeared on NBC's Meet the Press, CNN, the History Channel, NPR News and many news radio stations. Follow Fischetti on X (formerly Twitter) @markfischetti

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https://www.scientificamerican.com/article/december-2024-science-history-from-50-100-and-150-years-ago

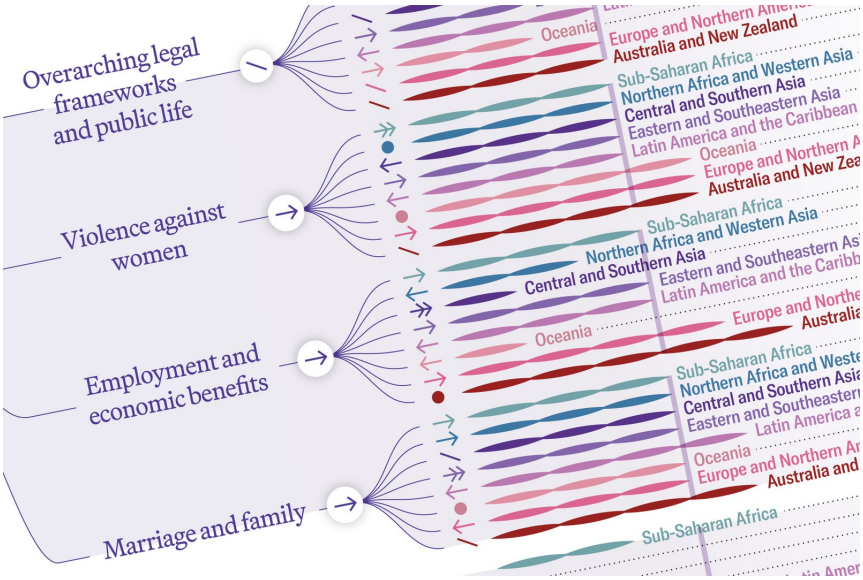
Inequality

- **See How Close We Are to Gender Equality around the World**
  U.N. statistics show progress toward the goal of gender equality but a long way left to go

See How Close We Are to Gender Equality around the World

U.N. statistics show progress toward the goal of gender equality but a long way left to go

By Clara Moskowitz & Federica Fragapane



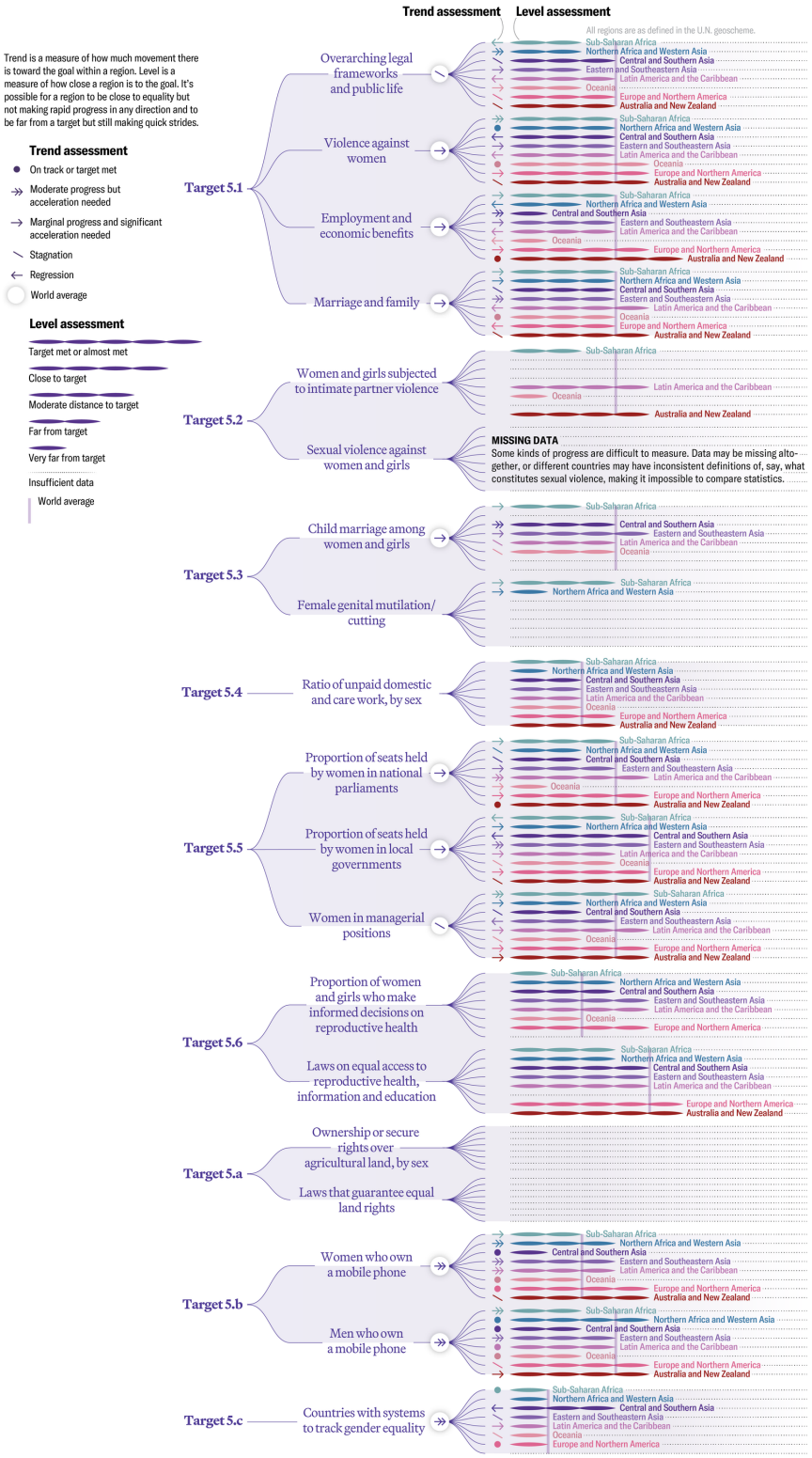
Federica Fragapane

Around the world, women and girls still face disproportionate discrimination, poverty and violence, as well as a lack of access to education, health care and property ownership, among other disadvantages. Every year the United Nations agencies U.N. Women and U.N. Department of Economic and Social Affairs track progress toward global gender equality—one of the U.N.'s 17 Sustainable Development Goals, which all U.N. member countries agreed to try to reach by 2030. The project gathers data from government questionnaires and household surveys and from other agencies such as the World Health Organization, the World Bank and the U.N. Children's Fund (UNICEF).

The report highlights some important gains: child marriage is declining, women make up a slightly larger share of parliaments and local governments, and 56 legal reforms have been enacted to close the gender gap since 2019. “There’s been some progress to celebrate,” says Papa Seck, chief of U.N. Women’s research and data division. “But that progress has just not been enough to get us where we want to be by 2030. Much more can be done and should be done.” At the current pace of progress, gender parity in parliaments won’t be achieved until 2063, child marriage will persist until 2092, and it will take 137 years to end extreme poverty among women.

Goal 5

Achieving gender equality, Goal 5, is one of the U.N.’s 17 Sustainable Development Goals. Others include ending poverty (Goal 1), ending hunger (Goal 2) and ensuring education for all (Goal 4). All of the goals are related, and many of their targets overlap—for instance, achieving gender equality involves ending women’s poverty and hunger and broadening their access to education. Goal 5 encompasses 9 targets and 14 indicators.



Federica Fragapane; Source: *Progress on the Sustainable Development Goals: The Gender Snapshot 2024*, Published by UN-Women and the United Nations Department of Economic and Social Affairs (*data*)

Clara Moskowitz is a senior editor at *Scientific American*, where she covers astronomy, space, physics and mathematics. She has been at *Scientific American* for a decade; previously she worked at Space.com. Moskowitz has reported live from rocket launches, space shuttle liftoffs and landings, suborbital spaceflight training, mountaintop observatories, and more. She has a bachelor's degree in astronomy and physics from Wesleyan University and a graduate degree in science communication from the University of California, Santa Cruz.

