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Redefining Time

The Trouble with Flowers

The Bird That Broke the Binary

Anatomy of an Insight

Scientists close in on the elusive essence of "aha! moments"

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Features

The Brain Science of Elusive ‘Aha! Moments’

What happens in your mind when insight strikes?

By John Kounios & Yvette Kounios edited by Madhusree Mukerjee


Mark Ross

One evening in 1951 astronomer William Wilson Morgan was strolling home from Yerkes Observatory in Wisconsin when he looked up at the night sky and had a “flash inspiration ... a creative intuitional burst.” It solved one of the great mysteries of astronomy.

The observable universe contains billions, possibly even trillions, of galaxies. With a modest telescope, their varied forms are discernible—spirals, ellipsoids and others with irregular structures. But what about our own galaxy, the Milky Way?

Morgan had been calculating the distances from Earth of groups of big, hot, bright stars, nowadays called OB associations. He knew that in spiral galaxies these clusters reside in the trailing arms. Gazing at the sky while walking home, he located the familiar dots of the OB associations. But this time the flat image of the night sky merged in his mind with the star distances that he had calculated and committed to memory, and it sprang to three-dimensional life. Morgan's vision: the stars of the OB association are arranged in a long strand—an arm of our spiral galaxy.

An "aha! moment," such as Morgan's marvelous insight that the Milky Way is a spiral, is a new idea or perspective that arrives abruptly, often bursting into an ongoing stream of thought. It may pop up while someone is actively trying to solve a problem, but it can also arrive spontaneously. "When I write songs, it's never a conscious decision—it's an idea that floats down in front of me at four in the morning or in the middle of a conversation or on a tour bus or in the mall or in an airport bathroom," singer-songwriter Taylor Swift related to an interviewer. "I never know when I'm gonna get an idea and I never know what it's gonna be."

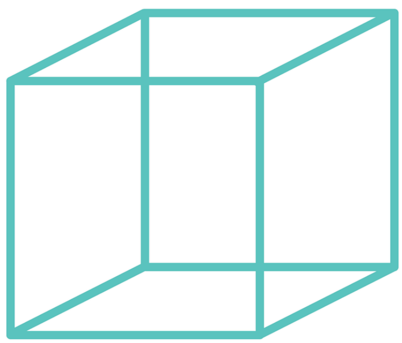
These revelations feel pleasing, even thrilling, and they can be portals to a scientific breakthrough, an innovative business proposal, a hit song or the plot of a best-selling novel. Or they may provide a life-changing perspective on a personal dilemma. People can overcome many challenges by analyzing them step by arduous step, but leaps of insight are more often associated with out-of-the-box ideas. And though often obvious in hindsight, the revelation can be astounding when it arrives.

Scholars have sought to capture the elusive essence of the aha! moment for more than a century, and it is finally within our grasp. We now know where it happens in the brain and when it's more likely to happen. And we're discovering some surprising benefits of insight, including elevated mood, memory and, oddly, the ability to distinguish fake news from real.

Psychologists of the Gestalt school, based in Germany in the 1910s, were the first to systematically study insight. The term "aha! moment" was popularized by media magnate Oprah Winfrey. Defined by *Merriam-Webster* as a "sudden realization, insight, recognition or comprehension," the aha! moment is also known as the Eureka! moment, as Archimedes is said to have exclaimed the Greek word *eureka* when he realized an object displaces a volume of water equal to its own. The Gestalt psychologists, who were interested in how the mind interprets patterns or forms, used visual illusions to argue that a problem could have features that mislead one's brain into misinterpreting it. The correct interpretation emerges when a shift of attention enables a person to restructure their understanding and see the problem in a new light.

Necker Cube Illusion

This illustration can be viewed in two ways, with the left square to the front or back, but not in both ways at the same time.

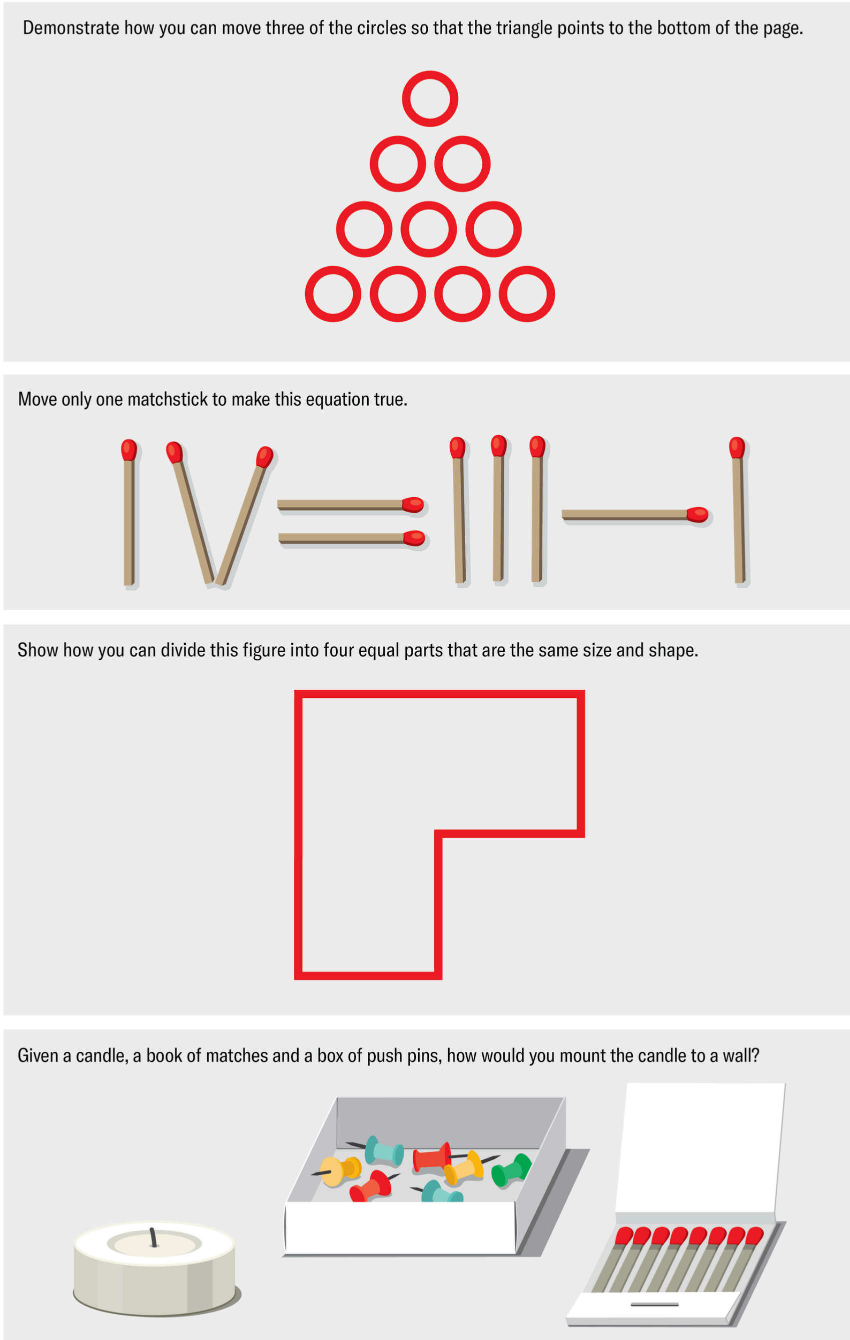


Jen Christiansen

These pioneering psychologists tasked people with complex brainteasers designed to reveal how and when humans are likely to have revelatory insights. They were the first to demonstrate that insight is driven by unconscious processes. Later, during the 1980s and 1990s, cognitive psychologists applied more powerful experimental methods that tracked progress toward solving a problem. Janet Metcalfe of Columbia University showed that "warmth," a person's feeling of being close to a solution, increases gradually while they work on a problem that requires step-by-step, analytical thinking, such as one involving algebra, but more sharply just before they solve a brainteaser through insight. Jonathan Schooler of the University of California, Santa Barbara, discovered that requiring participants to describe their thought processes while they solve problems suppresses insight but not analysis.

Brainteasers

Insight studies make use of puzzles like these in their experimental setups. *See the end of the article for solutions.*



Jen Christiansen; Sources: “Intuition in Insight and Noninsight Problem Solving,” by Janet Metcalfe and David Wiebe, in *Memory & Cognition*, Vol. 15; May 1987 (*triangle and polygon reference*); “Restructuring Processes and Aha! Experiences in Insight Problem Solving,” by Jennifer Wiley and Amory H. Danek, in *Nature Reviews Psychology*, Vol. 3; January 2024 (*candle problem reference*)

The 1990s saw rapid developments in neuroimaging. By the early 2000s cognitive neuroscientist Mark Beeman and one of us (John), both then at the University of Pennsylvania, concluded that imaging technologies were advanced enough for us to try to see what happens in the brain when a person has an insight. We used two complementary methods: electroencephalography (EEG) and functional magnetic resonance imaging (fMRI). EEG measures the electrical activity of the brain with electrodes placed on a person's scalp. It provides very precise information about when something is happening in the brain. In contrast, fMRI measures slower changes in blood flow (when a region of the brain is working harder, it draws more blood) and provides very detailed maps of where things are happening. By using EEG and fMRI in parallel experiments with different people solving the same puzzles, we were able to isolate the brain's aha! moments in both space and time.

We couldn't rely on difficult brainteasers, because to get statistically significant results, we needed each test subject to solve many problems. Instead we used little verbal puzzles such as compound remote associates (CRAs), which people can solve either insightfully or analytically. Each CRA consists of three words, such as "pine," "crab" and "sauce." The participant's job is to think of a fourth word that can be used to form a compound word or familiar phrase with each of the three given words. Immediately after a volunteer solved one of these puzzles, they reported whether the solution had popped into awareness suddenly or been discovered through deliberate, step-by-step thinking. We were thus able to isolate aha! moments and compare the brain activity during them with the brain activity for analytical solutions. (If you're curious, the answer to the CRA in this paragraph is "apple.")

Our key result: an aha! solution corresponds to a burst of high-frequency brain waves in the brain's right temporal lobe, just above the right ear. That part of the brain, the right anterior superior temporal gyrus, connects with many other brain regions. It is associated with our ability to realize connections between concepts that may initially seem unrelated, as occurs when comprehending metaphors, jokes and the gist of conversations. Our findings linking this specific area of the brain to the aha! experience supported previous work by Edward M. Bowden of the University of Wisconsin–Parkside and Beeman suggesting that the solution to such a problem can be unconsciously present in the right hemisphere, ready to emerge into awareness as an insight.

> The number of puzzles people solved by insight—but not analysis—predicted how well they could discriminate between real news stories and fake ones.

Our later research revealed, however, that aha! moments may excite other areas of the brain, depending on the type of puzzle. In 2020 John and his co-workers showed that insights that solve pattern-reorganization problems activate the frontal lobe rather than the right temporal lobe. Anagrams—for example, rearranging the letters in BELAT to get the solution TABLE—are among such problems. Thus, the distinctive feature of an insight is the sudden burst of high-frequency brain-wave activity, which can occur in various parts of the brain, depending on the type of problem solved.

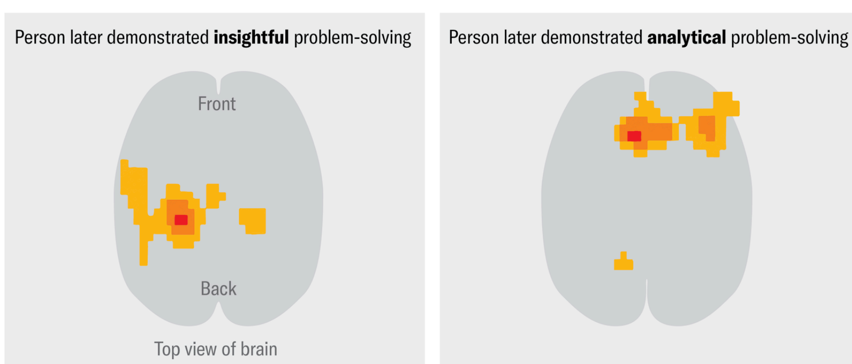
Some problems lend themselves to an analytical, as opposed to an insightful, solution. Analytical problem-solving recruits areas of the brain involved in "executive" processes such as "working" memory that rely on the brain's frontal lobes. Virtually everyone can use either insightful or analytical methods, but many people tend to use one rather than the other. Nobel laureate physicist and mathematician Roger Penrose, for example, can obviously think analytically but seems to be inherently insightful: "I had this strange feeling of elation, and I couldn't quite work out why I was feeling like that," he once said in an interview. It turned out he'd had an epiphany about the formation of black holes while crossing a road. "I do most of my thinking in visual terms," he related, "rather than writing down equations."

In the 2010s Brian Erickson, then a doctoral student in John's laboratory at Drexel University, and his colleagues demonstrated that people's tendency toward insightful or analytical thinking is evident during “resting-state” brain activity—while a person relaxes with no task to perform or expectation about what is to come. Erickson recorded people’s resting-state EEGs and then, weeks later, tasked the same participants with solving a series of anagrams. The astonishing result: a few minutes of EEG predicted, up to seven weeks in advance, whether a person would solve the puzzles mostly insightfully or analytically. Our predominant thinking style is stable over time.

The subjects who relied mostly on insight had greater resting-state activity at the back of the brain, whereas the analytical subjects had greater activity in frontal areas. The frontal lobes, the seat of a person’s executive processes, organize activity in the rest of the brain. These executive processes enable people to think in a focused and strategic way, but they can also curb creativity by limiting thought to straightforward plans, just as a horse’s blinders block out distractions that would lead it to meander from its path. When frontal lobe activity is relatively low, as it was for the insightful subjects, posterior areas can be disinhibited and “go rogue,” sometimes resulting in aha! moments.

The Insightful vs. Analytical Brain

These brain maps, based on electroencephalography (EEG), show differences in “resting-state” brain activity between people who, up to seven weeks after the scans, were asked to solve verbal puzzles called CRAs. People who showed greater activity near the back of the left side of the brain (*left*) solved more puzzles with insight up to seven weeks later. In contrast, those who had greater activity in the right frontal areas of the brain (*right*) solved more puzzles in a deliberate, analytical fashion.



Jen Christiansen; Source: “Resting-State Brain Oscillations Predict Trait-like Cognitive Styles,” by Brian Erickson et al., in *Neuropsychologia*, Vol. 120; November 2018 (*reference*)

Although individuals may be inclined toward more analytical or insightful thinking, we aren’t locked into one or the other. Your thinking style can shift or be nudged, at least temporarily, to the other strategy. One factor is mood. In a 2009 study led by Karuna Subramaniam, then a doctoral student in Beeman's lab at Northwestern University, researchers found that participants who reported feeling more positive solved more puzzles by insight, whereas those who reported greater anxiety solved more puzzles analytically.

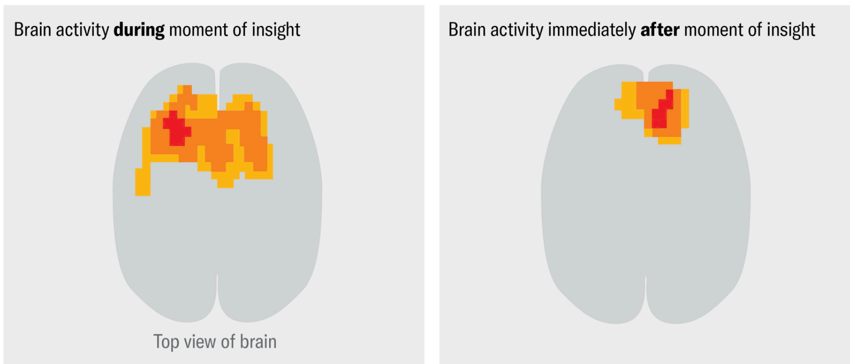
Why might that be? Consider the following example, courtesy of Beeman. Imagine you are in Africa 25,000 years ago. You see a lion off in the distance and are gripped with fear. Your thinking immediately becomes very careful and deliberate—analytical—because one mistake and you are finished. Can the lion see me or hear me? Am I upwind or downwind? If I run, is the lion close enough to catch up?

You manage to escape. That evening you are back in the cave with your people. There's a fire, so it's warm, and the day's catch is cooking on a rack. You are enjoying what researchers call psychological safety. In your protected haven, you don't have to suppress rambling, fanciful thoughts—the stuff of creativity. You are empowered to say or do something imaginative. That may be why, 25,000 years later, we find the innovative, practical flint tools and breathtaking cave paintings that sustained and inspired the lives of the ancients.

Creative insight has an evolutionary purpose: it helps us and our offspring survive and thrive. This relation is evinced by the fact that, like feasting or procreating, insight is enjoyable. In 2020 Yongtaek Oh, then a doctoral candidate in John's lab at Drexel, identified a distinct neural signature of this pleasure: a second eruption of high-frequency brain waves immediately after the initial pulse signaling an insight. (Only participants who had at least some "reward sensitivity," the motivation to approach or acquire things, had this second burst; the others did not appear to respond with pleasure to solving the puzzles.) This second brain-wave pulse was in the front of the brain behind the right eyebrow, in the orbitofrontal cortex, a part of the reward system that responds to delicious foods, addictive substances, orgasms—and, evidently, aha! moments.

The Delight of Insight

The EEG map at the left shows a burst of high-frequency brain waves that occur when someone solves an anagram by insight. On the right is a second burst of high-frequency brain waves, 100 milliseconds later, appearing in the orbitofrontal cortex, a part of the brain's reward system. It marks the thrill of an aha! moment.



Jen Christiansen; Source: "An Insight-Related Neural Reward Signal," by Youngtaek Oh et al., in *NeuroImage*, Vol. 214; July 2020 (*reference*)

To discover whether more complex insights could lift mood over a longer time, Christine Chesebrough, then a doctoral student in John's lab, developed word pairs that formed ongoing analogies, such as steering wheel/car followed by rudder/boat, both of which suggest an implement that guides a vehicle. The next word pair could be either handlebars/bicycle, which continues this theme, or voting/government, which forces the subject to reinterpret the ongoing analogy in a more abstract way as one entity controlling another. This conceptual expansion sparked strong aha! experiences that elevated participants' moods for at least the hour-long test session—the more insights, the better their mood. The vibe persists. The joy of insights can thus impel scientists, artists, writers, and others to feel such a strong drive to express their creativity that they forgo a well-paying job to immerse themselves in their vocation, contributing essential ideas to culture and science.

The thrill of an aha! moment can increase risk-taking. As a doctoral student in Beeman's lab, Yuhua Yu led a study in which she and her colleagues gave people CRA puzzles to solve. Between some of these puzzles, they offered the participants a choice between taking a small payment—a sure thing—and taking a chance to win a larger prize with the risk of no payoff. After finding an analytical solution, the volunteers tended to take the smaller, guaranteed payoff. But after enjoying an insight, participants were more likely to gamble on winning the bigger prize. Experiencing an aha! moment can therefore promote an appetite for risk, which, as Maxi Becker of Humboldt University of Berlin and her colleagues showed in 2023, involves the nucleus accumbens, a dopamine-rich part of the brain's reward system.

Tolerance for risk can be good or bad depending on the circumstances. But one unequivocal benefit conferred by insightful thinking is reduced "bullshit receptivity," as Carola Salvi of John Cabot University in Rome and her collaborators have found. People are flooded by biased information and slanted reporting, and their limited capacity to deal with this torrent of information makes them vulnerable to false messages. Fortunately, insightful thinking is largely unconscious and does not tax attention or working memory the way analytical thinking does. Salvi and her co-workers observed that the number of puzzles the participants in their study solved by insight—but not analysis—predicted how well they could discriminate between real news stories and fake ones, as well as between meaningful statements and "pseudo-profound bullshit" statements. Insightfulness is not only for dreamers: it confers real-world skills that help people navigate the overwhelming information landscape.

Insight also enhances learning and memory. Amory H. Danek of Heidelberg University in Germany and her colleagues showed participants videos of magic tricks and asked them to explain how the tricks were done. Later the subjects remembered the solutions that were experienced as aha! moments better than explanations that were not. Danek and Jennifer Wiley of the University of Illinois at Chicago followed up this study by showing that the pleasure accompanying insights made them easier to recall. Jasmin

Kizilirmark of the University of Hildesheim in Germany and her colleagues have been exploring how this so-called insight memory advantage can be applied to improve memory in older adults.

Aha! moments can have a downside. Insights are more likely to be correct than analytical solutions—but they are not always correct. The dilemma is that people tend to be particularly confident about their insights, even the false ones. Furthermore, work by Ruben Laukkonen of Southern Cross University in Australia and his colleagues suggests that statements presented along with anagrams that people solve by insight also feel more believable than statements presented with anagrams solved by analysis. Aha! moments may create an aura of truth that envelops accompanying information.

The fact that mood can alter one's thinking style has profound implications for our understanding of creativity. Subramaniam's fMRI analyses isolated the lone area of the brain that responds to both differences in mood and differences in thinking style. This area, the anterior cingulate cortex, located in the middle of the front of the brain, detects conflicting strategies. When you are relaxed, your anterior cingulate cortex is better able to detect the presence of an alternative to the most obvious, but possibly ineffective, problem-solving strategy and switch to it, sparking an aha! moment. But when you are anxious, it is less able to detect the subtler strategy, and you will continue to grind through the problem in a straightforward, analytical manner.

An obvious way to increase insightfulness is therefore to relax and carve out a span of time when you aren't anxious or rushed. Another way is expansion in space: When you are in a large room or the great outdoors—under a starry sky, as Morgan was—your attention expands to take in the large space. That broadened awareness shifts the mind toward considering the whole rather than the parts, thereby enhancing insightful thinking. Filtering out the world around you can have a similar effect: aha! moments are often preceded by eye blinks and looking away from a problem to reduce distractions. People solve more thinking problems when they close their eyes. In contrast, objects that grab attention will narrow your focus on details and induce you to think analytically.

Steven Smith of Texas A&M University and his collaborators have also shown that if you take a break from a problem to do something else, preferably a relatively undemanding task such as light gardening or housework, any misleading information or misinterpretation will loosen its grip, and you will be more likely to achieve an insight. Kristin Sanders, now at the University of Notre Dame, and Beeman showed that sleep can enhance this process, supporting the many stories of scientists who have experienced great ideas during or right after sleep. Colleen Seifert and David E. Meyer of the University of Michigan and their colleagues reported another benefit of breaks: you may encounter a trigger—a person, a street sign, anything—that can spark an aha! moment because the trigger bears some resemblance to or association with the needed solution.

How about drugs? The thought of popping a pill that would unlock creative insights may be appealing for some people. Microdosing psychedelic drugs has been proposed to increase innovative thinking. We are not aware of any rigorous scientific evidence that psychedelics can increase the likelihood of insights, although they may cause a person to feel creative and profound. But alcohol, if not taken to extremes, does seem to enhance insightful solving. (That is not an endorsement!)

Perhaps there are other ways to directly intervene in brain function to produce aha! moments. Several researchers, including Beeman, Salvi, Amna Ghani of Charité–Universitätsmedizin Berlin, Caroline Di Bernardi Luft of Brunel University London and Joydeep Bhattacharya of Goldsmiths, University of London, have shown that direct electrical stimulation of test subjects' right temporal lobes with electrodes placed on their heads—in some cases, synchronized with hints—can increase the likelihood that they will solve CRA puzzles using insight. For various reasons, though—including the fact that different types of insight involve different areas of the brain—it is unlikely that electrical stimulation will become useful as a technique for sparking aha! moments.

Here's what does not work: expectations of monetary prizes or bonuses. Payments can coax a person to tackle a problem—and people should certainly be compensated for their work—but they can also inhibit insights. A focus on an expected payoff grabs and narrows one's attention, limiting creative thought. Messages about rewards can enhance insight—but only when they are displayed so briefly that a person cannot consciously perceive them. When innovation is the goal, conspicuous rewards may therefore be counterproductive, as are strict deadlines that switch one's thinking to an analytical mode by inducing anxiety and narrowing mental focus.

Alternatively, you could just go get groceries. Vishal Rao, an oncologist in India, endured years of frustration before a surprising twist enabled him and his unique team to create an amazing medical device. As a surgeon specializing in neck and throat cancer, Rao knew that most of the tens of thousands of new patients with throat cancer each year in India could not afford the prohibitive cost of surgery to replace their diseased voice box with an artificial one. So, in 2013, Rao formed a team that developed an inexpensive artificial voice box costing less than a dollar.

But there was one roadblock remaining. The artificial voice box had to be replaced yearly in a surgical procedure that costs hundreds of dollars, a regular expense way beyond the means of most of his patients. He needed an inexpensive, nonsurgical tool that a patient could use to remove an old artificial voice box and implant a new one—a challenge that seemed insurmountable.

One day Rao went to the supermarket with his toddler. The boy broke free and started running down the aisles, gleefully knocking things off the shelves. Rao chased and caught him, but only after the boy had knocked down a box of tampons, the contents of which spilled out onto the floor. When Rao saw the tampon applicator, it sparked an aha! moment: here was a safe, inexpensive, nonsurgical implement that could be a model for a voice-box applicator.

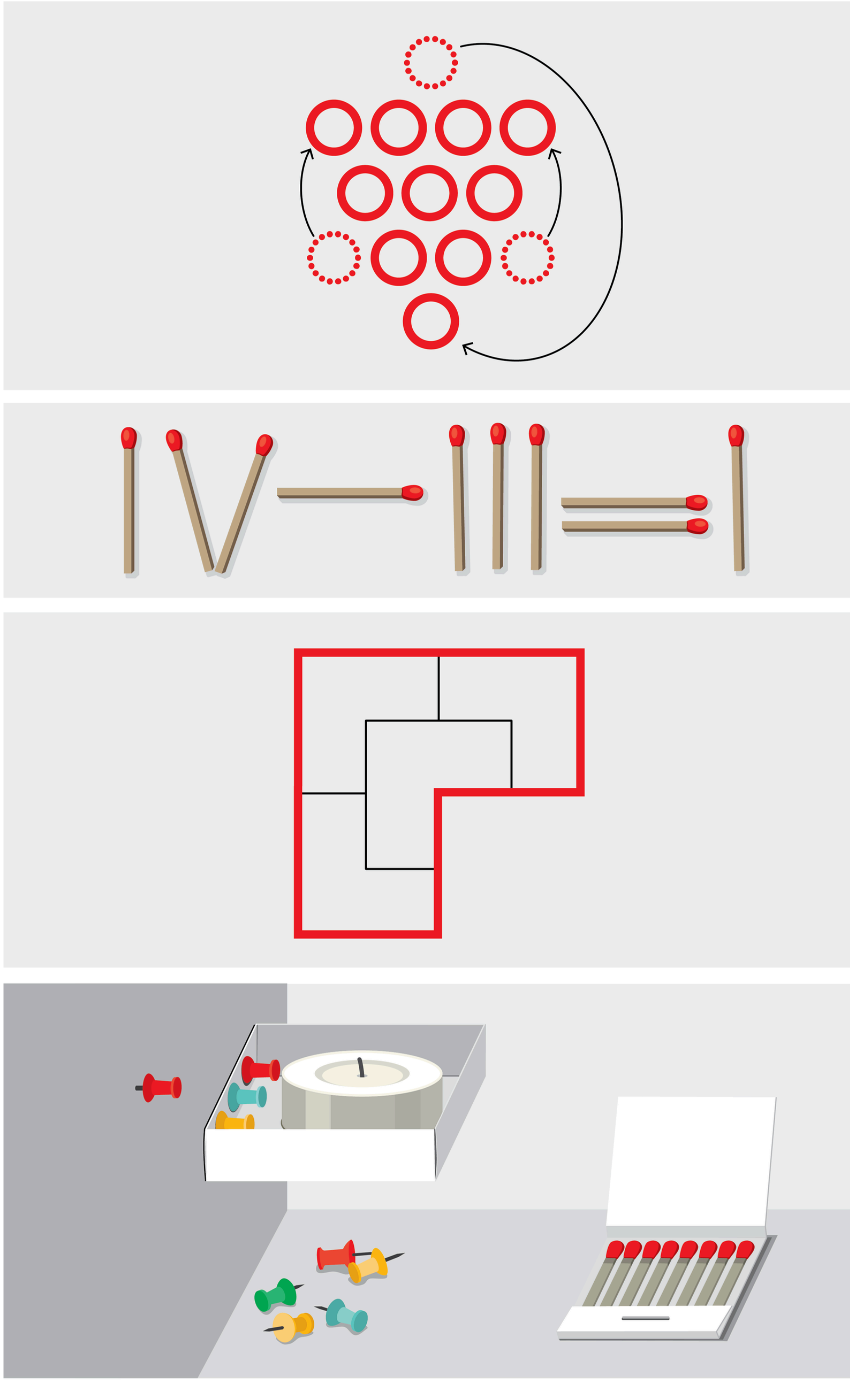
When Rao explained this idea to others, they said the device he wanted sounded more like a toy than a surgical instrument. This comment triggered the doctor's second aha! moment. He recalled that Channapatna, a nearby city, is nicknamed "toy town" because of its centuries-old tradition of master craftsmen who design and make inexpensive wood toys. After interviewing Channapatna toy makers, he found Kouser Pasha, who was intrigued by the idea. It took Pasha just a couple of hours to come up with a design for an inexpensive voice-box applicator.

Just as hungry people tend to notice anything related to food, Rao's initial failure to imagine an inexpensive applicator sensitized his brain to anything around him that looked like it could help him solve the problem. When he took a break from his problem, his old ways of thinking relaxed their grip as he was exposed to a variety of objects in the supermarket. One of those objects, the tampon applicator, was potentially related to the problem, so it grabbed his attention. Once he figured out that a similar device would work, the surgeon still had to figure out how to design and manufacture it. The need for a solution sensitized him to the word "toy," which triggered his insight about recruiting a toy maker from "toy town."

The upshot: when you are stuck, take a break and expose yourself to a variety of environments and people to increase the chance you will encounter a triggering stimulus. Perhaps the most important scientific lesson about insight, though, is that it is as fragile as it is beneficial. The aha! moment brings new ideas and perspectives, lifts mood, increases tolerance for risk, and enhances the ability to discern truth from fiction. But anxiety and sleep deprivation can squash these precious gifts.

Modern society’s unrelenting demand for productivity and speed often denies insight the time and opportunity to work wonders at its own pace. Even so, we need to remember the value and power of insights and the conditions that spark them. As Morgan’s galactic epiphany shows, when it comes to aha! moments, the sky is the limit.

Brainteaser Solutions



Jen Christiansen; Sources: "Intuition in Insight and Noninsight Problem Solving," by Janet Metcalfe and David Wiebe, in *Memory & Cognition*, Vol. 15; May 1987 (*triangle and polygon reference*); "Restructuring Processes and Aha! Experiences in Insight Problem Solving," by Jennifer Wiley and Amory H. Danek, in *Nature Reviews Psychology*, Vol. 3; January 2024 (*candle problem reference*)

John Kounios is a professor of psychological and brain sciences at Drexel University. He is co-author of *The Eureka Factor: Aha Moments, Creative Insight, and the Brain* (Random House, 2015) and co-inventor of a brain-age estimation technology. Follow him on X (formerly Twitter) @JohnKounios or on LinkedIn.

Yvette Kounios is a writing instructor at Widener University and a Philadelphia Press Association Award recipient.

https://www.scientificamerican.com/article/the-elusive-brain-science-of-aha-moments

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The Beauty of ‘Slow Flowers’ versus the Pretty Poison of Plants Grown with Dangerous Chemicals

New “slow flower” farms grow beautiful blooms—without health-harming chemicals used by overseas operations that dominate the U.S. flower market

By Maryn McKenna edited by Josh Fischman

Dahlias bloom at the Maine Flower Collective, a group of local growers.
Jesse Burke

On a low hill near the coast of Maine, the fresh petals of double daffodils shake frills of gold and peach in a gusting breeze. It is the middle of May, a clear blue sky overhead, and the lacy burgundy foliage of peonies and new stalks of twiggy curly willow are poking through swaths of black landscape fabric. Against the walls of a greenhouse, seedlings of cosmos and celosia, lisianthus and snapdragons rise in plastic trays. Mud season is barely over, but the turf is vivid green.

Those fragrant, frilly blooms will make up wedding arches and table settings and bouquets, the mainstays of the profitable farm and floral studio that farmer Bo Dennis, 35, has built since he bought this parcel several years ago. “When people come to us, we say, this is what we’re good at: local flowers that are sustainably grown,” he says, tucking a curl of light hair back under his beanie with muddy hands. “Sometimes I do get clients that say, ‘We want all hydrangeas and all roses, and we want them in May’”—a date when those popular flowers won’t yet have bloomed in Maine. “I will say, ‘Great! Have a good celebration. I don’t think we’re the vendor for you.’”

What Dennis grows won’t be found among the blooms that cram the entrances of supermarkets, big-box stores, downtown florists—most of the places where people buy flowers in the U.S. The bouquets that fill those spaces overwhelmingly come from equatorial countries, such as Ecuador and Ethiopia, where cheap labor and minimal environmental regulation make growing affordable. Those flowers are part of an enormously successful international market that sells blooms thousands of miles from their fields of origin and earns more than $25 billion every year.

But pesticides and other agrochemicals required to sustain that scale of production can injure workers and their families. One ongoing study of children in Ecuador whose parents work at flower farms has documented deficits in attention and eye-hand coordination, particularly after periods when these chemicals are heavily sprayed. Children born to women who work in floriculture regions have higher-than-normal rates of birth defects, another study found. And the risks extend to people around the world. In Belgium, florists with imported flowers had unhealthy levels of pesticide chemicals on their gloves, levels high enough to burn the skin if it wasn’t protected. And in the Netherlands, prolific use of antifungals on the country’s signature tulips has fostered the emergence of deadly drug-resistant fungi.

The remedy for at least some of these problems is rising in small U.S. operations such as Dennis’s Dandy Ram Farm and others in

North Carolina and Utah and throughout the country. Dennis came to floriculture out of a desire for economic self-sufficiency and career-long concern for the environment. He and other growers are building a new, surprisingly lucrative agricultural model—a "slow flower movement," akin to the Slow Food movement, that offers a cleaner, greener alternative to modern floral production. They aim to protect ecosystems and build new economic pathways while bringing a bit of beauty—ungroomed, imperfect, unpredictable—back into the world.