Federica Fragapane is an independent information designer who specializes in creating projects and data visualizations as a freelancer. Many of her projects take an experimental approach, carefully selecting visual languages to encourage readers to engage with the narratives conveyed by the data. In 2023 three of her projects were acquired by the Museum of Modern Art (MoMA) in New York City, becoming part of its Permanent Collection. Her work can be found at www.be.net/federicafragapane

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https://www.scientificamerican.com/article/see-how-close-we-are-to-gender-equality-around-the-world

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Language

- **Science Crossword: Equine Emergence**
  Play this crossword inspired by the December 2024 issue of Scientific American

Science Crossword: Equine Emergence

By Aimee Lucido

This crossword is inspired by the December 2024 issue of Scientific American. *Read it here.*

We'd love to hear from you! E-mail us at games@sciam.com to share your experience.

Aimee Lucido writes crosswords and trivia puzzles that are published everywhere from the *New Yorker* to the *New York Times* to independent publications such as AVCX. She is also author of the middle-grade novels *Emmy in the Key of Code* and *Recipe for Disaster,* as well as the brand-new picture book *Pasta Pasta Lotsa Pasta*. Lucido lives with her husband, daughter and dog in New York.

https://www.scientificamerican.com/article/science-crossword-equine-emergence

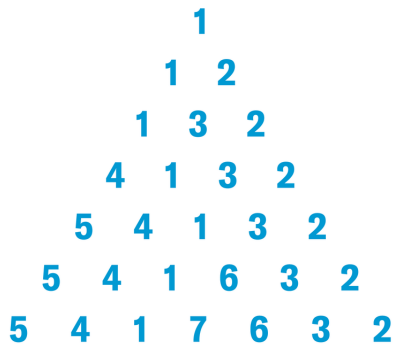
Mathematics

- **Math Puzzle: Find the Secret System**
  How are these numbers organized?
- **How a Doodler's Problem Sparked a Controversy in Math**
  The twisty history and surprise ending of the four-color-theorem saga

Math Puzzle: Find the Secret System

By Heinrich Hemme

The numbers in this triangle are arranged according to a certain system. What would the next row be?



In each row *n* of the triangle, the integers from 1 to *n* are in alphabetical order. In the next row the number 8 would be added, and because “eight” comes before “five” in alphabetical order, it must be at the beginning of the row, giving us this sequence:

8 5 4 1 7 6 3 2

(Note that *Scientific American*’s editors had to adjust the order on this one from the original German.)

We’d love to hear from you! E-mail us at games@sciam.com to share your experience.

This puzzle originally appeared in Spektrum der Wissenschaft *and was reproduced with permission.*

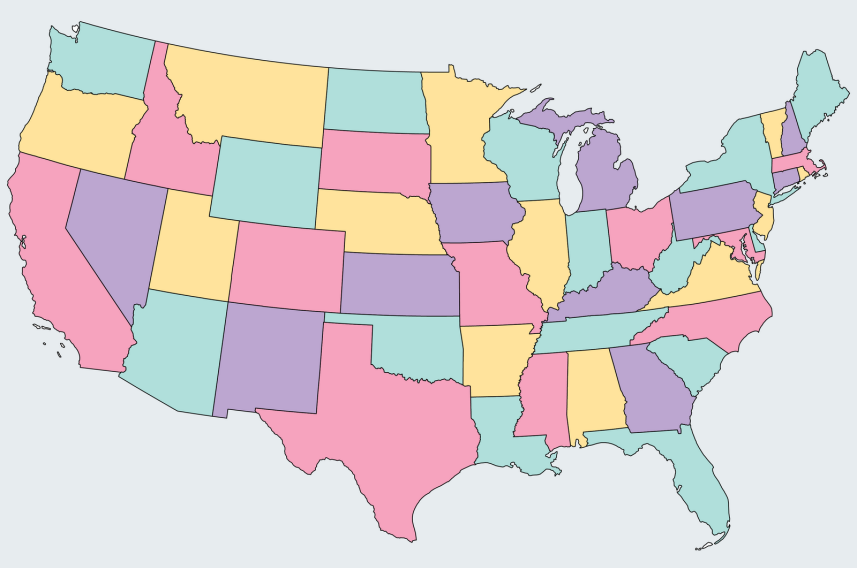
Heinrich Hemme is a physicist and a former university lecturer at FH Aachen–University of Applied Sciences in Germany.

https://www.scientificamerican.com/article/math-puzzle-find-the-secret-system

How a Doodler’s Problem Sparked a Controversy in Math

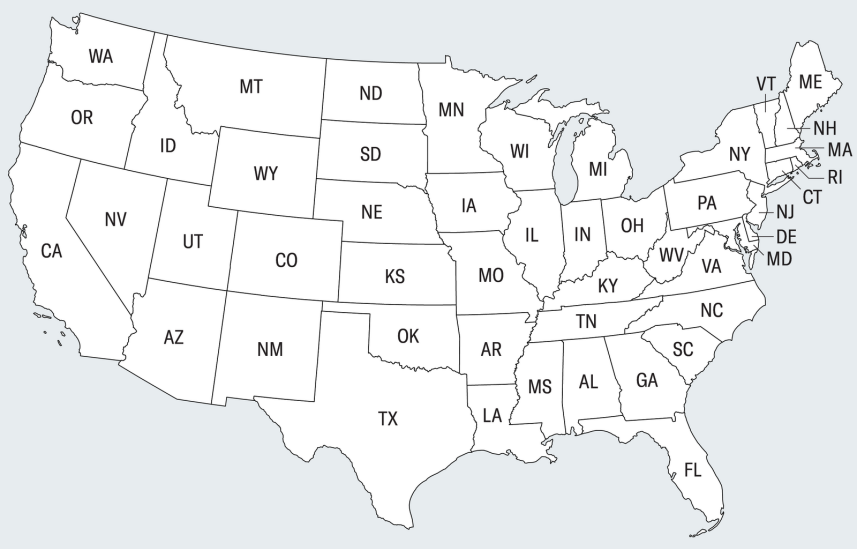
The twisty history and surprise ending of the four-color-theorem saga

By Jack Murtagh



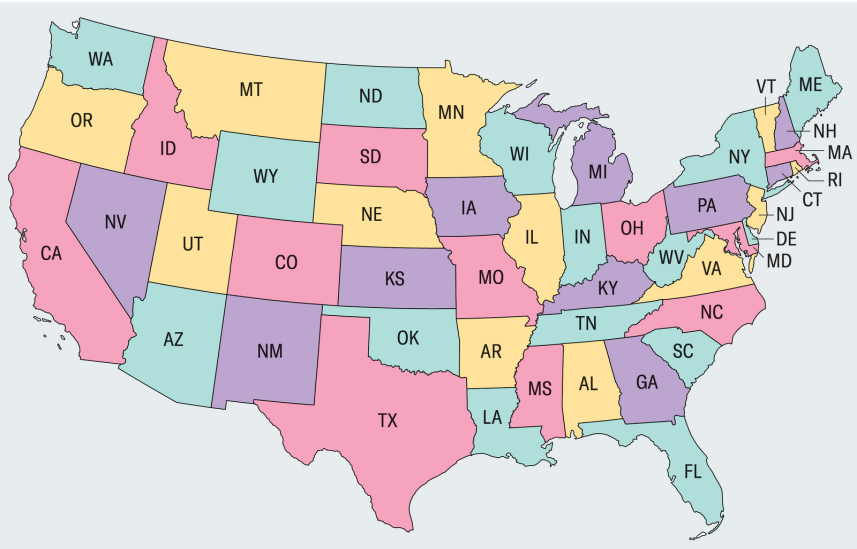
In this map, no two adjacent states are colored in the same hue.
June Kim

In 1852 mathematician Francis Guthrie asked a seemingly simple question that triggered endless dispute, left a trail of overturned publications in its wake and culminated in a resolution that has stretched the very tenets of math. The conundrum that stirred up so much trouble was: What is the minimum number of colors needed to color a map so that no neighboring states or other designated areas have the same hue? Here’s how it works. Check out the black and-white map of the contiguous U.S. below. It looks a little bare-bones. To make maps more vivid and clearly highlight their borders, cartographers tend to color in the regions.