Flowers are so present in our lives that we almost do not see them: sheathed in paper in every market, plunked in a vase on a table in any cafe. But while they are quotidian, they are also monumental; in many cultures, they memorialize the most important days of our lives, from graduations and promotions to weddings and funerals. They are vital to Catholic rituals, Hindu festivals, Buddhist temple offerings and Mexico's Day of the Dead—and also, via chrysanthemums, to the quasi-religion of U.S. college football homecoming games. (Mums are funeral flowers in parts of Europe and Asia, which might be a comfort to the losing team.) We invest them with so much meaning that we demand they always be perfect—although like any crop, they are fungible and fragile, subject to weather, diseases and decay.

And like any product, they are subject to the lure of cheaper production offshore. The movement of American manufacturing to countries with fewer regulations over land and labor is an old story, reenacted in products from furniture to cars to food. But the relocation of flower growing was not an accident of global economics. It was deliberately fostered by the U.S. government, part of the 20th-century war on drugs.

A bag at Maine’s Dandy Ram Farm protects a delicate dahlia from pests, avoiding the use of chemicals.
Jesse Burke

In the 1990s, when cocaine flowing from South America was the main focus of drug interdiction, President George H. W. Bush proposed measures to boost legal businesses in the drug’s most important production areas. A 1991 law lifted or reduced tariffs on thousands of products produced in Bolivia, Colombia, Ecuador and Peru. Cut flowers were on the list, and it gave them an enormous boost. U.S. flower production shrank, and the market for imported flowers skyrocketed.

Take roses, the U.S. national flower. In 2002, according to Department of Agriculture data, 157.2 million homegrown roses were sold in the U.S. By 2019 that shrank to 17.2 million. Revenue from homegrown roses plunged as well, from $58.9 million in 2002 to $13.3 million in 2019. “About 25 years ago approximately 85 percent of what was sold in the U.S. was grown here; today it’s about 22 percent,” says Camron King, CEO of the trade group Certified American Grown. That decline represents an economic burden—and, given the resonance of flowers, an emotional one, too. King feels that weight when he watches patriotically colored wreaths of red, white, and blue carnations being laid at sacred military sites such as the Tomb of the Unknown Soldier. “There aren’t commercial-level carnation producers here in the United States any longer,” he points out. “Those are imported flowers honoring our American fallen heroes.”

Multiple global trends have benefited offshore flower growers: larger planes, easier refrigeration, low-cost labor and land. But so has freedom from the rules that protect U.S. workers and consumers. “In California, but also in many other states, there are very strict regulations in terms of pesticides,” says Gerardo Spinelli, a production adviser at the University of California Cooperative Extension San Diego County. “Being in compliance is expensive.” But overseas, “these regulations are not there or are a lot less strict.”

Jose Ricardo Suárez, a physician and epidemiologist at the University of California, San Diego, saw the changes the tariff exemptions brought. His parents, both academics, are from Ecuador. The family moved around, but when they were in his parents’ home country, they often visited Pedro Moncayo *cantón*, a county perched in Ecuador’s Andean foothills. Suárez remembers the high green landscape and how abruptly it changed in the 1990s: “All of a sudden, these greenhouses started popping up in many different parts of the county.”

The explosion of construction was the first bloom of the floriculture encouraged by that 1991 law, which would make Ecuador the third-largest exporter of flowers in the world, a billion-dollar trade that fields a workforce of more than 100,000 people. Ecuador specializes in roses; the cool mountain climate and consistent sunlight of its equatorial days are uniquely suited to producing straight-stemmed, big-blossomed flowers, highly sought after for celebratory bouquets. But those perfect plants don’t grow that way without assistance; they are sprayed routinely with fungicides and insecticides, especially organophosphates, which kill insects by interfering with their nervous systems. As Suárez earned his medical degree in Quito and then his Ph.D. back in the U.S., he became curious about how those compounds might affect the people living nearby.

Kate Del Vecchio collects deliveries at the Maine Flower Collective.
Jesse Burke

In 2008 he founded the Study of Secondary Exposures to Pesticides among Children and Adolescents, known as ESPINA for its acronym in Spanish, to explore whether children in Pedro Moncayo were affected by living in the center of greenhouse production and having parents and family members employed there. “We found what we call take-home pesticide pathways, in which the workers are exposed, and then those pesticides adhere to their clothing or their hair and skin, or maybe they bring home tools, or they bring some pesticides to use in their own backyards,” Suárez says.

“We’ve also looked at the proximity of homes to different spray sites. We tend to think of greenhouses as totally closed, but the fact is that they’re not: They have windows because you need some circulation of air, so the pesticide is not contained just within the crop.”

The study launched with a cohort of 313 children between four and nine years old and then expanded. Approximately half of the kids lived in the same household as workers from flower plantations. The children contributed blood and urine samples, underwent medical exams, and participated in neurological and behavioral assessments. The team began publishing results in 2012. From the beginning, they found problems in the children of flower-farm households that those with no farm connection did not share: first, changes in enzyme levels that affect neurotransmitters and indicate pesticide exposure—and later, effects on learning ability, depression, thyroid function and blood pressure. In one especially poignant result, they found that children linked to flower farms experienced months-long damage to attention, self-control, and eye-hand coordination after one of the biggest spraying episodes of the year: the lead-up to the harvest to make Mother’s Day bouquets.

During reassessments, the investigators recruited additional participants to the cohort, topping out at 554 children and teens and collecting fresh samples of blood and urine from both new participants and long-standing ones. They repeatedly found evidence of exposures to pesticides, demonstrating an ongoing problem. “There haven’t been any changes in regulations when it comes to pesticide use,” Suárez says. National political interest in the issue has waxed and waned, he adds, but local governments have consistently supported their agricultural workers as well as his research.

Suárez and his fellow investigators have tried to do so also. His parents, physician-epidemiologist Jose Suárez-Torres and anthropologist Dolores Lopez Paredes, created a local organization, Fundación Cimas del Ecuador, that gathers international funding for educational exchanges and local initiatives. Perceiving that flower production doesn't produce anything nutritious and also sends its products out of the country, the foundation sought to demonstrate another vision of agriculture, creating an organic produce farm where more than 3,000 teens and young adults have received training in agroecology. "You have to give workers an alternative," Suárez says. "You can't just say, 'Well, don't work in flowers.'"

Other researchers have focused on risks run by the workers themselves. Two decades ago epidemiologist Jinky Leilanie Lu, now a research professor at the University of the Philippines Manila, documented physical and neurological symptoms—chills and fever, dizziness and headache, for example—in about one third of workers whose jobs were mixing and spraying pesticides on flower farms. In 2009 researchers at the University of New Mexico and the University of Michigan reported on high miscarriage rates among the large number of women who worked in the Ecuadorian flower industry. They had a 2.6 times greater risk of miscarriage than other women. In 2015 a paper about flower greenhouse workers in Ethiopia uncovered a series of health troubles. The country had experienced an explosion of rose cultivation over 10 years thanks to its mild climate and high elevation, going from a tiny industry to the fourth-largest exporter in the world. The research found that a large number of workers had rashes and other skin problems, and some had chronic coughs and shortness of breath.

In 2017 a research team at the Autonomous University of Mexico State showed that birth defects in children born in a floriculture region, to women who worked in or near flower farms, occurred in 20 percent of births. That contrasted with 6 percent among women in the same state who worked outside of the flower industry. That same year a separate team of researchers showed that greenhouse workers in two Mexican states who mixed and applied pesticides had higher levels of pesticide biomarkers in their urine than did workers who had less contact with the chemicals. Then last year another paper reported that men who work in the Mexican flower industry and were often exposed to pesticides and fungicides have high blood levels of pro-inflammatory cytokines—small messenger proteins that normally alert the immune system to fight infection but can trigger chronic diseases when they are too abundant.

The colorful flowers are grown in season on local farms.
Jesse Burke

The perils posed by extensive pesticide use on flower farms outside the U.S. do not stay confined to those properties and their workers. In 2016 researchers in Belgium, who were alarmed by reports of flower workers' illnesses, published a study on the hazards of flowers after they were cut and shipped. The blooms were not subject to strict rules imposed on food, because they are not a crop intended for eating. In two studies, the scientists tested flower bouquets sold at florists and in supermarkets and found levels of fungicides and pesticides—especially on roses—that could be harmful to the human nervous system if they were absorbed through the skin.

To ascertain whether any real risk existed, in follow-up research the scientists asked a group of florists to wear cotton gloves for several hours on two consecutive days while trimming flowers and assembling bouquets and then analyzed what the gloves had picked up. They found 111 different agricultural chemicals, mostly pesticides and fungicides, present in concentrations up to 1,000 times higher than are allowed on produce. Several were present in such high concentrations that they represented both immediate and chronic risks to the florists' health, capable of causing skin burns and eye irritation, risking damage to a fetus or exposing a breastfed child. The researchers noted that wearing gloves while working and not eating or smoking with flowers nearby would reduce the danger.

In the most troubling example, chemical use on flower farms has reached far beyond the farm environment, and farm workers and flower handlers, to affect people not involved with agriculture at all. In the early 2000s a group of physicians in the Netherlands began to notice a worrisome pattern in the sickest patients in their intensive care units. People whose immune systems have been undermined by illness and repeated rounds of drugs are vulnerable to what are called opportunistic infections, triggered by organisms that don't cause disease in healthy people.

One of the most feared is a fungus called *Aspergillus fumigatus*, which lives in compost heaps and decaying vegetation and puffs out spores that drift through the air. A healthy immune system will sweep inhaled spores from the lung and dispose of them, but in someone with diminished defenses, they lodge in the lung lining and reproduce. The overwhelming infection that results, invasive aspergillosis, occurs in more than two million cases worldwide every year. It was almost always a death sentence until a class of antifungal drugs called azoles debuted in the 1990s and began saving patients from it.

A new greenhouse at Dandy Ram Farm holds snapdragons, zinnias, and many other flowers grown using organic farming principles.
Jesse Burke

But within 10 years of the drug class debuting, that trend reversed. ICU patients began dying again from invasive aspergillosis; when experts investigated, they discovered the fungus had developed resistance to azoles and was no longer vulnerable to the drugs' attack. In critical care medicine, it is not unusual for infections to become resistant after rounds of drugs. But these azole-resistant infections were occurring in people who had never received those antifungals—and their organisms displayed an identical genetic pattern even in patients hospitalized many miles from one another.

An informal strike force of physicians and microbiologists assembled to investigate the problem. If patients were suffering from azole-resistant infections yet had never received azoles in health care, the fungi that had taken hold in their bodies must have been exposed to antifungal compounds somewhere else first—and that exposure must have been common enough, across the Netherlands, to exert the same selective pressure everywhere at the same time.

The answer, it turned out, was flowers: the tulips that the Netherlands is famous for and the other bulb-making blooms, lilies and hyacinths and alliums, in which it leads the world. At the same time that medicine was benefiting from the new class of azole drugs, agriculture had been using a class of fungicides based on the same chemical structure. Bulbs planted in the Netherlands, grown to flowering and then harvested for sale around the world, were dipped into azoles or sprayed with the fungicides to protect the investment they represented. That blanket distribution had found its way to *Aspergillus* in discarded plants and compost heaps of trimmed foliage, and the spores of the newly resistant fungi had been breathed in by patients and made them untreatably ill.

By processes that no one has fully defined—simultaneous evolution, or international sales of plants and bulbs, or fungal spores carried on the wind—lethal azole-resistant *Aspergillus* spread worldwide. It is a persistent danger, says Paul Verweij, chief of medical microbiology at Radboud University Medical Center in the southern Netherlands, one of the first researchers to identify the problem. “The rate of occurrence is quite stable; it is not going down.”

To this point, there has been no indication that international flowers pose a danger to everyday consumers buying a bouquet at a supermarket. Patients who were sickened or killed by exposure to resistant *Aspergillus* were often already ill, and workers harmed by the procedures of flower growing were exposed by the nature of their jobs. But absent major changes in mass floriculture, those risks will remain.

Bo Dennis (*left*) and Catalina Rodriguez (*right*).
Jesse Burke

In the U.S., it is much less likely that small flower farmers will create risks for their workers or their communities. These small growers don’t have the land or equipment to field thousands of acres of identical flowers that may be overwhelmed by a single disease or pest. Nor are small growers compelled by contract to produce thousands of perfect stems to catch the market for graduation or Valentine's Day. Both of those circumstances can drive up agrochemical use.

"The market has pretty much bifurcated into two streams," says John Dole, a professor of horticultural science at North Carolina State University and an adviser to the Association of Specialty Cut Flower Growers. ("Specialty" designates less common flowers, outside the market domination of roses, chrysanthemums and carnations.) "We have the very large international growers, who ship primarily through Miami. They focus on low-cost production. They are primarily supporting the big-box stores, which would be grocery stores and mass-market wholesalers. Most U.S. growers are not facing competition from Colombia and Ecuador, simply because they're growing different products."

Out of preference and for differentiation in the marketplace, many small-scale flower farmers follow organic principles, such as no synthetic fertilizers or pesticides, although they may not pursue the years-long process to get USDA organic certification. "Getting that designation is expensive, so a lot of people say that they grow responsibly, sustainably," says Val Schirmer, president of the specialty growers association and a founder of Three Toads Farm in central Kentucky. "Most of our growers don't want to use pesticides. They are much more likely to use beneficial insects and to improve their habitat, like for birds." (Instead of the USDA route, some farmers opt instead for Certified Naturally Grown, a peer-reviewed process developed for small farms that allows growing flowers for which no organic seed is available.)

Without the pesticides and fungicides in use on large farms, workers and owners are safer, and research conducted on flower farms that grow organically or sustainably backs up the assumption that they are healthier for the environment, preserving the diversity of the soil microbiome. "Part of the reason these farms work fairly well is they mimic nature more closely," Dole says. "Because of our diversified operations, we have a lot of insect pests. But we also have a lot of insect enemies."

Dennis harvests a field of dahlias, each flower covered in a bag to shield it from the tarnished plant bug, a crop-destroying insect.
Jesse Burke

None of that would matter, of course, if small farms could not sell their product. "When I first started in this business, I would load my flowers into the back of my pickup truck and drive around to florists, and they would refuse categorically to buy local flowers," says Kate Swift, a flower grower who has operated Cedar Farm Wholesale in New York's Hudson Valley since 1997. "They felt that the quality was inferior. That's how strong a hold overseas production had on the psyche of the buyer."

By 2014, though, a USDA analysis pegged floriculture as the most lucrative product for most small farms (under 10 acres) in the U.S. that specialize in a class of crop, outpacing livestock, poultry and produce in earnings per acre. In 2024 two thirds of people responding to an annual survey by the National Gardening Association said they would preferentially buy local flowers to support family farms and keep agricultural jobs in their regions. Small flower farmers found customers first at farmers markets and among members of community-supported agriculture programs, then at local florists, and finally by linking up with restaurants and event designers where they could charge a premium—in some cases, as at Dandy Ram, by becoming farmer-florists themselves.

To accomplish that, the farmers had to persuade their clients to embrace a new aesthetic: less polished and more primal, twining and frondy, founded on blossoms that might be too lush and soft to endure weeks of refrigerated storage but could be guaranteed to look and smell like nothing else. "I'm trying to convince other floral designers that what they really want are locally grown, beautiful, interesting, unique flowers," says Stacy Brenner, a Maine state senator and one of the proprietors of Broadturn Farm in Scarborough, Me. "Trying to push them to think about shape and color and less about specific blooms, that you can make things look certain ways with color and texture, and you can use local flowers to do it."

If this sounds like the journey of food production in the late 20th century—away from conventional agriculture and toward sustainable and regenerative farms growing heirloom vegetables and heritage breeds—the parallels are close. Debra Prinzing was a journalist writing about architecture and interiors for glossy magazines when she started to think about the provenance of flowers. The international Slow Food movement had launched 20 years earlier, and in the U.S., food activists had begun to talk about consuming only food raised within strict geographic limits. In 2007 novelist Barbara Kingsolver published the best-selling *Animal, Vegetable, Miracle*, about relocating her family to Appalachia so they could eat from their own property, and the *New Oxford American Dictionary* decreed "locavore" the word of the year.


In the floral design barn, Dennis arranges cut flowers.
Jesse Burke

Prinzing lives in Seattle, infamous for its short, dark, winter days—yet in the wet worst of that season, she would walk into local supermarkets and encounter bright cellophane-wrapped bouquets that looked plucked from a summer field. The contrast jarred her. She wrote a book in 2012, *The 50 Mile Bouquet*, to support local flower production, and then a second the next year, *Slow Flowers*, borrowing the "slow food" nomenclature to provide a manifesto for local production. In 2014 she founded the Slow Flowers Society and directory to help consumers find designers and producers. It has 750 members now. “If someone was tied into understanding where their food came from, it wasn’t much of a leap for them to say flowers are a legitimate form of agriculture,” she says, calling slow flowers an attempt to “redefine what is beautiful and redefine that if you live in the seasons—which is the slow food ethos as well—you are not going to have everything all the time, 24/7, 365 days a year.”

The benefit of the emergence of U.S. slow flowers extends beyond supporting the farms themselves. By offering an alternative to foreign flowers, they are creating economies where their products and their vision can find a home.