June Kim

Naturally, we don’t want neighboring states to have the same color, because that would make the boundaries more confusing. Under this constraint, we used four colors to fill in the black-and-white map. Could we have done it with only three? Might other maps require five or six?



June Kim

The map in this problem doesn’t need to correspond to real geography—any partitioning of a flat surface into distinct regions qualifies. The question, given any such map, is how many colors are required to fill in each region so that no two adjacent regions have the same shade. Some ground rules: Each distinct region must be contiguous (technically Michigan violates this rule in U.S. maps

because Lake Michigan severs the state into two disconnected parts). For two regions to count as adjacent, they must share some length of contiguous border; touching at a single point (or discrete set of points) doesn't qualify. For example, Utah and New Mexico touch at only one corner and so do not count as neighbors for our purposes.

With the rules established, here are some questions with surprising answers. Suppose I printed out a large poster with a complicated map containing a few thousand regions. How long would it take you to determine whether the map could be colored with two colors? Three colors? Four colors? You don't necessarily need to find a coloring scheme; just decide whether it exists for each number of colors. Curiously, although the task seems nearly identical for all the numbers, it requires radically different amounts of time to complete for each. Using the best-known methods:

- Deciding whether two colors suffice would take about an hour. To do it, pick out any region and color it, say, red. This forces all the region's neighbors into your second color, say, blue. In turn, all their neighbors become red and so on, propagating through the map. Eventually you either encounter a conflict where neighboring regions share a color, in which case no "two-coloring" exists, or the colors spread through the entire map conflict-free, in which case you've found a valid coloring. A back-of-the-envelope calculation with 3,000 regions at a rate of one second per coloring yields 50 minutes of time well spent.

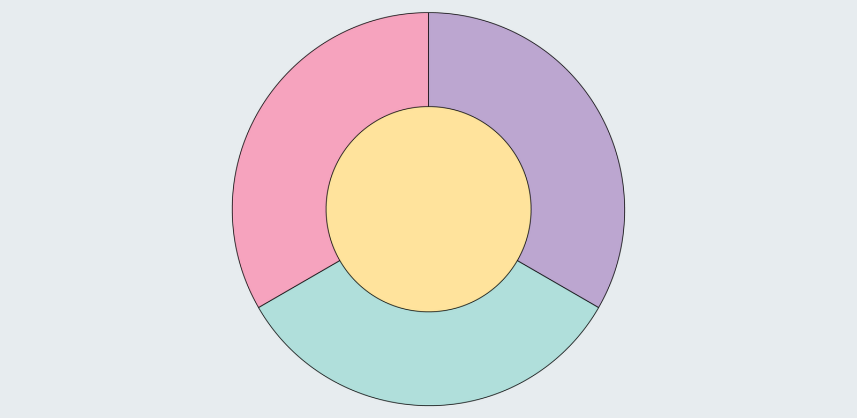
- Suppose the map can't be filled with only two colors. Deciding whether three colors suffice would take longer. The afternoon would pass you by. The weeks would peel off the calendar as you furiously scribbled endless configurations, searching for one that works. To carry forth, you'd have to pass down the ongoing task to your children and they to their children. Generations of lives devoted to nothing other than finding a

three-coloring of this map wouldn't put a dent in the workload as the sun inevitably engulfed Earth in some billions of years and put an end to the silly endeavor, leaving us barely closer to an answer.

Determining whether an arbitrary map has a three-coloring is hard. Here "hard" is a technical term indicating that it falls into a class of computational problems renowned for their time-consuming difficulty, called NP-complete problems. For problems in this class, we don't know any faster methods than more or less brute-force searching through every possible solution. That search space grows exponentially as the size of the problem increases. For a small map with only a few regions, we could afford to exhaustively look through every possible three-coloring until we find one that works (or conclude that there isn't one). But the number of ways to assign three colors to maps with thousands of regions is so astronomical that it renders exhaustive searches hopeless.

- And four colors? Well, that takes about one second or the time you need to say "yes" because *every* map can be colored with four colors. This outcome is the infamous and long-disputed four-color theorem.

When Guthrie first conjectured the four-color theorem in 1852, he noticed that he needed only four colors to properly fill the counties of England. He suspected this rule would generalize to any map, but although any kindergartner could understand the question, neither he nor his colleagues could prove it. It was clear that three colors wouldn't always hack it, as evidenced by the circle diagram below, where every region borders every other one.



June Kim

But nobody could find a map that required five colors. Stymied by the problem, mathematician Augustus De Morgan grew obsessed with it and concluded that a new axiom—which in math is a statement that is assumed to be true without proof, from which more complicated statements can be derived—must be added to the foundations of math to resolve Guthrie's conjecture.

The fevered frustration ostensibly ended in 1879, when a proof emerged that four colors always suffice. This was underscored by a second, independent proof a year later. With the matter settled and accolades distributed, captivated mathematicians returned to their usual research pursuits—except for some. Eleven years after the publication of the first proof, both proofs were overturned, and the slippery four-color theorem reverted to the four-color conjecture. Percy John Heawood of Durham University in England, who exposed a hole in the original proof, made some progress, however, by proving that *five* colors always suffice for filling any map.

This left the math world in a rather embarrassing position. A problem so seemingly simple had one of two answers—four or five—but which was correct? It would stand this way for almost a century more.

Although nobody could find a map requiring five colors, no one could rule out the possibility of one, either. Because there are an infinite number of maps, one could never check each of them

individually. A key step toward a solution involved reducing the problem to a finite set of cases that could be checked individually. The leap from infinite to finite seems vast, but the monstrous number of cases to check still far exceeded what any person could manually process.

So mathematicians Kenneth Appel and Wolfgang Haken, then both at the University of Illinois, turned to a daring idea: program a computer to process them instead. In 1976, after years of fine-tuning and more than 1,000 hours of computer time, their algorithm finished exhaustively checking every case, and the four-color theorem was established. It was the first major theorem to use a computer in its proof.

The math world lit ablaze with equal parts celebration and dismay. One of Appel and Haken's colleagues, William Tutte of the University of Waterloo in Ontario, rejoiced that they "smote the kraken." Others despised the thought of computers encroaching on human ingenuity. The affair also posed a philosophical problem in the math community. Does a proof that can't be verified by humans count as a proof at all? Many expected the work to eventually be retracted like both the alleged proofs that preceded it. The *New York Times* even refused to report on the announcement at first because proofs of the four-color theorem "were all false anyway."

Multiple attempts to refute the computer-assisted proof failed in the following decades. Mathematicians have since drastically simplified the proof and verified the computer code, but to this day no proof of the theorem derived without the aid of computers is known. And although the four-color theorem has become widely accepted as a fact, a yearning lingers over it. A computer program that systematically analyzes reams of configurations does not explain exactly why every map can be filled with four colors. Even though mathematicians now welcome computers as partners in discovery, they are still searching for a more illuminating proof of this colorful puzzle.

Jack Murtagh is a freelance math writer and puzzle creator. He writes a column on mathematical curiosities for *Scientific American* and creates daily puzzles for the Morning Brew newsletter. He holds a Ph.D. in theoretical computer science from Harvard University. Follow Jack on X @JackPMurtagh

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Milky Way

- **Will the Milky Way and Andromeda Galaxies Ever Collide?**
  Andromeda and the Milky Way may collide, or they may safely swing past each other. Time will tell

Will the Milky Way and Andromeda Galaxies Ever Collide?

Andromeda and the Milky Way may collide, or they may safely swing past each other. Time will tell

By Phil Plait

A pair of far-distant colliding spiral galaxies, as seen by NASA's Hubble and Spitzer space telescopes. A similar fate may await our own Milky Way billions of years from now if it collides with our nearest neighboring spiral galaxy, Andromeda.
NASA, ESA, and The Hubble Heritage Team (STScI)

A cosmic train wreck may be looming in our future. The Andromeda galaxy, a near twin of our Milky Way, is barreling toward us. You can already see it coming if you know where to look—Andromeda's great spiral appears as a fuzzy smudge, faint but larger than the full moon, in Earth's late summer and autumn skies in the Northern Hemisphere. Over the eons, as our neighboring galaxy approaches, it will grow larger in the heavens until it engulfs our entire view—at which point it will physically collide with our galaxy, spawning chaos and flinging stars asunder in the resulting merger and perhaps even ejecting our own solar system into intergalactic space.

Or this might not happen. It's hard to say.

Although a lot of research indicates a potential collision between these two colossal structures—and certainly there's been no shortage of reporting on the possibility over the years—the galactic smashup is by no means inevitable. In fact, an international team of European scientists contests the idea. In a (not yet peer-reviewed) research paper posted on the preprint server arXiv.org, the researchers show that when the effects of other nearby galaxies are taken into consideration, the chance of the Milky Way colliding with Andromeda is only about 50 percent. A decent likelihood, though nowhere near a sure bet.

> Although Andromeda is headed *mostly* toward us, it may also be moving to the side. If this lateral shift is large enough, the galaxy could miss us.

The Milky Way is a flattish disk galaxy that is about 120,000 light-years wide. It contains hundreds of billions of stars, as well as clouds of gas and dust, assorted dead stars, and one very large black hole at its center. It's also surrounded by a colossal halo of old stars and invisible dark matter. The total mass of the Milky Way is approximately 1.5 trillion times the mass of the sun. Our galaxy is immense.

Andromeda is much the same but perhaps 30 percent more massive. The galaxy is located across a vast reach of intergalactic space, about 2.5 million light-years away from us. Andromeda and the Milky Way are the two biggest members of the Local Group, a small clutch of about 100 galaxies, most of which are much smaller and fainter. The two next largest are the Triangulum galaxy (M33), which is about 2.7 million light-years from the Milky Way (and only 700,000 light-years from Andromeda; they lie close together in the night sky), and the Large Magellanic Cloud (LMC), a satellite of the Milky Way that is about 160,000 light-years away. These four dominate the Local Group.

In galaxy clusters—large collections of hundreds or thousands of galaxies—we see members colliding fairly often. The gravitational interactions between galaxies can draw them together in a cosmic dance that can take the better part of a billion years to complete. Two interacting galaxies usually first make a close pass and then circle back and slam into each other sometime later. The two can merge, forming a single, larger object that eventually settles into a cotton-ball-shaped elliptical galaxy.

That simple summary belies the mind-crushing chaos of such an event, however. A close pass can stretch the pair of galaxies like taffy as each gravitationally grasps at the other, drawing out streams of gas and stars called tidal tails, which can be hundreds of thousands of light-years long. Angular momentum causes the tidal tails to curve gracefully as the two galaxies swing by each other. This process also steals orbital energy from the galaxies, allowing them to slow, drop back toward each other and merge. The pandemonium involved in the collision can drastically change the orbits of stars, hurling some toward the galactic center or flinging them far out into the galactic suburbs.

Worse, the myriad gas clouds orbiting in a galaxy are huge—some are hundreds of light-years wide. They very much *can* collide, and when they do, they can collapse and form lots of stars, creating tremendous outbursts of energy. Not only that, but enormous amounts of dust and gas can be dislodged to plummet toward each galaxy’s central supermassive black hole, piling up just outside to form an infernally hot accretion disk. As all that accumulated material approaches its final plunge into the black hole’s maw, it can blast out more energy than all the stars in both galaxies combined.

So despite taking eons to unfold, galactic mergers can be quite ostentatious occurrences. They’re not usually great places to have a habitable planet.

This naturally raises the question of whether Andromeda and the Milky Way are doomed to merge. Early studies of Andromeda showed that (unlike nearly every other galaxy in the universe) it's blueshifted, meaning it's moving through space toward the Milky Way. This motion isn't subtle: the galaxy is approaching at a staggering speed of about 110 kilometers per second.

That makes it seem like a collision is inevitable. How could something approaching so fast not score a hit? The answer is that although Andromeda is headed *mostly* toward us, it may also be moving to the side. If this lateral shift—astronomers call it transverse velocity—is large enough, the galaxy could miss us.

The problem is measuring that transverse motion. Andromeda is a long way away, and its apparent motion across the sky is incredibly small. It was only very recently that astronomers were able to measure this tiny movement at all. The uncertainties are still large, but the overall transverse velocity indicates that Andromeda and the Milky Way will, at the very least, experience a close pass. *How* close, we can't yet say.

The new research takes that into account. The scientists created computer simulations of the motions of the two galaxies and ran them forward in time to see whether a collision will occur. The team took a different approach than others had in the past, running the simulations over and over again, changing the input parameters a little bit each time—for example, increasing or decreasing the velocities a tad—to cover the uncertainties in the measured numbers.

This approach builds up statistical models, giving a likelihood of collision. When the researchers did this for *just* the Milky Way and Andromeda, they found the galaxies collided slightly less than half the time. It's almost a coin flip: heads means a collision, and tails gives us a close pass but avoids an actual merger—although the

interaction will cause a somewhat less disruptive version of the chaos described earlier.

What's also new in this study is the inclusion of both M33 and the LMC, both of which are massive enough to gravitationally affect the trajectories of their much larger siblings. Including just the LMC reduces the chance of a crash to only about 30 percent—it orbits the Milky Way, and in most cases, it essentially pulls us to the side just enough to dodge a collision. Adding M33 in, however, pulls us back toward Andromeda, once again giving us even odds of an impact.

That's better than inevitability but perhaps not terribly reassuring. If you prefer to breathe easier, note that if this tryst does happen, it won't occur for roughly another eight billion years. By then the sun will have evolved past its red giant stage, cooked Earth and shrunk into a white dwarf. That's cold comfort, I know.

On the other hand, collisions and mergers such as this one are how galaxies grow. The Milky Way is a bruiser among galaxies, and it got here by what is essentially galactic cannibalism. And despite the chaos, the future merged object—which some astronomers call Milkomeda—may for a time be rejuvenated, with millions of new stars born in the aftermath. (To be honest, I'm not a fan of the name Milkomeda, but I can't think of anything better. Andromeway is way worse.)

There are bleaker fates. And again, this crash may not happen at all. As time goes on and astronomers make more observations of Andromeda, we'll get better data, and we'll know for certain what literally lies ahead.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Phil Plait is a professional astronomer and science communicator in Virginia. He writes the *Bad Astronomy Newsletter*. Follow him online.