On a sunny spring afternoon, vans pull up to a low white clapboard building on Crystal Spring Farm in Brunswick, Me., a historic property marked at the roadside by a long horizontal sign of a big wood carrot with a bite taken out. The vans unload bucket after bucket of paper-wrapped sheaves of flowers: delicate lily of the valley and glowing pink bleeding hearts, refined pale-blue nigella, smooth and frilly tulips in purple and apricot, branches of lilac and beech and peach and apple blossoms, and dozens more colors and types. The sheaves come from farms; inside the shed, workers assess their contents and sort them into new buckets to match 24 pages of orders tacked to the wood walls. Each order comes from a florist who placed it in the previous few days on the software platform of the Maine Flower Collective, a member-owned cooperative launched in 2023 that aggregates the products of local growers to make them easier for local designers to buy.

Cosmos and other cut flowers are made into bouquets at Dandy Ram Farm.
Jesse Burke

Before the collective began, the closest wholesale flower market was two states and 130 miles to the south in Chelsea, Mass., in Boston's infamous traffic. "There was one in Bangor years ago, and it closed down," says Sofia Oliver, the collective's operations manager, tugging down a knit cap to protect against the chilly fragrant air. "Which I think was part of the reason a lot of growers and buyers started working together to get this collective started."

Every week local flower growers—41, on this May afternoon—post whatever looks ready on the collective's private site, and designers peruse the offerings and place orders. On a morning after orders close, the collective's vans take off on long loops around the state, scooping up harvested flowers and delivering them to the shed for sorting. Once they are matched to their orders and rebucketed, the flowers go into the shed's coolers and get delivered the next day. It makes up a web of selling and buying and connection, an economic network that, thanks to local flowers, stitches together the state.

The new economic opportunities that small farm flowers represent stretch across the country. Take Utah, where flower farms have proliferated from 18 in 2018 to 199 in 2023. Floriculture may fit well with local norms because it allows women to develop home-based businesses. “We have a lot of women who are household managers and primary caregivers,” says Melanie Stock, an associate professor and extension specialist at Utah State University’s College of Agriculture and Applied Sciences who surveys the industry. “It is such a premium, high-value crop, and they are entrepreneurs, so they are finding these small parcels of land and making it into a profitable business. It helps families out of underemployment without imposing associated childcare costs.”

And at its best, flower production allows farmers to extend to others the opportunities they have developed for themselves. For Dennis, owning Dandy Ram offers the possibility of bringing more LGBTQ people into agriculture. He and his partner have set aside some of their acreage to lease to brand-new queer farmers, creating an incubator for those who cannot yet afford their own. “A big reason why I keep farming is to build community,” he says, “so we share land with a few people who are learning how to grow.”

The collective action, the support for others, the community building—as much as the flowers themselves, they are acts that bring beauty into the world. For flower farmers, it is especially poignant that these investments in the future arise from something so ephemeral. “It may look very glamorous from all of the things that people see and post online, but it’s definitely still difficult,” Oliver notes. But the blooms are worth it, she says: “Flowers are like food for the soul. They fill a different kind of need. Some people might think of them as frivolous, but they bring people joy.”

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https://www.scientificamerican.com/article/look-for-slow-flower-bouquets-plants-grown-without-health-harming-chemicals

Where Are the Universe’s Missing Planets?

Planet demographics reveal a puzzling lack of worlds in a certain size range throughout the galaxy

By Dakotah Tyler edited by Clara Moskowitz

Ron Miller

For centuries our solar system was the only planetary system known to humans. We had no proof other worlds existed beyond those in our own cosmic backyard, and we imagined that if other planetary systems were out there, they would mirror ours: small, rocky worlds orbiting close to their stars, with giant planets similar to Jupiter and Saturn farther out. Scientists studied the history of our sun and its satellites with all the tools they had, and they used the knowledge they gained to shape our understanding of how planets form and evolve. But about three decades ago astronomers discovered exoplanets circling stars that were not our own. In the years since, we have found thousands of them, shattering what we thought we knew about planets.

It turns out that planetary systems in our galaxy exhibit remarkable diversity—some have tightly packed planets in exotic configurations; others are dominated by gas giants skimming their stars. Now a new era of planetary science has emerged: exoplanet demographics. By analyzing patterns in the sizes, orbits and compositions of the planets they detect, scientists are uncovering the real processes that shape planetary systems. What we are finding is not a simple narrative but a puzzle: striking trends in planet populations that challenge our understanding of how planets are born and grow.

These trends offer new clues about the answers to fundamental questions: Why are there very few planets in particular size ranges—most notably a swath of "missing planets" somewhat larger than Earth? Why does our solar system lack the most common types of planets in the galaxy—those larger than Earth but smaller than Neptune? And perhaps most important, how do these findings affect our search for habitable worlds?

Unraveling these mysteries isn't just about studying individual planets—it's about seeing the big picture. By investigating the patterns in exoplanet demographics, we're learning not only what makes planetary systems tick but also where our solar system fits into this galactic context. Ultimately, we want to know whether our planet is rare—or whether the conditions that allowed life to arise here might be plentiful out there.

The first confirmed exoplanets were discovered in 1992 orbiting a pulsar—a radio-wave-emitting, rapidly rotating neutron star formed from the aftermath of a massive star turned supernova. It's still unclear whether these pulsar planets survived the supernova explosion or formed from its debris. In either case, they are outliers in the known exoplanet dataset.

The real breakthrough came in 1995 with the discovery of 51 Pegasi b, the first exoplanet found orbiting a sun-like star. This world defied all expectations. Rather than a distant gas giant like Jupiter, 51 Pegasi b was a behemoth half the mass of Jupiter but orbiting astonishingly close to its star, whipping around it once every 4.2 days. At such proximity the planet would broil at around 1,800 degrees Fahrenheit, hot enough to vaporize some metals. Although 51 Pegasi b has only about half Jupiter's mass, this extreme temperature causes the gas to inflate, giving the planet a radius twice as big as Jupiter's. Astronomers dubbed this strange new class of planets "hot Jupiters."

The existence of hot Jupiters threw a wrench into the leading planet-formation models. Theories had been based on the structure of our solar system, where rocky worlds orbit close to the sun, and gas giants stay much farther out in colder regions where they can accumulate hydrogen and helium gas. But here was a Jupiter-mass world that somehow occupied the searing-hot inner reaches of its planetary system. If massive planets could form so close to their stars—or form farther out and move there later—what other unexpected arrangements might exist?

> We want to know whether our planet is rare—or whether the conditions that allowed life to arise here might be plentiful.

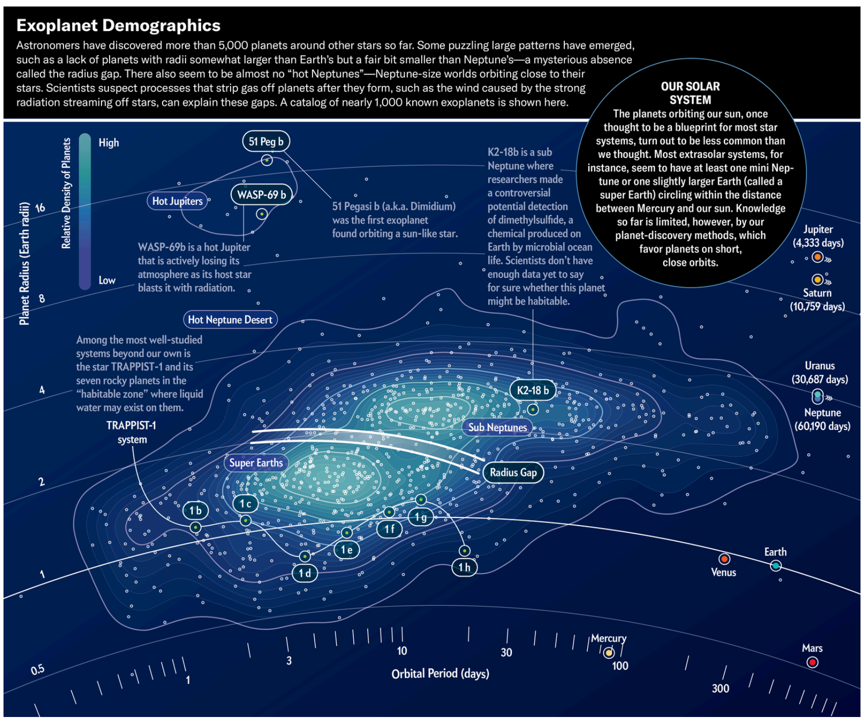
Astronomers discovered 51 Pegasi b by detecting a wobble in its star's motion caused by the gravitational tug of the orbiting planet—a technique called the Doppler (or radial velocity) method. As a planet orbits, it pulls its star slightly toward it. From our perspective on Earth, that star moves closer toward and then away from us (if the orbit is at the right angle from our line of sight), causing the star's light to alternately redshift and blueshift, similar to the way the pitch of an ambulance siren rises as it approaches and falls as it passes by. The more massive the planet and the closer its orbit, the greater the stellar wobble and the easier it is to detect.

That's why the first exoplanets found with this method were hot Jupiters—and why this strategy has a strong detection bias for large planets in close orbits. As more planets were discovered with the radial velocity method, patterns began to emerge. By 2008, after surveying hundreds of stars, researchers found that about 10 percent of sun-like stars host giant planets within a few times the Earth-sun distance (called an astronomical unit). Yet these early demographic patterns were clouded by our observation biases.

A major step forward in planetary demographics came when NASA launched its Kepler Space Telescope. By staring continuously at more than 150,000 stars for four years, Kepler detected thousands of planets, using what's called the transit method. It searched for the slight dimming of a star's light that occurs when a planet passes in front of it from our point of view. The results were startling: Erik A. Petigura, my Ph.D. adviser at the University of California, Los Angeles, analyzed the Kepler data and showed that approximately half of all sun-like stars host at least one planet between Earth and Neptune in size. These planets, which don't exist in our solar system at all, seem to make complete orbits around their stars in weeks or months rather than years. In retrospect, it had been shortsighted to think our solar system was the galactic template. As a rule of thumb in astronomy, however, it's usually safe to assume our perspective is average and not special, so I think we can be forgiven.

As the Kepler sample grew, a mystery became more and more apparent. Astronomers saw a striking dearth of planets with sizes around 1.6 to 1.9 Earth radii, which they called the radius gap. This finding was no detection-bias fluke—after researchers had accounted for all the selection effects and biases in the observations, the gap remained. Something about planet formation or evolution must actively prevent planets from maintaining this intermediate size, most likely a process that strips atmospheres from planets in this range.

Adding further intrigue to this puzzle is a phenomenon known as the "hot Neptune desert." Planets the size of Neptune are conspicuously absent on orbits shorter than about three days. The reasons for this scarcity are still under investigation, but extreme radiation from stars at this distance and tidal forces probably contribute to this trend. Just as we see with smaller planets that have masses near the radius gap, short-period Neptunes are especially vulnerable to atmospheric loss. Over time their thick gaseous envelopes may be completely stripped away, leaving behind bare, rocky cores that we might classify as super Earths—scaled-up versions of our rocky world. Scientists think the hot Neptune desert is therefore a more extreme case of the same processes shaping the radius gap. (As we gathered more observations, some theories even predicted these features as a consequence of the radiation streaming from stars.)



Nadieh Bremer; Source: "The California-Kepler Survey. X. The Radius Gap as a Function of Stellar Mass, Metallicity, and Age," by Erik A. Petigura et al. in *Astronomical Journal*, Vol. 163; March 2022 (*data*)

Follow-up radial velocity observations with ground-based telescopes added another crucial piece to the puzzle. By measuring the masses of known exoplanets, astronomers found that the radius gap corresponds to a transition in composition. Planets with masses below the gap are dense and rocky like Earth, whereas those above it have lower densities, indicating substantial atmospheres. The smaller planets appear to be super Earths. The larger ones are "mini

Neptunes" with rocky cores enshrouded by thick layers of hydrogen and helium.

This demographic pattern poses fundamental questions. Do all small planets start with substantial atmospheres, and do some lose them over time? Or do they form with different compositions from the beginning? Recent observations of planets actively losing their atmospheres suggest gas loss plays a significant role.

Astronomers think there are several processes that can rip atmospheres off planets or limit their formation in the first place. The two leading contenders are photoevaporation and core-powered mass loss. Together they may explain the radius gap and the hot Neptune desert.

Photoevaporation is one of the best explanations for the radius gap. When young stars ignite, they unleash extreme ultraviolet and x-ray radiation, along with powerful winds of charged particles. Planets that orbit too close to their host stars find themselves bathed in this radiation, which heats their atmospheres to the point where particles can escape into space.

Imagine two newly formed planets orbiting at the same distance from their respective stars, each starting with a rocky core and a substantial hydrogen-helium gas envelope. Planet A has a lower mass and weaker gravity, so it can't hold on to its atmosphere as the star pumps energy into it. It quickly loses all its gas to space and becomes a dense, rocky super Earth. When we observe this system, the atmosphereless planet appears smaller in size. Planet B, however, has a higher mass and stronger gravity, which allows it to retain most of its atmospheric envelope. When we observe this system, the planet appears large because of its light and puffy primordial cocoon.

The photoevaporation theory makes several predictions that match observed patterns. For example, the radius gap should slope downward with orbital period because planets closer to stars experience more intense radiation and need to be more massive to survive with their atmospheres intact. Similarly, we see a lack of Neptune-size planets with orbits shorter than three days, the so-called hot Neptune desert. This region is where atmospheric escape is so efficient that only rocky cores can survive.

The second mechanism for the disappearance of planet atmospheres is core-powered mass loss, which is caused by the heat generated within a planet. After planets form, they hold on to significant amounts of heat from the process of pulling mass into themselves. This residual internal energy can warm the base of the atmosphere as the planet cools, lifting up the primordial envelope from below and helping gas to escape, along with the pull from stellar radiation.

> Our solar system, once thought to be the blueprint for all planetary systems, now stands as just one of countless possibilities.

Core-powered mass loss suggests that smaller and less massive planets, with weaker gravity and less insulating gas, lose their atmospheres from below as they cool over hundreds of millions of years. Larger planets, in contrast, have enough gravitational strength to retain their envelopes despite the internal heating. This mechanism also aligns with the radius gap, given that intermediate-size planets are most susceptible to atmospheric loss through this process.

Ultimately, hot planets cool off, and stellar irradiation heats up atmospheres. Astronomers think both mechanisms are at work, but the jury is still out on which theory has its thumb pressed more heavily on the planetary-evolution scale. It’s likely the outcome depends on the specific conditions of the planet in question.

Other processes may also contribute. The rapid boil-off theory, for instance, posits that during a planet's early years, shortly after its star has formed, the debris disk circling the star—which contains the raw ingredients that were used to build the planets—gets cleared out. The resulting rapid drop in pressure around the planet may drive a sudden boil-off phase for its atmosphere.

In other cases, planets may form in gas-poor environments. These worlds would naturally lack thick atmospheres from the start, leading to a rocky composition. Finally, massive impacts between young planets could strip away their atmospheres, leaving behind bare, rocky cores in what's called collisional stripping. Although this process is probably rare, it may explain some planetary populations.

Recent observations have begun to catch some of these situations in action, providing direct evidence of atmospheric escape. Because planets are most likely to let go of mass when they're young, most small planets we can observe aren't undergoing significant loss. There is, however, a favorable scenario for observing an atmosphere escaping in real time: a gas giant on a close-in orbit, also known as a hot Jupiter.

A compelling example is the planet WASP-69b, which my group observed using the telescope at the W. M. Keck Observatory in Hawaii. WASP-69b is a Jupiter-size, Saturn-mass gas giant orbiting so close to its star that a full trip around it takes the planet only 3.8 days. In a paper we published in 2024, we reported outflows of material around the planet that indicate it is actively losing helium. In this case, the mass-loss mechanism must be photoevaporation. The planet is too massive to lose mass to internal heating; instead it's getting blasted with high-energy radiation from its host star. Our observations revealed that WASP-69b is losing about 200,000 tons per second, or one Earth mass per billion years. Furthermore, there have been dramatic variations in the shape of the outflow of escaping gas: sometimes it has a cometlike tail stretching over 350,000 miles, and at other times it appears far less prominent.

This variability in outflow probably stems from changes in the host star's activity. Much as our sun cycles through periods of heightened and decreased activity during its magnetic cycle, stars can experience periods of more or less intense radiation and flaring. Stretches of heightened stellar activity might boost atmospheric escape rates and change the shape of any material rushing off the planet. This dynamic interplay between star and planet illustrates that atmospheric loss may not be a steady, uniform process even in more mature planets. Rather it's an ongoing battle shaped by both the properties of the planet and the mood of its star.

Our findings and others show how photoevaporation can help explain both the radius gap and the hot Neptune desert by demonstrating this mass-loss process in real time. For a given orbital distance, planets require a minimum mass to hold on to their atmospheres amid the onslaught of high-energy stellar radiation. The radius gap separates the planets that are massive enough from those that are not. The hot Neptune desert demonstrates how this concept is amplified as a planet gets nearer to the star and the stellar irradiation increases exponentially. At sufficient proximity to a star, *only* hot Jupiters have the mass required to retain an atmosphere—all other planets get stripped to their bare, rocky core.

The next decade should be an exciting stage for refining our understanding of planetary demographics. Although most astronomers agree that atmospheric mass loss is the primary reason we don't see slightly bigger Earths or hot Neptunes on close orbits, the finer details remain unresolved. Is photoevaporation, driven by stellar radiation, the dominant factor? Or does core-powered mass loss, fueled by a planet's internal heat, play a larger role? Untangling the contributions of these mechanisms requires a new generation of telescopes and instruments capable of precisely measuring planetary masses, compositions and atmospheres.

We hope to better understand how the radius gap depends on stellar type. For low-mass stars, such as M dwarfs, the radius gap appears to shift—smaller planets around these stars are able to retain atmospheres more often because they are exposed to less radiation than larger stars put out. The radius gap is usually less defined because low-mass stars put out different kinds of radiation than larger stars. The planets around these stars also tend to have greater core-composition diversity, and these systems may have an increased rate of major collisions.

Planets around M dwarfs also tend to orbit much closer, where stellar activity such as flares and winds can have a big effect on atmospheric retention. Close inspection of these worlds has revealed hints that some of them might harbor significant amounts of water, potentially in the form of deep global oceans underneath hydrogen-rich atmospheres. These “water worlds” would occupy a unique position in planetary demographics, challenging simple models of rocky super Earths and gas-rich mini Neptunes.

New ground-based instruments such as the Keck Planet Finder, which recently went online at the Keck observatory, and other high-precision radial velocity tools will be indispensable in testing our theories. By enabling us to measure planetary masses across a wide range of star types, these advances will help us determine whether the masses of super Earths and sub Neptunes align with predictions from our various models. In multiplanet systems, these kinds of data can help disentangle the effects of stellar irradiation history, allowing researchers to compare planets that formed under similar conditions.

NASA’s Transiting Exoplanet Survey Satellite mission is conducting extended monitoring over long timescales that could reveal planets with slightly wider orbits around their stars than most known worlds have. By filling out this sparsely populated region of small exoplanets with longer orbital periods, these discoveries will provide crucial data for understanding how atmospheric loss and composition vary across a broader range of planetary environments.

The big leap forward should come when some big-ticket telescopes come online in the next decades. Ground-based super telescopes, such as the European Southern Observatory's Extremely Large Telescope, are expected to see first light in the late 2020s. These instruments will excel at observing young, luminous planets still glowing with the heat of their formation. Such gigantic telescopes will offer critical insights into the chaotic early stages of planetary evolution, when atmospheres are most vulnerable to loss.

The Habitable Worlds Observatory, a NASA flagship space telescope, is planned to launch in the 2040s. It is being designed to detect and study Earth-like planets in the habitable zones of sun-like stars. The aim is to use the observatory to directly image these worlds and analyze their atmospheres to search for signs of oxygen, methane and water vapor—key indicators of habitability.

What we learn from all these new tools will reach far beyond planetary demographics. By studying how planets lose or retain their atmospheres, we are unlocking the secrets of habitability, diversity and the forces that sculpt worlds across the galaxy.

Our solar system, once thought to be the blueprint for all planetary systems, now stands as just one of countless possibilities—a unique configuration in a cosmos teeming with variety. Most stars host planets unlike anything in our cosmic neighborhood, reminding us that the universe is richer and more surprising than we have imagined. By untangling the forces that shape these distant worlds, we inch closer to answering some of humanity's oldest questions: How common are planets like Earth? Is there other life among the stars? And what does our place in this vast and intricate universe truly mean?

Dakotah Tyler is an astrophysics Ph.D. candidate at the University of California, Los Angeles. His research focuses on exoplanet atmospheres and how planets lose mass as they evolve.

https://www.scientificamerican.com/article/exoplanet-census-identifies-missing-planets-gap

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This Backyard Bird Has a Lot to Teach Us about Sex Variability

White-throated Sparrows demonstrate that traits we usually associate with sex can be influenced by genes that are not on sex chromosomes

By Donna L. Maney

© Joel Sartore/Photo Ark

It’s springtime in your backyard. You watch a pair of little brown songbirds flit about, their white throats flashing in the sun. One of the birds has striking black and white stripes on its crown and occasionally belts out its song, “Old Sam Peabody, Peabody, Peabody.” Its partner is more drab, with tan and gray stripes on its head and brown streaks through its white throat. Knowing the conventional wisdom about songbirds—that the males are flashy show-offs and the females more camouflaged and quiet—you decide to name the singer with bright plumage Romeo and the subtler one Juliet.

But later that day you notice Juliet teed up on the fence, belting out a song. Juliet's song is even louder and showier than Romeo's. You wonder, Do female birds sing? Then you see Romeo bringing a twig to the pair's nest, hidden under a shrub. Your field guide says that in this species the female builds the nest by herself. What is going on?

Turns out, when you named Romeo and Juliet, you made the same mistake 19th-century artist and naturalist John Audubon did when, in his watercolor of this species, he labeled the bright member of the pair "male" and the drab one "female." Romeo might look male, even to a bird expert such as Audubon, but will build a nest and lay eggs in it. Juliet, who might look female, has testes and will defend the pair's territory by singing both alone and alongside Romeo, who also sings.

Juliet and Romeo are White-throated Sparrows (*Zonotrichia albicollis*). At first glance, members of this species of songbird might look rather ordinary. For example, like many other songbirds, one member of each breeding pair of these sparrows has more striking plumage—that is, its appearance is what we would traditionally consider malelike for songbirds. The other bird in the pair is more femalelike, with drabber plumage.

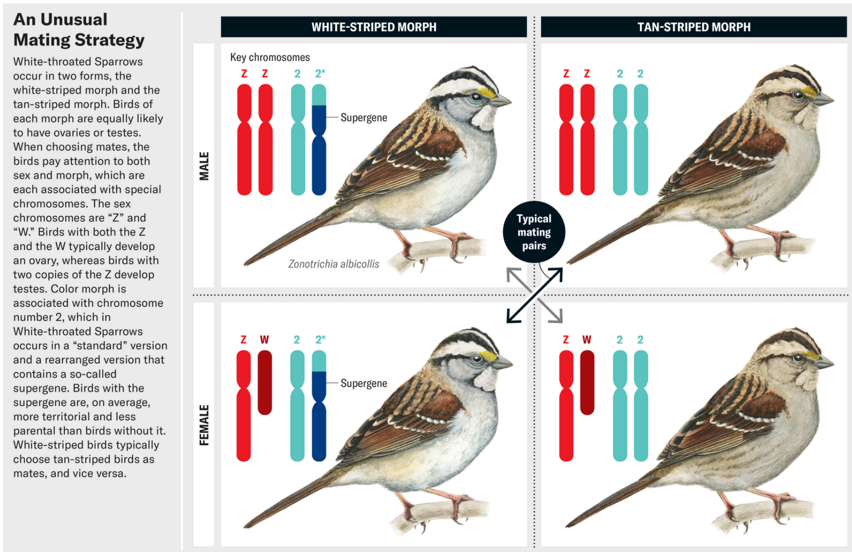
On closer inspection, White-throated Sparrows are quite remarkable. If we were to assume that the brighter bird in each breeding pair is the male, we'd be right only half the time. In about 50 percent of breeding pairs of White-throated Sparrows, the brighter bird has the testes and the drabber bird has the ovaries, in keeping with the typical songbird pattern. In the rest of the breeding pairs, however, the bird with the more striking plumage is the one with the ovaries, and the duller bird has the testes.

> White-striped birds with ovaries behave in a way that is more masculine than we expect for female songbirds.

Researchers have known since the 1960s that White-throated Sparrows occur in two color forms: a brighter “white-striped morph” and a plainer “tan-striped morph.” Even though morph has nothing to do with sex—birds of each morph are equally likely to have ovaries or testes—the birds still pay attention to morph when choosing mates. Whether male or female, tan-striped birds almost always choose white-striped mates, and vice versa. Each bird, therefore, chooses a mate from only 25 percent of the population; if you are a tan-striped female looking to make some babies, a male of the same morph just won’t do. You want a male with *white* stripes on his head.

This interesting and complex situation has earned this species the nickname “the bird with four sexes.” But to be clear, White-throated Sparrows do not have four different types of gonads. As in other birds, each individual typically has either two testes that produce sperm or a single ovary that produces eggs. Nevertheless, as recent research has shown, this species has much to teach us about the nature of sex variability—the way in which sex-related behaviors are influenced by genes, the complex structure of sex-associated chromosomes and the evolution of sexual reproduction itself. Importantly, this species challenges the practice of flattening nature’s wondrous diversity into two categories, male and female.

I have spent the past 25 years studying this fascinating species, trying to understand how social behavior and the structure of genomes can influence each other’s evolution. White-throated Sparrows are a particularly good model for this line of research because the categories of sex and morph are each associated with special chromosomes. The sex chromosomes, which in birds are known as Z and W, influence whether primordial gonads develop as ovaries or testes. Birds with both the Z and the W typically develop an ovary, whereas birds with two copies of the Z develop testes. Color morph is associated with a different chromosome, chromosome number 2. Like sex chromosomes, chromosome 2 in White-throated Sparrows occurs in two versions. The first, which we’ll call the standard version, was the first to be sequenced by scientists. The other is a rearranged version that contains a “supergene,” which is technically a collection of genes bound together. Whether male or female, birds with a copy of the supergene develop as white-striped; birds with only the standard chromosome develop as tan-striped.



Rebecca Gelernter; Source: “Multivariate Models of Animal Sex: Breaking Binaries Leads to a Better Understanding of Ecology and Evolution,” by J. F. McLaughlin et al., in *Integrative and Comparative Biology*, Vol. 63; October 2023 (*reference*)

Although color morphs in White-throated Sparrows are not technically sexes, the standard and supergene-bearing versions of chromosome 2 share features with the human sex chromosomes X and Y, respectively. In a typical breeding pair, one bird has two copies of the standard version, analogous to the XX genotype in humans. The other bird has one copy of the standard and one copy of the supergene, analogous to the XY genotype. Just as humans with two Y chromosomes are rare, the number of White-throated Sparrows with two copies of the supergene is vanishingly small. Almost all birds of the white-striped morph have one standard version of chromosome 2 to pass down and one version with the supergene. As a result, half the offspring of each breeding pair will inherit the supergene, and half will not.

The supergene-bearing version of chromosome 2 resembles the mammalian Y chromosome in other ways. To understand the similarities, let’s consider how it came to exist. Geneticist James W. Thomas, who was then at Emory University, and his laboratory demonstrated that the supergene itself is made up of several inversions—large sections of DNA sequence that long ago flipped 180 degrees relative to the standard sequence. The rearranged region on chromosome 2 in White-throated Sparrows is so large that the two different versions cannot line up precisely beside each other and swap genes, a process known as recombination. Generally speaking, mismatched sequences aren’t a big problem, so long as there is another copy of the same version of the chromosome nearby to line up and swap genes with. But for the supergene version of chromosome 2, there usually isn’t one. As is the case for the mammalian Y chromosome, individuals with the supergene chromosome typically have only one copy of it. So, whereas in the tan-striped birds the two copies of the standard version of chromosome 2 can recombine freely with each other, in white-striped birds the supergene version of the chromosome stands alone, unable to recombine with a partner.

This isolation has caused the gene sequences inside the supergene to slowly diverge from the corresponding sequence on the standard version, becoming less and less similar to it over time. Escaping recombination also causes the genes inside the supergene to become locked together, meaning that each white-striped bird inherits a large block of increasingly differentiated genes. For these sparrows, those differentiated genes translate to differences in plumage and behavior.

The evolutionary changes taking place in chromosome 2 in White-throated Sparrows loosely recapitulate a classical theory of the evolution of sex chromosomes. In the case of the X and Y chromosomes in mammals, suppression of recombination has been hypothesized to cause progressive loss of gene function and even the loss of entire genes. Over time the Y chromosome has degenerated such that it shares only a handful of genes with the X. The same scenario has played out for sex chromosomes in a wide variety of species, including other mammals, birds and many insects: a chromosome associated with either testicular or ovarian development has stopped recombining with its former partner and has differentiated substantially. The supergene-bearing chromosome 2 in White-throated Sparrows seems to be in the same situation. To investigate these parallels more closely, we worked with researchers at the Georgia Institute of Technology, led by Soojin V. Yi. Our study revealed that the supergene shows only minimal signs of degeneration. Thus, although the chromosome with the supergene may be recapitulating the evolution of a sex-chromosome-like system in many ways, we don’t see obvious evidence that it will end up small, like the Y, anytime soon.

In White-throated Sparrows, both white-striped birds (*bottom*) and the drab tan-striped birds (*top*) sing.
Glenn Bartley/Minden Pictures (*top*); Scott Leslie/Minden Pictures (*bottom*)

The White-throated Sparrow’s chromosome 2 also resembles the mammalian XY chromosome system with respect to its consequences for behavior. Birds with the supergene version—that is, the white-striped birds—defend their breeding territories more vigorously on average than do their tan-striped counterparts, who spend more of their time bringing food to offspring in the nest. In other words, behaviors we expect to be associated with the Y chromosome in mammals—namely, prioritizing territorial aggression over parental care—have become associated with the supergene even though the supergene is not located on a sex chromosome. These behaviors have become dissociated from the gonads.

This dissociation makes this species especially valuable for understanding the evolution of sex-related traits and the extent to which any individual can be said to be one sex versus another. In White-throated Sparrows, we see “masculine” and “feminine” traits distributing themselves in a manner clearly orthogonal to gonadal sex. White-striped birds with ovaries behave in a way that is more masculine than we expect for female songbirds, and tan-striped birds with testes look and behave in a relatively feminine way. Because the behavioral differences between the morphs can be attributed to a genetic sequence not associated with sex or sex chromosomes, the supergene provides an important tool with which to identify gene variants that nudge a sparrow in one behavioral direction or another no matter what gonads it has.

Twentieth-century geneticist Theodosius Dobzhansky, who once said, “Nothing in biology makes sense except in light of evolution,” speculated that inversions are adaptive because they capture and bind together gene variants that confer a collective benefit when inherited together. The inversions that make up the White-throated Sparrow supergene have captured about 1,000 genes that are slowly differentiating from the standard versions—certainly a rich source of possibilities for co-adaptation.

In my laboratory at Emory, we went on the hunt for gene variants inside the supergene that shift the behavior of the white- and tan-striped sparrows in masculine and feminine directions, respectively. We knew that circulating levels of steroid hormones—namely, testosterone in males and estradiol in females—are higher in white-striped than tan-striped birds. This morph difference in hormone levels does not, however, explain the differences in their behavior. When we experimentally equalized levels of steroid hormones between the morphs, the white-striped birds were still more aggressive, despite having levels of steroid hormones identical to those of the tan-striped birds. Perhaps the white-striped birds are simply more sensitive to their own circulating steroids. If so, we wondered, what is the biology underlying that sensitivity?

To answer that question, Brent M. Horton and I led a team to take a neuroscience approach. We reasoned that increased sensitivity to steroid hormones in white-striped birds might come from higher levels of the receptors for those hormones in their brains. Sure enough, in a part of the brain associated with reproductive behaviors, white-striped birds have extraordinarily high activity of a gene encoding a steroid-hormone receptor important for territorial aggression. This gene, called *ESR1*, is located inside the region of chromosome 2 that corresponds to the location of the inversions. Over evolutionary time the variant of *ESR1* inside the supergene has diverged genetically from its counterpart on the standard chromosome. This genetic divergence has revved up the activity of the supergene variant such that white-striped birds have higher levels in this brain region than do tan-striped birds. Moreover, the more active the supergene variant of *ESR1* relative to the standard version, the more aggressive the bird. We had our smoking gun.

To show definitively that this receptor plays a causal role in white-striped aggression, Jennifer R. Merritt, then a graduate fellow at Emory, led an effort to experimentally manipulate the molecular products of the *ESR1* gene. We hypothesized that if white-striped birds were more aggressive because of higher levels of the hormone receptor, then the morph difference in aggression should disappear if we experimentally reduced production of the receptor in those birds down to the tan-striped level in the brain region in question. Just as we predicted, white-striped birds with reduced receptor levels showed no more aggression than tan-striped birds. In other words, we were able to change their behavior from white-striped to tan-striped by altering the activity of a single gene.

As exciting as that finding was, we were under no illusion that the aggressive behavior of the white-striped morph can be explained by just one gene. We believe, as Dobzhansky would have, that the behavior is influenced by multiple, co-adapted genes inside the supergene. Our analysis of all the genes inside the supergene, spearheaded by Emory researcher Wendy M. Zinzow-Kramer, showed that *ESR1* is part of a large network of genes inside the supergene that predict territorial aggression. Perhaps these genes act together somehow to alter both plumage and behavior.

> White-throated Sparrows help us see past the sex binary by forcing us to acknowledge sources of variability other than sex.

Armed with the knowledge that the neighbors of influential genes can have related functions, we directed our attention to a gene that is practically adjacent to *ESR1* inside the supergene. This gene, known as *VIP*, is active widely in the brain and influences a variety of social behaviors across vertebrates. In songbirds, it promotes aggression when activated in one part of the brain and parental behavior in another. Because these behaviors are the ones that differ between the morphs in White-throated Sparrows, this gene was a prime candidate for further investigation.

Horton and his team showed that in the brain region where *VIP* is associated with aggression, activity of the *VIP* gene is higher in the white-striped morph. In the brain region associated with parenting, its activity is higher in the tan-striped morph. Because white-striped birds are more aggressive and tan-striped more parental, this finding strongly suggested a role for *VIP* in the behavioral differences. But how can the same gene variant be revved up in one brain region and ramped down in another?