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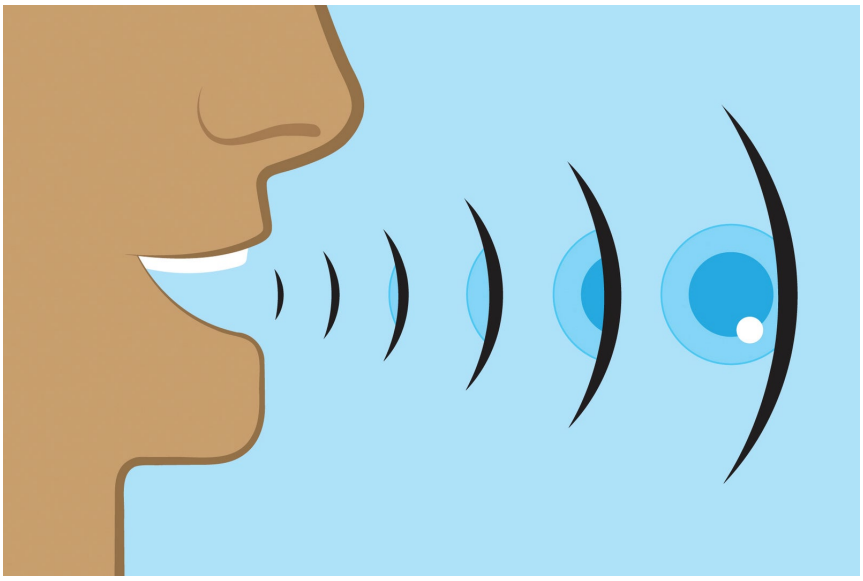
Neuroscience

- **Anyone Can Learn Echolocation in Just 10 Weeks—And It Remodels Your Brain**
  Human echolocation repurposes parts of the brain’s visual cortex for sound, even in sighted people
- **Concussions Are Remarkably Common and Can Cause Long-Term Problems**
  New diagnostic techniques can pick up these brain injuries and ensure people get help

Anyone Can Learn Echolocation in Just 10 Weeks—And It Remodels Your Brain

Human echolocation repurposes parts of the brain's visual cortex for sound, even in sighted people

By Simon Makin



Thomas Fuchs

Human echolocation has at times allowed people to ride bikes or play basketball despite being completely blind from a very young age. These echolocators typically perceive their environment by clicking sharply with their tongues and listening to differences in the sounds reflected off objects.

Brain-imaging studies reveal that expert echolocators display responses to sound in their brain's primary visual region, and researchers have speculated that long-term input deprivation could lead to visual regions being repurposed. "There's been this strong tradition to think of the blind brain as different, that it's necessary to have gone through that sensory loss to have this neuroplasticity,"

says Lore Thaler, a neuroscientist at Durham University in England.

Thaler co-led a 2021 study showing that both blind and sighted people could learn echolocation with just 10 weeks of training. For more recent work in the journal *Cerebral Cortex*, she and her colleagues examined the brain changes underlying these abilities. After training, both blind and sighted people displayed responses to echoes in their visual cortex, a finding that challenges the belief that primary sensory regions are wholly sense-specific.

The researchers trained 14 sighted and 12 blind people for between two and three hours twice a week over 10 weeks. They started by teaching participants to produce mouth clicks, then trained them on three tasks. The first two involved judging the size or orientation of objects. The third involved navigating virtual mazes, which participants moved through with the help of simulated click-plus-echo sounds tied to their positions.

Both groups improved on all the tasks. “This study adds a significant contribution to a growing body of evidence that this is a trainable, nonexotic skill that’s available to both blind and sighted people,” says Santani Teng, a psychologist at the Smith-Kettlewell Eye Research Institute in San Francisco, who studies echolocation and braille.

During brain scans before and after training, participants also performed a task that involved recognizing mazes, with and without click echoes. After training, both groups showed increased auditory cortex activation in response to sound in general, as well as higher gray matter density in auditory areas.

Most surprisingly, after training, both blind and sighted participants also showed visual cortex activation in response to audible echoes. “We weren’t sure if we would get this result in sighted people, so it was really rewarding to see it,” Thaler says. She suspects that

rather than just processing visual data, this brain area takes in information from varied senses that aid spatial understanding.

Three months after the 2021 study, a follow-up survey found that 83 percent of blind participants who had learned echolocation reported improvements in independence and well-being. The researchers are working on disseminating the training more widely, Thaler says: “It’s a powerful sensory tool for people with vision impairments.”

Simon Makin is a freelance science journalist based in the U.K. His work has appeared in *New Scientist*, the *Economist*, *Scientific American* and *Nature*, among others. He covers the life sciences and specializes in neuroscience, psychology and mental health. Follow Makin on X (formerly Twitter) @SimonMakin

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https://www.scientificamerican.com/article/anyone-can-learn-echolocation-in-just-10-weeks-and-it-remodels-your-brain

Concussions Are Remarkably Common and Can Cause Long-Term Problems

New diagnostic techniques can pick up these brain injuries and ensure people get help

By Lydia Denworth

Jay Bendt

Fifteen years ago I slipped on a wet patio deck and fell backward, slamming the back of my skull into a pillar. I saw stars and briefly felt nauseated. But I picked myself up, checked that I wasn’t bleeding and went about my day. The back of my head was sore for a few days, but there weren’t any lingering effects, and I didn’t see a doctor.

Still, those symptoms I did have might have been signs of a concussion, the common term for a mild traumatic brain injury (TBI). Such injuries are a lot more common than you might think and may cause long-term problems. When more than 600 average middle-aged people in the U.K. and Ireland were asked careful questions about past incidents in which they might have hit their heads, a full third turned out to have suffered a TBI of some kind. And nearly three million people in the U.S. are officially diagnosed with a TBI every year in emergency departments and hospitals. About 75 to 80 percent of their injuries are described as mild.

But “mild,” it turns out, can have consequences years later for many people. For example, in 2023 the multicenter TRACK-TBI study revealed that out of more than 1,200 people, 33 percent of those with mild TBI and 30 percent of those with moderate or severe TBI showed deterioration one to seven years after injury. Complaints can include problems sleeping, headaches, and memory and psychiatric issues. Long term, a TBI can lead to dementia, and it may also trigger several types of cardiovascular disease.

> “What we need to do is pay more attention to what happens in the months and years after injury.” —David Sharp *Imperial College London*

Doctors have misunderstood or misdiagnosed these problems because of an old way of looking at and thinking about concussions. For 50 years physicians have relied on symptoms they observe, such as loss of consciousness and motor or verbal changes, and on patient reports to classify traumatic brain injury as mild, moderate or severe. But this system isn’t very accurate at predicting either short- or long-term outcomes.

Experts have been pushing for change for several years. A 2022 National Academies report listed reclassification of these three grades, based on stronger evidence, as its first recommendation. “We know these terms are not accurate; they’re not precise. In fact,

they can actually be problematic for patients," says Nsini Umoh, who is the TBI program director at the National Institute of Neurological Disorders and Stroke (NINDS).

Now the field is doing something about the problem. After a January 2024 meeting hosted by NINDS, experts are proposing a new system of diagnosis and classification that provides neurobiological detail instead of a vague term such as "mild." Called the CBI-M model, it includes clinical symptoms (C), blood-based biomarkers (B), imaging (I) and modifiers (M). The last item includes social determinants of health such as access to care.

If doctors use this model, they will have to approach concussions and their treatment differently. Breast cancer patients, for instance, are not told that their cancer is mild or severe but are informed of the exact size of the tumor, whether it is estrogen-receptor-positive, and so on. People with a potential TBI could get that level of detail. Under the proposed guidelines, they will get a TBI score on a scale based on their responsiveness to a clinician's questions (as they do today), as well as blood biomarker results and possibly imaging results. The biomarkers are proteins released in the brain in response to injury; new technology can measure concentrations of these proteins in the bloodstream. The U.S. Food and Drug Administration has approved two tests, for the proteins GFAP and UCHL1, that can predict whether intracranial lesions are present in the brain and whether a CT scan is warranted to confirm them.

Someone with no visible changes in imaging and low blood biomarkers would be told that their recovery prognosis was good. Someone with more worrisome indicators might be told to follow up with specialists over months or even years. Physicians would adjust these risk assessments based on modifiers—for example, a person with a history of mental health issues is at higher risk than someone without.

“What we need to do is pay more attention to what happens in the months and years after injury,” says neurologist David Sharp of Imperial College London. “The way to do that is to do blood tests for particular things we think are relevant.”

And nonprotein biomarkers are turning up too. Neuroscientist Audrey Low of the University of Cambridge and the Mayo Clinic used imaging to uncover signs of cerebral small-vessel disease, a risk factor for dementia. One such sign, tiny chronic brain hemorrhages called microbleeds, was associated with past TBIs. The more TBIs a person had, the more likely they were to have had these microbleeds. “Implementing more standardized tools to screen for traumatic brain injury could be a way to pick these up,” Low says. Such screening also will allow doctors to better assess the risk of dementia.

Fortunately, health-care providers now take mild TBI far more seriously than in the past, when you’d have been told “you’ve had your bell rung, and you’re fine,” says neuropsychiatrist Thomas W. McAllister of the Indiana University School of Medicine. Thanks in part to modern concussion protocols—which call for several days of cognitive and physical rest, followed by other supervised treatments—most patients do feel better in a few weeks or months if diagnosed properly. And the new methods should help even more.

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

Lydia Denworth is an award-winning science journalist and contributing editor for *Scientific American*. She is author of ***Friendship*** (W. W. Norton, 2020).

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https://www.scientificamerican.com/article/concussions-are-remarkably-common-and-can-cause-long-term-problems

Privacy

- **What Giant Data Breaches Mean for You**
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The security expert who created Have I Been Pwned? shares advice for protecting sensitive data

By Ben Guarino

Shideh Ghandeharizadeh

At some point in the past year, one or more hackers quietly breached a background-checking company called National Public Data (NPD) and exposed millions of U.S. Social Security numbers (SSNs), names, phone numbers, and e-mail and mailing addresses. The accuracy and significance of some of these data, much of which NPD had probably scraped from public governmental records, is questionable. The reality of the leak itself is not: in August, NPD acknowledged an incident involving “a third-party bad actor that was trying to hack into data in late December 2023,” according to a notice on the data-aggregating company’s website. The stolen information appears to have been put up for sale online beginning in the spring.

It is deeply unpleasant to imagine SSNs and other sensitive information circulating like so much digital plankton along the web's darker currents. And what has spilled out can't be recalled. So what does one do when this happens?

You can freeze your credit—preventing anyone from opening a new credit account in your name until the freeze is lifted—via the major reporting bureaus. (The three main agencies used in the U.S. are Equifax, Experian and TransUnion.) Such an incident offers a sobering reminder to practice good password hygiene going forward. Don't reuse passwords—their complexity and uniqueness are powerful—and consider a manager such as 1Password. Americans can check whether their SSN was exposed via a tool such as Pentester's NPD Breach Check. At the website Have I Been Pwned?, launched by Australia-based online security consultant Troy Hunt in 2013, visitors can see whether their e-mail addresses have been exposed in data breaches; an offshoot project similarly evaluates passwords.

In its decade-plus of existence, Have I Been Pwned? has ballooned to include six billion unique e-mail addresses. Each account has been breached slightly more than twice on average. "I had no idea it would become big—I wouldn't have given it such a stupid name," Hunt says. To "pwn" (pronounced "pone" as a pun on "own") someone is to utterly defeat them, per Internet slang that enjoyed a heyday in the early 2000s. It also means to take unauthorized control of someone's computer hardware or, say, e-mail account.

As Hunt puts it, the risk of a data breach is simply a cold reality that comes with being online. If the Internet is the information superhighway, leaks are among the roadside wreckage. "It's terrible that we have a road toll—and objectives toward zero are fantastic," he says. "But while we hurtle around at 100 kilometers an hour in metal machines, this is what's going to happen." Hunt talked with *Scientific American* about how to make sense of the potentially

alarming amount of data involved in massive breaches and what an increasingly online world means for our private information.

An edited transcript of the conversation follows.

Some major data breaches have been revealed this year, such as the AT&T breach, which exposed data from 73 million former and current customers. More recently, there was this National Public Data fiasco. One clear difference between those breaches is that NPD was this little-known data aggregator that sells services such as background checks—not a big, familiar corporation. Maybe there's no blueprint for what a standard data breach is, but you tell me: Is this an unusual case?

I'm looking at the list of the big breaches in the Have I Been Pwned? database, and often they are from the likes of data aggregators. People don't know who data aggregators are. Most of us, I think, are not too keen on the idea of data aggregation. We don't like the idea of organizations siphoning up and monetizing our data—without our knowledge or *informed* consent. I'll add that caveat.

When an incident like this happens, it's quite frustrating for people because they're going, "Who is this organization? Why do they have my data? What can I do?" And really, you don't have any recourse.

There are a few standard suggestions for what to do after a breach, such as placing freezes with credit reporting bureaus and making sure your passwords are robust. Is there anything else people should be doing?

There's no discrete thing you can do directly about this kind of incident. It's not like when infidelity dating website Ashley Madison got breached, where you should change your password and probably have a conversation with your spouse or partner. In

this case, it’s all the fundamental stuff you really should be doing anyway. You should have whatever freezes you have available on credit until you actually need to apply for it. For identity-theft monitoring services, you have to spend some money, but it’s not a bad idea. And then, of course, use strong, unique passwords and multifactor authentication.

Then just have that consciousness of “What are the things you should be looking out for that might indicate these data are being abused?”—phone calls from a bank, for example, asking about an application you’ve made that you have no idea about. The guidance doesn’t change because of this breach. It just reinforces it.

There were rumors of the NPD breach trickling around for a few months before it percolated into the mainstream media. When it first hit, some of the headlines described 2.9 billion hacked accounts, which was off base. The breach actually appears to consist of 2.9 billion or so rows of data. Also complicating matters, bad actors behind a leak or sale might not be trustworthy—they’ll boast and inflate file sizes or combine already exposed data from multiple breaches to make a leak look huge. How should we think critically about big, scary numbers in headlines about data breaches?

We’ve seen this so many times before. Over the summer we were seeing headlines of the biggest password dump ever, which had 10 billion records. But when bad actors include every word from the dictionary and every combination of it, does the average person have to worry about it? No!

Earlier this year there was another one going around. It’s called the “mother of all breaches.” That was 20 billion records or something. Well, it’s just that someone siphoned up a whole bunch of breaches and put them all together. Add one more, and now you’ve got the bigger mother of all breaches.

By the same token, the truth is always there in the data. The number of records in total is an important figure. But without the context of what that actually means, it's hard to understand it. So I think a much fairer metric is how many people are impacted. And clearly, if it's just U.S. Social Security numbers, it's going to be in the low hundreds of millions at the absolute upper limit.

Do we know for sure that every American Social Security number is in the NPD breach?

No, we don't know that for sure. Investigative journalist Brian Krebs has written some good stuff about this. There are lots of different places where these data might be published, and then they all get aggregated together. If you haven't, for example, been arrested or ended up in a public record somewhere, then you may not be in there.

The thing that really frustrates me about this is that clearly NPD had a breach. I don't think there's any question about that anymore. And when you look at its disclosure notice, there's basically nothing there. The company has really given us nothing of any substance.

[Editor's note: Scientific American *repeatedly e-mailed NPD to ask whether it had taken additional actions to contact affected individuals. The company did not respond. In a recorded message on its breach hotline, NPD says it "will try to notify you if there are further significant developments applicable to you."]*

You wrote about lackluster corporate disclosure in a June blog post entitled "The State of Data Breaches." People might be surprised to know that data-breach laws can have exceptions related to notification. In Florida, where NPD is based, if a security breach involves more than 500,000 people, what is legally sufficient is a notice "in print and to broadcast media"

and “a conspicuous notice on the Internet website of the covered entity.” How would you improve disclosure?