A group led by Mackenzie R. Prichard, then a graduate fellow at Emory, provided an important clue. The *VIP* variant inside the supergene differs from the standard version not only genetically but also in another important way. DNA can be tagged with chemical markers that are not part of the gene sequence—they attach to it epigenetically, which can silence the gene. In the brain region where *VIP* promotes aggression, these tags are significantly reduced on the supergene variant of *VIP*. Although we do not totally understand the mechanisms that regulate the tags, their removal from the supergene probably allows the peptide that *VIP* encodes to be produced at higher levels in this brain region in the white-striped birds. The situation looks different in the brain region associated with parenting, where the relative activity of the supergene variant of *VIP* is significantly lower.

The 19th-century artist and naturalist John Audubon mistakenly assumed that the whitestriped variants of the White-throated Sparrow were all males and the tan-striped birds were all females. Fine art images/Heritage Images via Getty Images

These findings are exciting because they show that production of the VIP peptide is regulated differently in each of these two brain regions in ways that are adaptive for each morph. In the brain region where *VIP* promotes aggression, the brakes have come off the supergene version of the gene. The resulting higher activity may allow the white-striped birds to produce more VIP peptide where it is needed for aggression. In the region where VIP promotes parental behavior, the brakes are applied a bit more to the supergene, which may reduce VIP production in this region in white-striped birds and make them less parental.

Is it significant that the two supergene variants of *ESR1* and *VIP* are so close to each other inside the supergene? Are they co-adapted at the molecular level? We don't yet know. Even if the gene products don't interact directly, both contribute toward the same aggressive, white-striped phenotype. Dobzhansky might argue that this shared function alone makes their linkage adaptive. Over evolutionary time the supergene is likely to accumulate even more gene variants and epigenetic tags that complement an aggressive phenotype, in keeping with the theory behind the evolution of chromosomes associated with sexes.

White-throated Sparrows demonstrate that traits we usually associate with sex can be influenced by genes that are not on sex chromosomes. In this species, some of those genes are linked to one another and to an obvious, sex-adjacent phenotype, making these associations easy to study. But the dissociation of sex-related genes from sex chromosomes isn't at all exceptional. In all sexually reproducing species, including humans, most genes that contribute to sex-related variation are not known to be linked to any particular genomic architecture. Even genes involved in gonadal development and hormone synthesis can be found on most any chromosome, mapping to locations throughout the genome that freely recombine. Each individual inherits a new combination of genetic and epigenetic material, resulting in diversity that defies binary categories.

In most sexually reproducing species, making an embryo requires two gametes: one egg and one sperm. That binary is clear. But the egg-sperm binary does not apply to the eventual development of that embryo into a sexed body with sex-related behaviors. That development is conceptually separate and decidedly nonbinary in many ways. To understand why, let's consider the theoretical evolutionary function of sexual reproduction.

Biologists have long argued that the genetic function of sex—namely, the mixing of genomes in the generation of offspring—is to create combinations of genes that could confer advantages in an unpredictable future environment. Sexual reproduction hurries the new combinations along, meaning the advantageous combinations become established much faster than if we simply cloned ourselves and waited for genes to randomly mutate into more beneficial forms. In other words, the entire point of having sexes is to generate diversity. Each new organism possesses a genome never seen before, unlike either parent's.

For reasons that so far remain mysterious to scientists, the most diverse traits are those that relate to reproduction itself. Beyond White-throated Sparrows, the diversity of sexual phenotypes across species is vast and spectacular. Even though embryos in most any sexually reproducing species are typically made from one egg and one sperm, the development of sexed bodies is characterized by profound flexibility and plasticity. Many fish change their gamete production from eggs to sperm, or vice versa; some worms produce both at once; some lizard species produce no sperm at all. In many reptiles, whether an embryo develops ovaries or testes is determined by the temperature at which the eggs are incubated, not by genetic code. The natural world is a parade of heterogeneity in sexual form and function.

Until recently, species such as sex-changing fish, all-female lizards and White-throated Sparrows with their "four sexes" were regarded as curiosities—oddball organisms that seemed to break the rules. But that view is rapidly changing. New tools for studying the processes underlying sexual development call the rules themselves into question. We are learning that the molecular pathways that guide a body to develop ovaries, testes, or other sex-related features are evolutionarily unstable and precarious. The genes and proteins that contribute to making a gonad are not the same across species, even closely related ones. These pathways are not well conserved, suggesting they remain flexible for good reason.

The development of sex-related traits is astonishingly diverse not only across species but within them. Every individual, sparrow or human, has masculine and feminine characteristics. That diversity is obscured when we lump individuals into two categories and consider each as a homogeneous group. When we compare the categories "female" and "male," we often report a "sex difference"—a binary outcome made inevitable by a binary approach. This approach fails to acknowledge the profound overlap between sexes on almost any measure.

White-throated Sparrows help us see past the sex binary by forcing us to acknowledge sources of variability other than sex, which is, in reality, only a small contributor to variability for many species. Diversity and plasticity of phenotypic expression is the norm, particularly for traits that correlate with sex. Sex-related traits are simply not hardwired. Evolutionary biologists believe that this plasticity—like the dazzling diversity of sex-determining molecular pathways—may be adaptive in changing environments. Individuals retaining maximal flexibility in the expression of sex-related traits are better able to adapt quickly to changing environments or, in some cases, may even be able to change their sex.

Sexual reproduction, by its very nature, generates diversity. The different pathways by which bodies develop as male, female, both or neither are perhaps as numerous as species themselves. Genomes are fluid, constantly changing and evolving. Gene sequences link together and separate in a never-ending dance. The environment also changes constantly, guiding development in unpredictable and sometimes disruptive ways. Every newly evolved avenue to develop into a sexed body begins a new, generative process that gives rise to still newer routes. Viewed this way, it is clear that sexual diversity within species is an evolutionary adaptation—a feature, not a bug. Like our backyard sparrows Romeo and Juliet, each of us is expressing our own unique phenotype just as nature intended.

Donna L. Maney is a neuroscientist at Emory University. Her current research focuses on how sex and gender are treated as variables in biomedical research.

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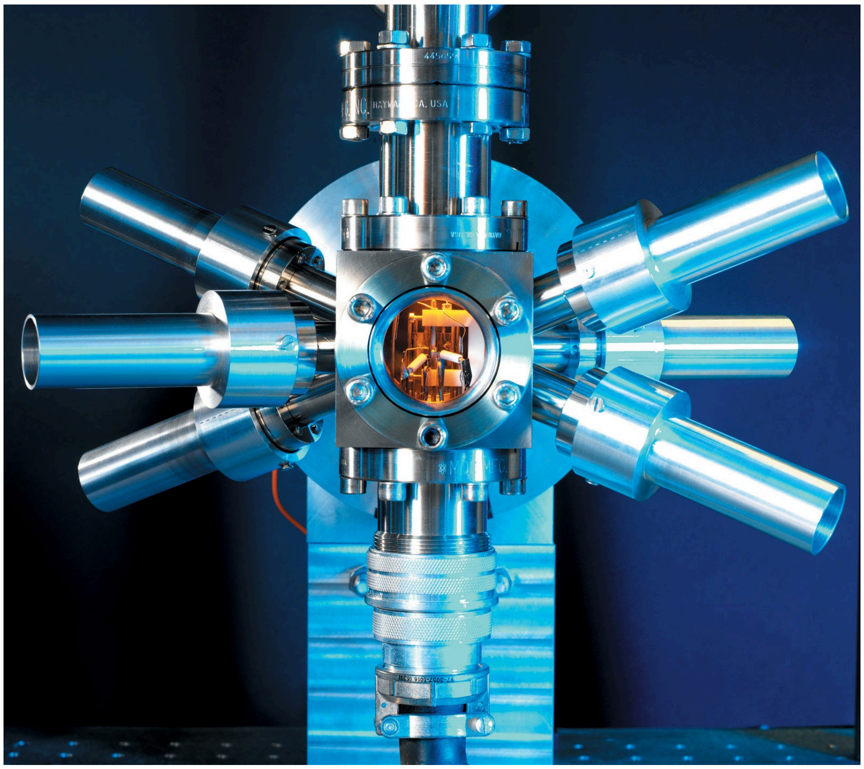
https://www.scientificamerican.com/article/a-backyard-bird-offers-a-new-way-of-thinking-about-sexes

Is It Time to Redefine Time?

New atomic clocks are more accurate than those used to define the second, suggesting the definition might need to change

By Jay Bennett edited by Clara Moskowitz



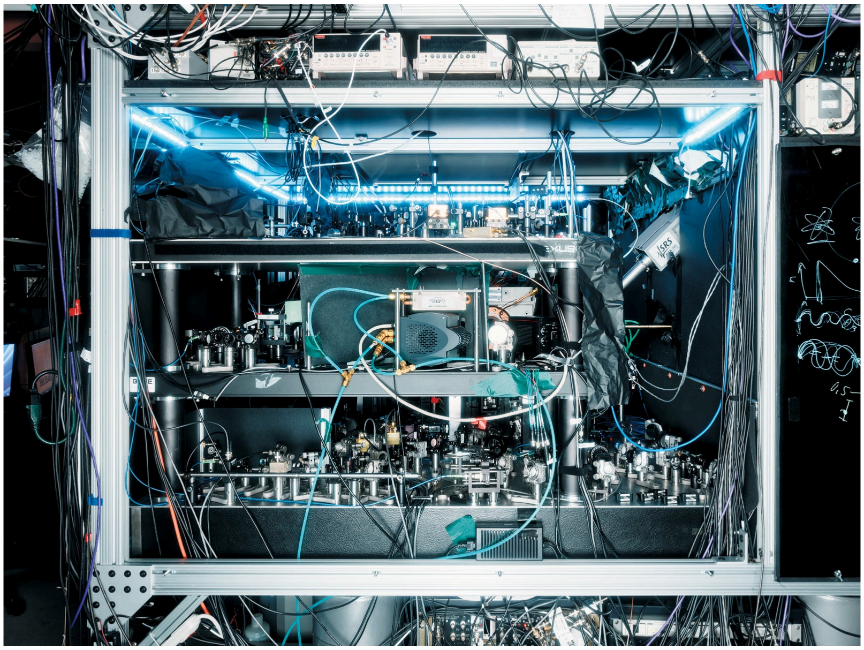
A strontium optical clock produces about 50,000 times more oscillations per second than a cesium clock, the basis for the current definition of a second.
Andrew Brookes/National Physical Laboratory/Science Source

Inside a laboratory nestled in the foothills of the Rocky Mountains, amid a labyrinth of lenses, mirrors, and other optical machinery bolted to a vibration-resistant table, an apparatus resembling a chimney pipe rises toward the ceiling. On a recent visit, the silvery pipe held a cloud of thousands of supercooled cesium atoms launched upward by lasers and then left to float back down. With each cycle, a maser—like a laser that produces microwaves—hit the atoms to send their outer electrons jumping to a different energy state.

The machine, called a cesium fountain clock, was in the middle of a two-week measurement run at a National Institute of Standards and Technology (NIST) research facility in Boulder, Colo., repeatedly fountaining atoms. Detectors inside measured photons released by the atoms as they settled back down to their original states. Atoms make such transitions by absorbing a specific amount of energy and then emitting it in the form of a specific frequency of light, meaning the light's waves always reach their peak amplitude at a regular, dependable cadence. This cadence provides a natural temporal reference that scientists can pinpoint with extraordinary precision.

By repeating the fountain process hundreds of thousands of times, the instrument narrows in on the exact transition frequency of the cesium atoms. Although it's technically a clock, the cesium fountain could not tell you the hour. "This instrument does not keep track of time," says Vladislav Gerginov, a senior research associate at NIST and the keeper of this clock. "It's a frequency reference—a tuning fork." By tuning a beam of light to match this resonance frequency, metrologists can "realize time," as they phrase it, counting the oscillations of the light wave.

The signal from this tuning fork—about nine gigahertz—is used to calibrate about 18 smaller atomic clocks at NIST that run 24 hours a day. Housed in egg incubators to control the temperature and humidity, these clocks maintain the official time for the U.S., which is compared with similar measurements in other countries to set Coordinated Universal Time, or UTC.

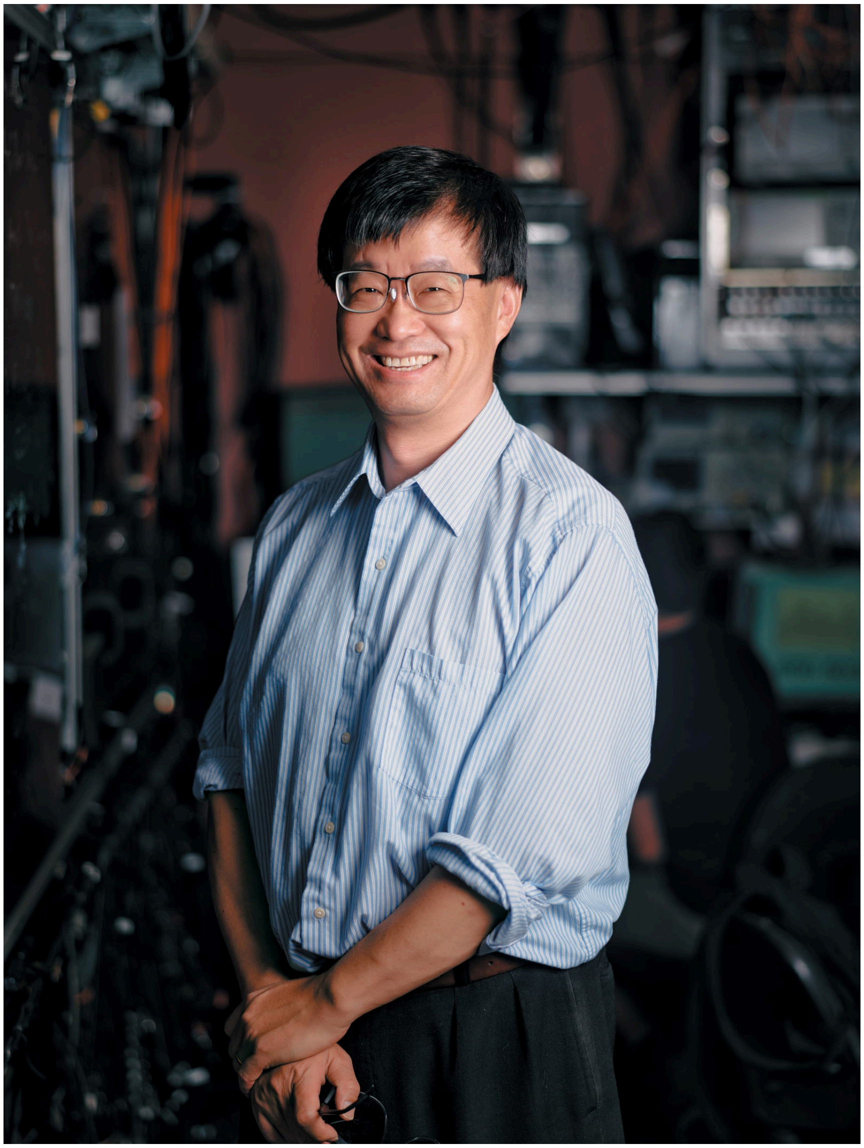

A thorium nuclear clock resides at the JILA laboratory in Colorado.
Jason Koxvold

Gerginov, dressed casually in a short-sleeve plaid shirt and sneakers, spoke of the instrument with an air of pride. He had recently replaced the clock's microwave cavity, a copper passageway in the middle of the pipe where the atoms interact with the maser. The instrument would soon be christened NIST-F4, the new principal reference clock for the U.S. "It's going to be the primary standard of frequency," Gerginov says, looking up at the metallic fountain, a three-foot-tall vacuum chamber with four layers of nickel-iron-alloy magnetic shielding. "Until the definition of the second changes."

Since 1967 the second has been defined as the duration of 9,192,631,770 cycles of cesium's resonance frequency. In other words, when the outer electron of a cesium atom falls to the lower state and releases light, the amount of time it takes to emit 9,192,631,770 cycles of the light wave defines one second. "You can think of an atom as a pendulum," says NIST research fellow John Kitching. "We cause the atoms to oscillate at their natural resonance frequency. Every atom of cesium is the same, and the frequencies don't change. They're determined by fundamental constants. And that's why atomic clocks are the best way of keeping time right now."

But cesium clocks are no longer the most accurate clocks available. In the past five years the world's most advanced atomic clocks have reached a critical milestone by taking measurements that are more than two orders of magnitude more accurate than those of the best cesium clocks. These newer instruments, called optical clocks, use different atoms, such as strontium or ytterbium, that transition at much higher frequencies. They release optical light, as opposed to the microwave light given out by cesium, effectively dividing the second into about 50,000 times as many "ticks" as a cesium clock can measure.

The fact that optical clocks have surpassed the older atomic clocks has created something of a paradox. The new clocks can measure time more accurately than a cesium clock—but cesium clocks define time. The duration of one second is inherently linked to the transition frequency of cesium. Until a redefinition occurs, nothing can truly be a more accurate second because 9,192,631,770 cycles of cesium's resonance frequency is what a second is.



Atomic clock scientist Jun Ye of JILA hopes such nuclear clocks can eventually beat today’s most accurate timekeepers.
Jason Koxvold

This problem is why many scientists believe it is time for a new definition of the second. In 2024 a task force set up by the International Bureau of Weights and Measures (BIPM), headquartered in Sèvres, France, released a road map that established criteria for redefining the second.* These include that the new standard is measured by at least three different clocks at different institutions, that those measurements are routinely compared with values from other types of clocks and that laboratories around the world will be able to build their own clocks to measure the target frequency. If sufficient progress is made on the criteria in the next two years, then the second might change as soon as 2030.

But not everyone is onboard with redefining the second now. For one thing, there's no clear immediate benefit. Today's cesium clocks are plenty accurate enough for most practical applications—including synchronizing the GPS satellites we all depend on. We can always improve the accuracy of the second later if new innovations come along that require better timing. "Today we don't really profit from an immediate change," says Nils Huntemann, a scientist at the Physikalisch-Technische Bundesanstalt (PTB), the national metrology institute of Germany. Redefining the second wouldn't be straightforward, either—scientists would be forced to pick a new standard from the many advanced atomic clocks now in existence, with improvements being made all the time. How should they choose?

> Many scientists say we should improve the definition of time simply because we can.

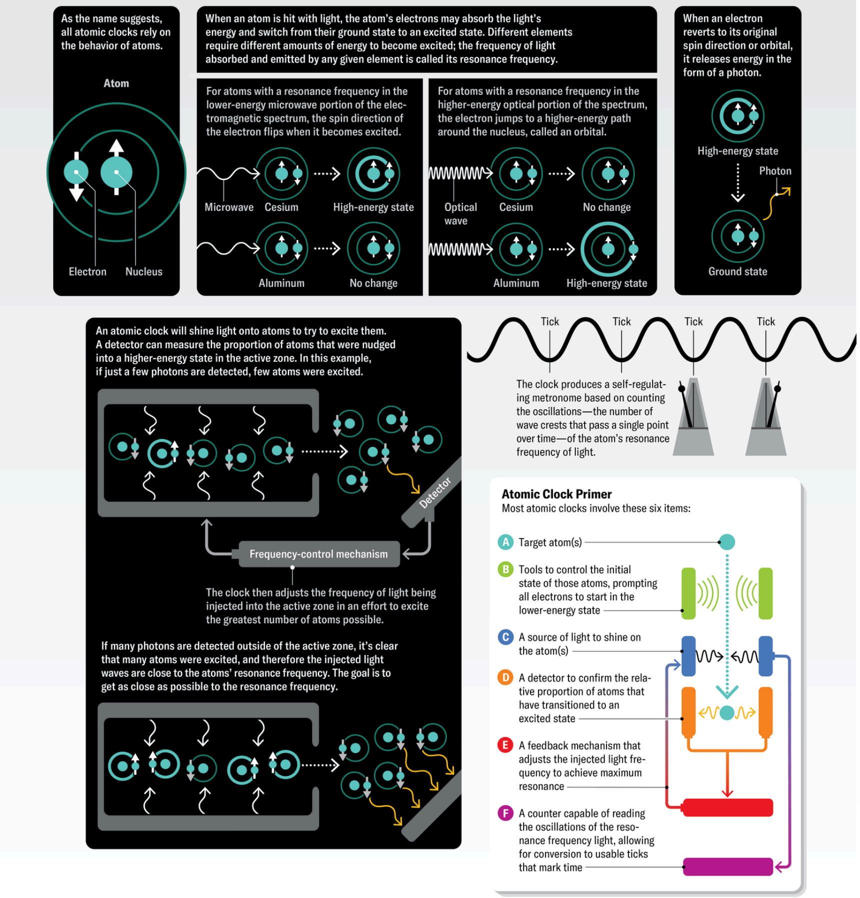
Regardless of the complications, some physicists believe that they have an obligation to use the best clocks available. "It's just a matter of basic principle," says Elizabeth Donley, chief of the time and frequency division at NIST. "You want to allow for the best measurements you can possibly make."

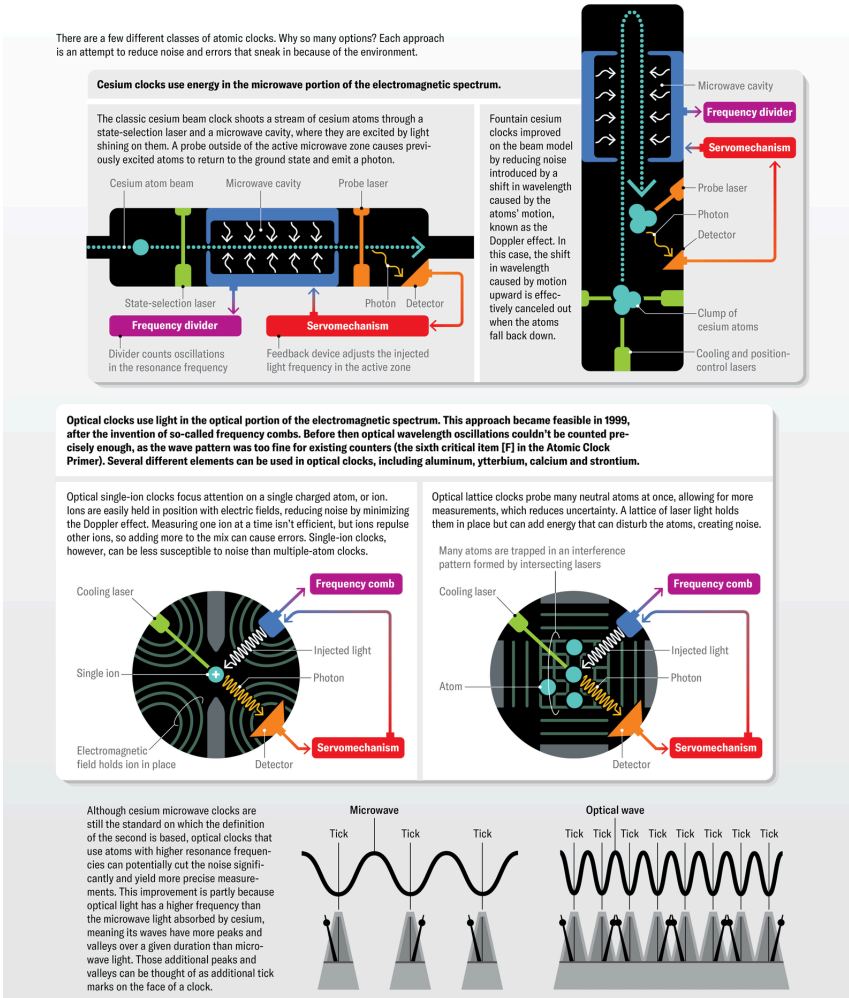
The world's first clocks were invented thousands of years ago, when the first human civilizations devised devices that tracked the sun's movement to divide the day into intervals. The earliest versions of sundials were made by the ancient Egyptians around 1500 B.C.E. Later, water clocks, first used by Egyptians and called *clepsydras*, meaning "water thieves," by the ancient Greeks, marked time by letting water drain out of vessels with a hole punched in the bottom. These instruments were perhaps the first to measure a duration of time independent of the movements of celestial bodies. Mechanical clocks driven by weights debuted in medieval European churches, and they ticked along at consistent rates, leading to the modern 24-hour day. The tolling of bells to mark the hour even gave us the word “clock,” which has its roots in the Latin *clocca*, meaning “bell.”

As mechanical clocks became more precise, particularly with the development of the pendulum clock in the mid-17th century, timekeepers further divided the hour into minutes and seconds. (First applied to angular degrees, the word “minute” comes from the Latin *prima minuta*, meaning the “first small part,” and “second” comes from *secunda minuta*, the “second small part.”) For centuries towns maintained their own local clocks, adjusting them periodically so the strike of noon occurred just as the sundial indicated midday. It wasn’t until the 19th century, when distant rail stations needed to maintain coordinated train schedules, that time zones were established and timekeeping was standardized around the world.

How Atomic Clocks Work

Atomic clocks are the most accurate timekeepers in the world. They use energy absorbed and emitted by atoms—which is always in the form of a very precise frequency of light—to measure time. A particular number of oscillations in the waves of light absorbed and emitted by cesium atoms, for instance, defines the duration of a second.





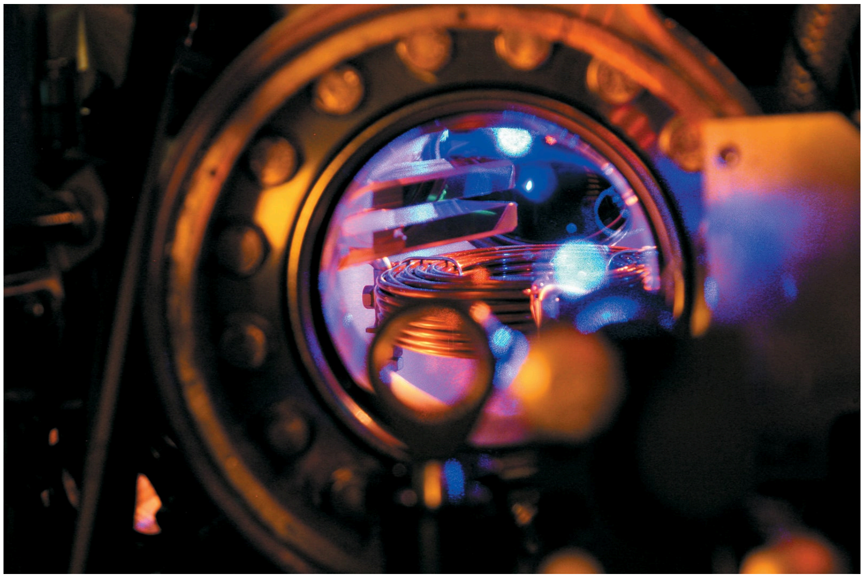
Jen Christiansen; Sources: Elizabeth Donley and John Kitching/National Institute of Standards and Technology (*scientific reviewers*)

Clocks improved drastically in the 20th century after French physicists and brothers Jacques and Pierre Curie discovered that applying an electric current to a crystal of quartz causes it to vibrate with a stable frequency. The first clock that used a quartz oscillator was developed by Warren Marrison and Joseph Horton of Bell Laboratories in 1927. The clock ran a current through quartz and used a circuit to divide the resulting frequency until it was low enough to drive a synchronous motor that controlled the clock's face. Today billions of quartz clocks are produced every year for wristwatches, mobile devices, computers, and other electronics.

The key innovation that led to atomic clocks came from American physicist Isidor Isaac Rabi of Columbia University, who won the Nobel Prize in Physics in 1944 for developing a way to precisely measure atoms’ resonance frequencies. His technique, called the molecular-beam magnetic resonance method, finely tuned a radio frequency to cause atoms’ quantum states to transition. In 1939 Rabi suggested using this method to build a clock, and the next year his colleagues at Columbia applied his technique to determine the resonance frequency of cesium.

This element was viewed as an ideal reference atom for timekeeping. It’s a soft, silvery metal that is liquid near room temperature, similar to mercury. Cesium is a relatively heavy element, meaning it moves more slowly than lighter elements and is therefore easier to observe. Its resonance frequency is also higher than those of other clock candidates of the time, such as rubidium and hydrogen, meaning it had the potential to create a more precise time standard. These properties eventually won cesium the role of defining the second nearly 40 years later.

But the first atomic clock was not a cesium clock. In 1949 Harold Lyons, a physicist at NIST’s precursor, the National Bureau of Standards (NBS), built an atomic clock based on Rabi’s magnetic resonance method using ammonia molecules. It looked like a computer rack with a series of gauges and dials on it, so Lyons affixed a clockface to the top for a public demonstration to indicate that his machine was, in fact, a clock. This first atomic clock, however, couldn’t match the precision of the best quartz clocks of the time, and ammonia was abandoned when it became clear that cesium clocks would produce better results.



A cloud of strontium atoms is seen in an optical lattice clock at the German national metrology institute Physikalisch-Technische Bundesanstalt.
Christian Lisdat/PTB

Both the NBS and the National Physical Laboratory (NPL) in the U.K. developed cesium beam clocks in the 1950s. A key breakthrough came from Harvard University physicist Norman Ramsey, who found that it was possible to improve the measurements by using two pulses of microwaves to induce the atomic transitions rather than one. Cesium clocks continued to advance for the remainder of the century and, along with atomic clocks using different elements, became more precise and more compact.

At the time, the second was defined according to astronomical time. Known as the ephemeris second, it was equal to 1/31,556,925.9747 of the tropical year (the time it takes for the sun to return to the same position in the sky) in 1900. Between 1955 and 1958, NPL scientists compared measurements from their cesium beam clock with the ephemeris second as measured by the U.S. Naval Observatory by tracking the position of the moon with respect to background stars. In August 1958 the second was calculated as 9,192,631,770 cycles of the cesium transition frequency—the same number that would be used for the new definition nine years later.

Since then, atomic clocks have continued to progress, particularly with the development of cesium fountain clocks in the 1980s. But by 2006 newer clocks were beating them.

In addition to the clocks at NIST, some of the most advanced timekeepers in the world can be found at the University of Colorado Boulder, down the street in another lab pushing the frontier of timekeeping. JILA, a joint venture of NIST and the university, houses four “optical lattice clocks” that are among the global record holders for accuracy. (The lab was previously called the Joint Institute for Laboratory Astrophysics and now is simply known by the acronym.)

These state-of-the-art instruments are housed in large rectangular boxes with sliding doors that double as dry-erase boards, each covered in equations and diagrams. Components twinkle in the dim light of the lab as lasers and readout devices pulse with light.

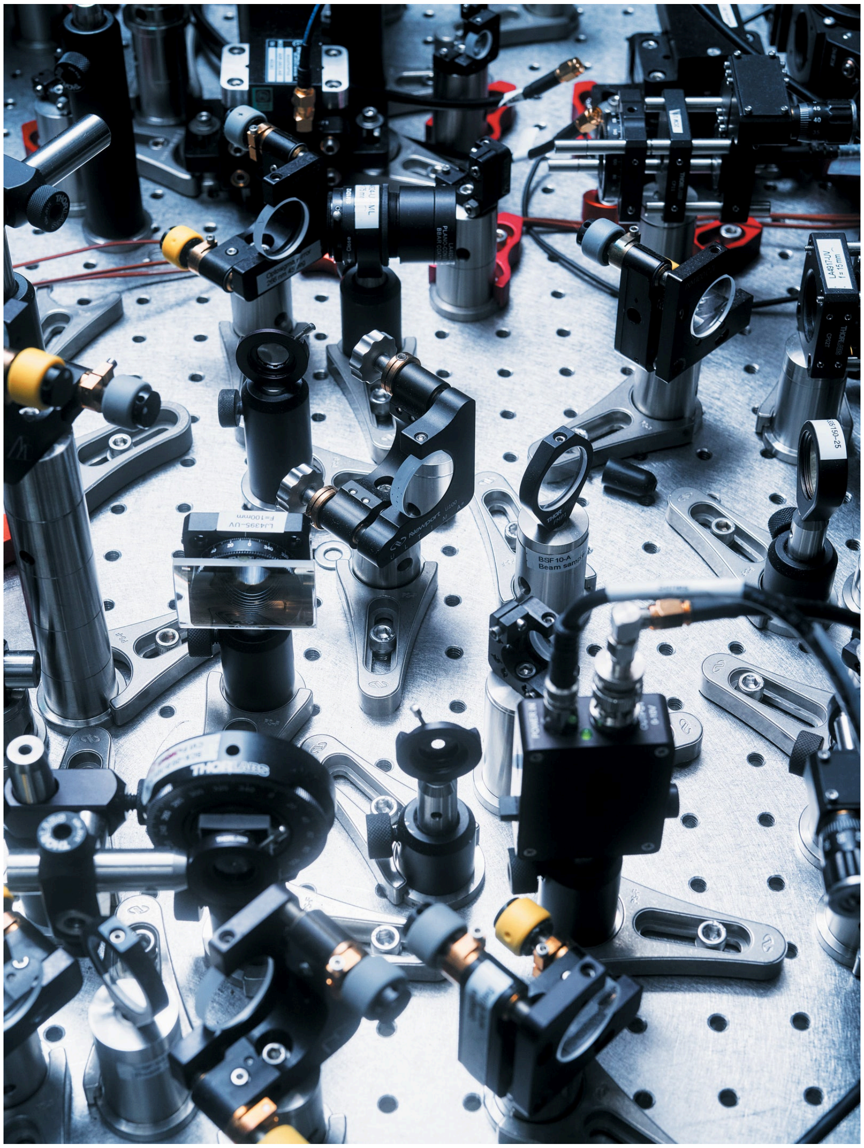
Elizabeth Donley is chief of the time and frequency division at the U.S. National Institute of Standards and Technology.
Jason Koxvold

Each clock works by firing two lasers at each other to create an interference pattern called an optical lattice, a grid with areas of high and low intensity. Pancake-shaped clouds of thousands of neutral strontium atoms become trapped in the high-intensity parts of the lattice, suspended in place.

Another laser then induces an electron transition in the atoms, pushing the outer electrons up an entire orbital level. This is a larger transition than occurs in the cesium atoms, where the electrons only move up one “hyperfine” level. But as in the cesium clock, detectors look for photons released when the electrons settle back to their original states to confirm that the laser is at the correct frequency to make the electrons hop. Compared with the cesium transition, which occurs at about nine billion hertz, the strontium transition requires a much higher frequency: 429,228,004,229,873.65 Hz.

Each of the four clocks in the lab serves a different purpose, measuring interactions between the atoms or effects from the environment—such as gravity, temperature fluctuations or wayward electromagnetic fields—in an attempt to reduce these sources of uncertainty. Optical clocks are so sensitive that the slightest disturbance, even someone slamming a nearby door, will shift the target transition frequency.