Disclosure doesn’t necessarily mean letting the individuals know. It’s usually disclosure to the regulator unless we’re talking about sensitive personal information—health data, for example. The carve-out in Australia is that there’s got to be a likelihood of causing serious harm. The Florida situation, like you just mentioned, is a notice. California’s got the California Consumer Privacy Act, but I believe even under that, companies can still decide whether or not to notify individuals in the vast majority of cases.

There are all of these people who get *pissed* when they don’t get told—like, really, really pissed, understandably! And I’m sitting here at Have I Been Pwned? going, “Well, I’ve got your data. I can let you know.” But it shouldn’t be my job, right? I should be completely redundant because organizations should notify people early.

You’ve worked on Have I Been Pwned? for more than a decade. But let’s look ahead. Where are data breaches headed in the next 10 years?

If you think about the factors that lead to data breaches or amplify data breaches, we’ll have more people. We’ll have more systems. We’ll have more devices that have data; we’ve seen a lot of Internet of Things–related data breaches. There are data collected from CloudPets toys—teddy bears that talk—in Have I Been Pwned? We’re also going down a path where we’re seeing a lot of breaches—such as all the ones from this year related to cloud data storage company Snowflake—where we’re so dependent on external services that a flaw or a practice on behalf of threat actors can get reapplied over and over and over again to everyone using that particular platform. So all these factors combine to amplify the problems we’re having now. In summary, I think it’s getting worse.

Ben Guarino is an associate technology editor at *Scientific American*. He writes and edits stories about artificial intelligence, robotics and our relationship with our tools. Previously, he worked as a science editor at *Popular Science* and a staff writer at the *Washington Post*, where he covered the COVID pandemic, science policy and misinformation (and also dinosaur bones and water bears). He has a degree in bioengineering from the University of Pennsylvania and a master's degree from New York University's Science, Health and Environmental Reporting Program.

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Psychology

- **How to Reconnect with Old Friends Who Have Become Strangers**
  People are reluctant to reach out to friends they have lost touch with—but both sides are gratified when they reconnect

How to Reconnect with Old Friends Who Have Become Strangers

People are reluctant to reach out to friends they have lost touch with—but both sides are gratified when they reconnect

By Lara B. Aknin & Gillian M. Sandstrom

Grace Cary/Getty Images

Take a look at the contact list on your phone. Chances are that you have dozens of names and numbers, but you're in touch with only a small subset of those people on a regular basis. Sure, some dormant entries may be functional, such as those for veterinarians or car-repair shops. But some contacts are probably friends who have faded from your life for no particular reason. Whether it be the childhood friend who had a baby, the colleague who transferred to a new department or the thoughtful neighbor who moved away, many of us can think of someone we care about but with whom we have lost touch.

Research from across the social sciences has consistently shown for decades that social relationships are critical for our mental and

physical health. Indeed, having at least one person to count on in times of need is one of the top predictors of life satisfaction around the globe. As a result, we may expect people to go to great lengths to maintain their social connections. Yet some inevitably wane, transforming active friendships into dormant contact-list entries.

In a paper published in *Nature Communications Psychology*, we examined how many people have an old friend whom they care about but have lost touch with and how willing they are to reach out to this person. In a series of seven studies conducted with more than 2,400 participants, we discovered that people are surprisingly reluctant to reconnect, although there are strategies for overcoming that feeling.

> Social relationships are a key source of happiness, but they fade for any number of reasons.

We began by asking 441 university students in Canada whether they had someone with whom they had lost touch and, if so, how willing they were to call, text or e-mail this person now and in the future. An overwhelming majority (91 percent) identified such a connection. People were neutral about the idea of contacting this person in the future, however, and even less willing to do so at the time.

To explore this hesitation, we asked the same people about various barriers to reaching out. These participants had many concerns, but they worried most that their old friend might not be interested in hearing from them and that it would be awkward to speak after so much time had passed. In other words, people seemed to worry about being an imposition in their friend's life. This worry is most likely unfounded; research shows that friends we've lost touch with appreciate hearing from us more than we think.

In fact, we discovered that if people could get past their worries, they were indeed interested in reconnecting. When we asked 199

young adults to think about either getting in touch with an old friend or hearing from one, they preferred the latter. It's not that people are uninterested but rather that they are reluctant to initiate these interactions.

So we conducted two experiments with more than 1,000 people to see whether we could encourage them to call or write to an old friend. This proved surprisingly tricky even though we tried to make it as easy as possible. We recruited only people who were able to think of an old friend whom they wanted to reconnect with and who they thought would be happy to hear from them. Moreover, we made sure that participants had their friend's contact information, and we gave them a few minutes to draft a message.

Despite these favorable conditions, fewer than a third of people sent the message. Yet people who did reported greater feelings of happiness immediately afterward than those who didn't.

In addition to providing a supportive context, we tried to make the task even easier for people in several different ways. We told some of our participants not to overanalyze the situation and just press "send." We encouraged others to take their friend's perspective and think about how much they would appreciate receiving a note from an old friend. We tried to downplay the fear of rejection by suggesting that participants should not expect to receive a response and instead should feel good about having performed an act of kindness by sending a message.

None of these interventions were successful. Nothing we tried seemed to move the needle on the number of people who would reach out to an old friend. We were stumped—until we realized that many obstacles participants identified when thinking about the task were similar to the ones that prevent people from talking to strangers.

This similarity made us wonder whether the passage of time makes old friends feel like strangers. So we tested this idea. In one study, we asked 288 people how willing they were to engage in various everyday actions, such as picking up garbage, booking a dentist appointment, listening to a favorite song from childhood and, critically, talking to a stranger. Sure enough, people were no more willing to reach out to an old friend than they were to pick up garbage or talk to a stranger.

But here is the good news: one of us (Sandstrom) has worked on an intervention shown to ease anxieties about conversing with strangers. We decided to adapt that approach—which entails practicing specific social interactions—to the case of reconnecting with old friends. We asked some of our study participants to complete a three-minute warm-up exercise in which they sent messages to current friends and acquaintances. Meanwhile others —our control group—simply scrolled through social media. Afterward we encouraged everyone to contact an old friend. Only about a third of people in the control group sent a message, consistent with our previous experiments. But about half the people in the warm-up group did so. We think that practicing the behavior involved in reaching out to others reminded people of how simple it is to send a message and how enjoyable it can be to connect.

Social relationships are a key source of happiness, but they fade for any number of reasons. That said, reaching out may lead to greater happiness and may be easier after warming up. So go through the contact list on your phone and message a few folks you talk to often—and then find someone you haven't spoken to in a while and have been missing and try to get hold of them, too.

Are you a scientist who specializes in neuroscience, cognitive science or psychology? And have you read a recent peer-reviewed paper that you would like to write about for Mind Matters? Please send suggestions to Scientific American's *Mind Matters editor Daisy Yuhas at dyuhas@sciam.com.*

This is an opinion and analysis article, and the views expressed by the author or authors are not necessarily those of Scientific American.

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Quantum Physics

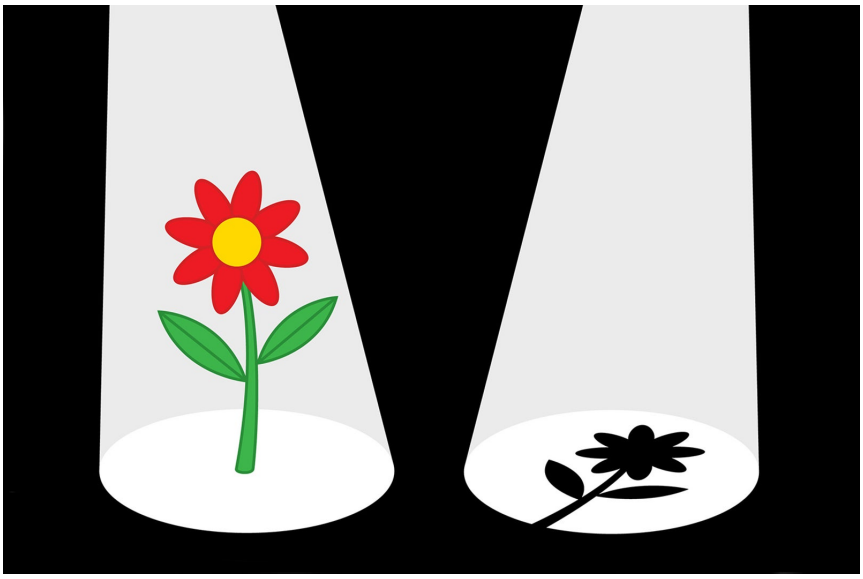
- ## Quantum ‘Ghost Imaging’ Reveals the Dark Side of Plants

  Entanglement lets researchers watch plants in action without disruptive visible light

Quantum ‘Ghost Imaging’ Reveals the Dark Side of Plants

Entanglement lets researchers watch plants in action without disruptive visible light

By Rachel Berkowitz



Thomas Fuchs

Imagine watching a time-lapse video of a garden you had filmed over the course of a year: you’d see details of flowers transitioning from day to night and season to season. Scientists would love to watch similar transitions on a molecular scale, but the intense light used to snap microscopic pictures of plants disrupts the processes biologists want to observe—especially at night. In the journal *Optica*, physicist Duncan Ryan of Los Alamos National Laboratory (LANL) and his colleagues recently demonstrated a tool for imaging live plant tissues while exposing them to less light than they’d receive under the stars.

A technique called ghost imaging, first demonstrated in 1995, involves splitting a light source to create two streams of photons

with different wavelengths at precisely the same times and locations. Each pair of photons is entangled—a quantum phenomenon that allows researchers to infer information about one particle in a set by measuring the other. Thus, a sample can be probed at one wavelength and imaged at another.

For plants, that means researchers can record visible-light photons, whose position can be measured accurately, and get knowledge about infrared photons that interact with water-rich molecules important to biological functions in the plants. In the new study, the team directed a stream of infrared photons at a plant in a transparent box with a photon counter behind it, and at the same time they aimed those particles' visible counterparts at an empty box at the same distance with a multipixel camera behind it. Each visible photon directed at the empty box hit a pixel and was detected in its exact location—a measurement with much more precision than an infrared camera could achieve. Meanwhile the infrared photons traveled to the plant box, but not all of them were counted: the plant absorbed some percentage of photons at a given spot. A computer logged the position of a pixel only when a photon hit both the camera and the counter simultaneously, revealing how much infrared light made it through each point. This way, the researchers could construct an image of a leaf using photons that never touched it, essentially forming an infrared image on a visible camera. "It's like a game of Battleship," Ryan says.

Ghost imaging has proved successful in capturing pictures of simpler test designs. But for low-light-transmission samples such as plants, microscopic features often differ in absorption by just a few percent. The new study was possible because of an extremely sensitive detector developed at LANL that tracks the arrival of each infrared photon with trillionth-of-a-second precision—letting the scientists map leaf tissues and peer into live plants' nighttime activities. "We saw [leaf pores called] stomata closing as the plants reacted to darkness," Ryan says.

Ghost imaging “creates possibilities for long-timescale dynamic imaging that does not damage live samples,” says laser spectroscopy and quantum optics researcher Audrey Eshun of Lawrence Livermore National Laboratory, who calls the new investigation a “truly innovative study.”

These kinds of observations make it possible to track how plants use water and sunlight throughout their circadian cycle. “We’re watching plants react to their environment,” Ryan says, “and not to our observations of them.”

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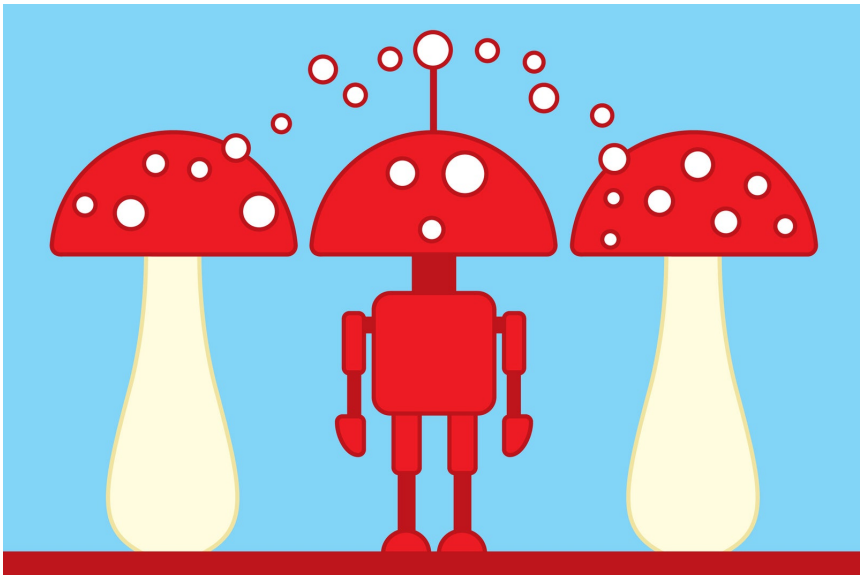
Robotics

- **This Is Your Robot Brain on Mushrooms**
  New rolling, hopping robots navigate via fungus

This Is Your Robot Brain on Mushrooms

New rolling, hopping robots navigate via fungus

By Saima S. Iqbal



Thomas Fuchs

The fungal network hidden under fleshy, white king oyster mushrooms doesn't just sprout elegant appetizers. It can also serve as a keen robotic sensor, helping to pilot a wheeled bot and a squishy, star-shaped hopping one.

Oyster mushrooms' rootlike mycelial threads generate voltage spikes when flashed with ultraviolet light. In an experiment for *Science Robotics*, researchers used this process to direct fungal tendrils, grown in a petri dish, to activate robots' motors via attached electrodes.

These bots join a family of machines known as biohybrids. Successes so far range from a silicone-based jellyfish that uses cardiac cells to propel itself in water to a two-legged robot powered by laboratory-grown skeletal muscle. Most of these efforts use animal tissue in place of mechanical motors; the new study uses a

radically different organism’s superpowers and thus expands engineers’ toolboxes, says Rashid Bashir, a biohybrid researcher at the University of Illinois Urbana-Champaign, who was not involved with the new study.

Fungi are inexpensive to maintain and excel at detecting subtle shifts—not only in light but also in nutrients and gases such as carbon dioxide and ammonia, says senior study author Robert F. Shepherd, an engineer at Cornell University. Shepherd dreams of agricultural uses for fungi-powered bots: machines that harvest ripe fruit, for instance, or add nitrogen to arid soil. His team began with light sensing for a simpler proof-of-concept experiment.

Translating a signal into motion for the rolling and starfish-shaped robots presented its own challenges. Beyond their electrical reaction to light, fungi produce a baseline current as they digest sugar; for the study, lead author Anand Kumar Mishra, also at Cornell, experimented with both minimizing and exploiting this extra information. In the latter case, robots reacted to all signals but moved faster in response to those prompted by UV light, which were larger. Mishra imagines that this model could come in handy for robots that might need to stop, slow down or switch directions in response to nitrogen-deficient pockets in agricultural fields.

In future work, Shepherd and Mishra hope to grow fungi throughout their robots so the devices can sense light or chemicals from every direction. If wired a particular way, the robots could also respond to these stimuli locally: fungus-controlled fruit pickers, for example, might extend multiple arms to the locations of different ripe peaches. The scientists will also investigate the longevity of the fungal tendrils.

For now Shepherd and Mishra are just glad that the proof-of-concept experiment succeeded. “We really had no idea where to start,” Mishra explains, “because these robots were the first of their kind.” It took the team three years to design one that could startle

in response to UV light. Watching the mechanical starfish scamper across the table for the first time, Shepherd himself felt keenly “alive.”

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