The key limiting factor in an optical lattice clock is blackbody radiation, says Jun Ye, lead researcher of the JILA lab. This radiation is the thermal energy released by any body of mass because of its temperature alone. To compensate for this effect, Ye and his team built a new thermal-control system inside the vacuum chamber of one of the clocks, a “fairly heroic effort” that Ye attributes to his students. The project allowed them to measure the transition frequency of strontium with a systematic uncertainty of 8.1×10^{-19}, the most accurate clock measurement ever made. This strontium optical lattice clock and other, similar models are now among the leading candidates to redefine the second.


Cesium fountain clocks use a maze of lasers to control and measure atoms.
Jason Koxvold

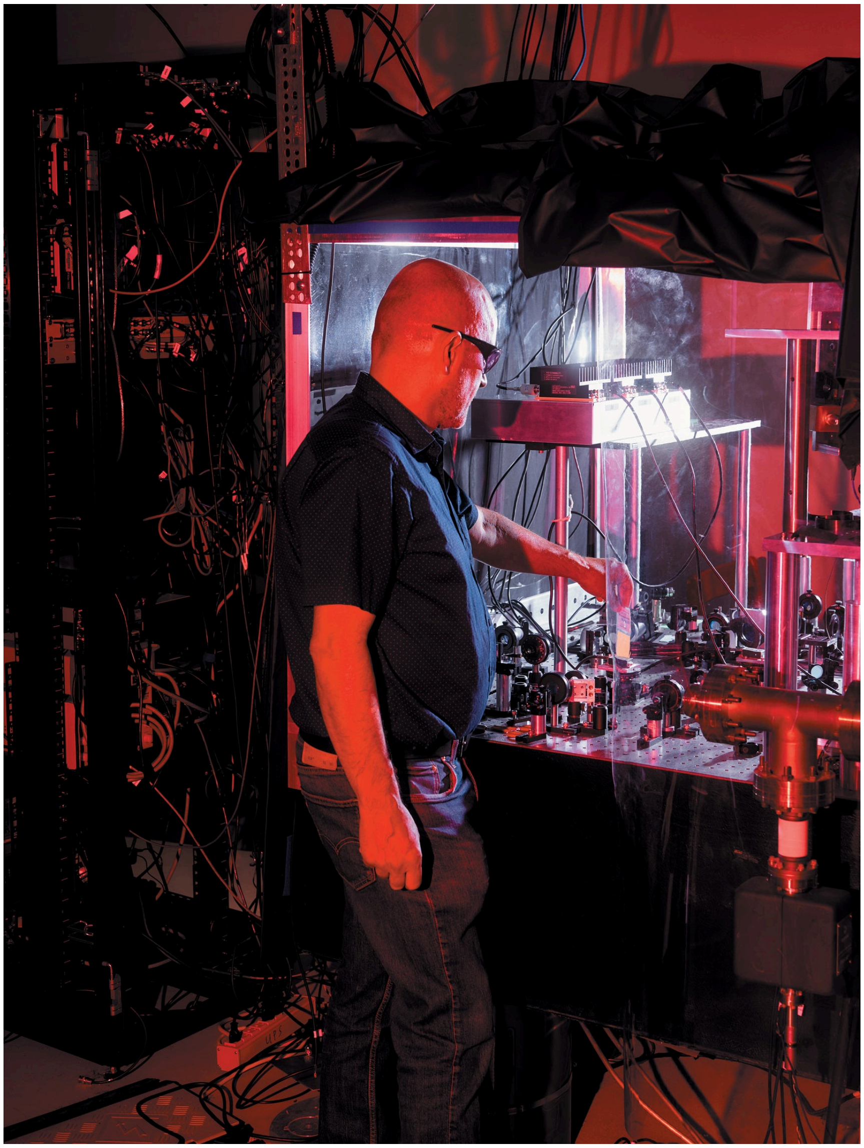
The other main contenders are called single-ion clocks. Some of the best examples can be found at NIST and at the German PTB lab. This type suspends one charged ion (in this case, an atom with one or more electrons removed so that it carries a positive charge) within a trap of electromagnetic fields and then induces an atomic transition with a laser. Currently the most accurate of these clocks uses an aluminum ion.

Single-ion clocks avoid the noise that light lattices introduce to a system, Huntemann says, and “there is generally a smaller sensitivity to external fields,” including fields in the experiment as well as the environment. Optical lattice clocks, however, scrutinize thousands of atoms at once, improving accuracy.

Huntemann is researching ways to trap and measure multiple ions at once, such as strontium and ytterbium ions, within the same clock. This approach would allow scientists to probe two different atomic transitions simultaneously, and the clock could average its frequency measurements more quickly—though not as fast as an optical lattice clock.

Ion clocks and optical lattice clocks have been trading the accuracy record back and forth for the past two decades. They have even demonstrated how time passes faster at higher elevations—a prediction from Einstein’s general theory of relativity, which showed that time dilates, or stretches, closer to large masses (in this case, Earth). In a 2022 experiment, parts of a strontium optical lattice clock at JILA separated by just a millimeter in height measured a time difference on the order of 0.0000000000000000001 (10^{-19}). This tiny aberration would have been too small for a cesium clock to detect.

If scientists choose to redefine the second, they must decide not only which clock to use but also which atomic transition: that of strontium atoms or ytterbium or aluminum ions—or something else. One possible solution is to base the definition on not just one atomic transition but the average of all the transitions from different kinds of optical clocks. If an ensemble of clocks, each with its own statistical weighting, is used to redefine the second, then future clocks could be added to the definition as needed.



Vladislav Gerginov works on one such clock called NIST-F4 at NIST's Colorado campus.
Jason Koxvold

Last year Ye and his team demonstrated the viability of a nuclear clock based on thorium. This type of clock uses a nuclear transition —a shift in the quantum state of atomic nuclei—rather than an electron transition. Because nuclei are less sensitive to external interference than electrons are, nuclear clocks may become even more accurate than optical clocks once the technology is refined.

If the second doesn't get redefined in 2030, scientists can try again in 2034 and 2038 at the next two meetings of the General Conference on Weights and Measures. A new definition won't change much, if anything, for most people, but it will eventually and inevitably lead to technological advances. Researchers are already dreaming up applications such as quantum communication networks or upgraded GPS satellites that could pinpoint any location on Earth to within a centimeter. Other uses are just starting to be envisioned.

By pushing clocks forward, scientists may do more than redefine time—they might redefine our understanding of the universe. Supersensitive clocks that can detect minute changes in the passing of time—as shown in the time-dilation experiment—could be used to detect gravitational waves that pass through Earth as a consequence of massive cataclysms in space. By mapping the gravitational distortion of spacetime more precisely than ever, such clocks could also be used to study dark matter—the missing mass thought to be ubiquitous in the cosmos—as well as how gravity interacts with quantum theory.

Such endeavors could even rewrite our understanding of time itself—which has always been a more complicated notion in physics than in practical life. “The underlying classical laws say that there is no intrinsic difference between the past and future nor any intrinsic direction of determination from past to future,” says Jenann Ismael, a philosopher of science at Johns Hopkins University.

In any case, now that we have clocks that outstrip the literal definition of the second, many scientists say the way forward is obvious: we should improve the definition of time simply because we can. “As with any new idea in science, even if it is not exactly clear who needs a better measurement, when a better measurement is available, then you find the application,” says Patrizia Tavella, director of the time department at BIPM, the organization that defines the International System of Units. “We can do better,” she says of the current second. “Let’s do better.”

**Editor’s Note (2/24/25): This sentence was edited after posting to correct the English name of the International Bureau of Weights* *and Measures.*

Jay Bennett is a science writer based in Copenhagen. He previously worked as a science editor at *National Geographic*, *Smithsonian* and *Popular Mechanics*.

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https://www.scientificamerican.com/article/worlds-most-accurate-clocks-could-redefine-time

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Too Much Salt in the Soil Is No Problem for These Crops

Halophytes that thrive in increasingly saline soils could help feed people and livestock

By Rachel Parsons edited by Mark Fischetti

Salicornia, a tasty halophyte, grows wild along the North Sea; farmers are also cultivating it to feed people.
Peter Eckert/500px/Getty Images

This article was produced in partnership with the Pulitzer Center.

Twenty years ago Dutch farmer Hubrecht Janse realized the tide was about to turn on his third-generation family business in the Netherlands. In 2004 the country's government installed a sluice gate in a dam that separated the glittering blue Lake Veere from the North Sea. An open gate would allow seawater to flow in, reducing damaging algae blooms in the lake's often stagnant waters. But the connection with the sea would make the lake saltier. "And for us," Janse says, "that was a problem."

Janse’s farm—a 160-acre, pancake-flat patchwork of sugar beet, onion, potato, wheat and grass-seed fields—hugs the southern shore of Lake Veere. Saltier water seeping into the soil meant his fields closest to the lake would be rendered useless. Salinity has been an enemy of agriculture for millennia because even though many crops can withstand low to moderate salt concentrations in water and soil, high levels can reduce their yield or outright destroy them by inhibiting osmosis, the process plants use to move water through their tissues.

Janse wondered whether he could cultivate salicornia, a halophyte—a type of plant that’s native to salty environments. After all, the skinny succulent grew wild, and prolifically, in the area. The plant has a leafless stem resembling a tiny asparagus stalk and a juicy, crunchy texture similar to steamed green beans, with a saltier flavor. Local residents have eaten it raw or cooked for hundreds of years. Janse planted his first crop of *Salicornia europaea*, sometimes called samphire or sea beans, in 2006. Today the farm also produces ice plant, sea lavender and sea fennel—all halophytes—in addition to more traditional vegetables farther inland. Janse says ice plant is popular; its young, delicate leaves have a spicy, somewhat tangy flavor. Sea lavender’s small, slender leaves are zesty and salty, and people frequently use them in salads. Sea fennel’s succulent stalks and leaves are typically boiled or steamed as a side dish.

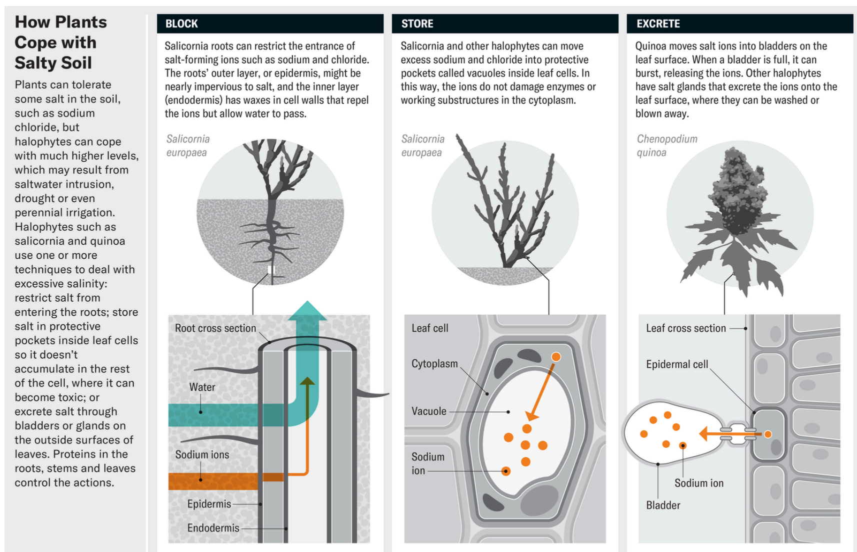
There are more than 7,000 edible halophytes in the world. Ancient texts show that people have foraged them for food, medicine and fuel for thousands of years. They appear in the historical record cooked, fermented, pickled and raw. Yet scientists didn’t begin studying their large-scale cultivation potential until the 1960s. The body of research they’ve generated shows that halophytic crops can grow at scale and provide a novel way to shore up food security. The work has also revealed that some halophytes are full of nutrients and chemicals crucial for human health. They are rich in antioxidant and anti-inflammatory compounds, and various species have anticarcinogenic and antimicrobial properties. Some may help lower blood glucose and blood lipids, including cholesterol.

> As taste tests prove, people may be ready to eat these foods even if they don’t know it yet.

Janse and other farmers are already selling halophytes to food companies as additives. Janse’s salicornia makes its way into mustard, mayonnaise and caramel as a low-sodium salt substitute. It goes into green pasta, a sparkling tea and gin. And people already eat loads of plants that were natively salt-tolerant at one point in their evolution or still are. Chard and beets come from halophytes originally found wild in saline environments around the Mediterranean. Multibillion-dollar businesses have been built around coconuts and palm dates. Quinoa, a hardy South American halophyte, burst on the food scene more than a decade ago, and today it can be found in grocery stores and restaurants around the world. So researchers say adding more salt-loving plants to the dinner plate isn’t a stretch. “Halophytes are going to be the future for sure,” says Giulia Mozzo, a junior research fellow at the University of Florence in Italy. “Most people don’t realize how big the problem is.”

That problem is a sharp increase in soil salinity across swaths of the planet, exacerbated by climate change. Sea-level rise is pushing salt water farther into coastal farmland; food producers from the U.S. Atlantic seaboard to Bangladesh are fallowing or abandoning coastal farmland because of salt, according to the United Nations Food and Agriculture Organization (FAO). Longer and deeper droughts are a problem, too, because they hasten evaporation, leaving higher concentrations of salty minerals in the soil.

Agricultural irrigation is also driving up soil salinity on inland farms around the world. Irrigation water contains naturally occurring elements—sodium, magnesium, calcium and potassium—that form salts and accumulate in soil over time as the water evaporates again and again. According to the FAO, salinity eliminates up to 3.7 million acres of farmland from production globally every year, and it decreases the yield of nearly 113 million acres a year. Salinity already affects 20 percent of the world's total cultivated land and 33 percent of its irrigated farmland. Studies predict that the issue will accelerate faster by 2050 because of intensifying drought, which eliminates rains that can dilute salts in the soil, and because of rising temperatures, which exacerbate evaporation. Freshwater deprivation "is going to be one of the major consequences of climate change," says Ed Barrett-Lennard, a soil-salinity expert at Murdoch University in Perth, Australia.



Jen Christiansen; Source: Tim Flowers/Emeritus Professor in Plant Physiology/University of Sussex (*scientific reviewer*)

In fields with high salinity and dwindling fresh water, growing halophytes may be the only agricultural alternative. Saltbush, for example, a shrub used in sheep feed in Western Australia, grows in arid, salty environments such as deserts, salt plains, inland marshes and, importantly, irrigated crop land. The feed may be one-third to one-half saltbush, which significantly decreases the volume of freshwater irrigation needed to create sheep food, Barrett-Leonard says.

Ecologists also see broader applications for halophytes because the plants can thrive in harsh ecosystems from the tropics to temperate zones, and they provide a variety of benefits. In marshes, for example, they buffer land from storm surges, hurricanes and sea-level rise, and they also can store massive amounts of carbon. How greatly halophytes benefit the environment will depend on how widely they are consumed—by humans or animals.

One bright, windy afternoon last May, Yanik Nyberg, CEO of NARA Climate Solutions, which is using halophytes to regenerate degraded salt marsh in southwestern Spain, led me along a foot path cut through the company's vast spread of marsh alongside the Guadalquivir River. It didn't look like much to my untrained eyes, but Nyberg was clearly delighted with the short, scruffy plants growing everywhere. Only a few months earlier, he told me, the area had looked like a flat wasteland.

He squatted, plucked a dry, weedy specimen out of the ground and invited me to lick it. It tasted like I had emptied a saltshaker into my mouth. The plant, *Suaeda maritima*, known as sea blite or seepweed, keeps the salt it takes up in its biomass, Nyberg said. The highly salty taste doesn't really matter, because, along with the rest of the halophytes growing in this formerly barren marsh—"in any given 10 square meters, there's seven or eight different species growing [wild] together," Nyberg said—the sea blite isn't destined for human consumption. NARA harvests the plants, mulches them together and sells the resulting biomass to Halorefine, a Danish company that extracts rich polyphenolic chemicals for use in nutritional supplements and cosmetics. Halorefine then processes what's left for fish food, which is sold to fish farms, ultimately helping to feed people.

Villagers in Fiaxor, Ghana, have created a fishpond (*left*) to help feed residents and will grow the halophyte sarcocornia on the adjacent, salty land as fish food. Fish waste will fertilize the plants.
Rachel Parsons

Enormous volumes of fresh water and land are used to grow crops for animal feed. Researchers and farmers around the world are trying to augment animal feed with halophytes grown on marginal land—think degraded coastlines and deserts—that doesn't compete with prime farmland for freshwater crops. In the U.S., for example, farmers are feeding *Distichlis spicata*, or salt grass, to cattle.

Nyberg's plants all around our feet and off into the distance looked like stems coated with hundreds of tiny green flowers because they had already gone to seed. A month prior they were barely seedlings themselves. "That's how quickly this restoration can take place, without us really having to do anything," Nyberg said. "It's in some ways the easiest type of farming, when you just flood a bit of land and let nature do what it does best."

People around the world are exploiting the natural growth of halophytes in their regions. A few weeks after sampling *S. maritima* in Spain, I arrived in the Ghanaian village of Fiaxor to visit one such agricultural site, a restoration run by Seawater Solutions, a developer and sister company of NARA. Seawater Solutions invests in wetland-restoration projects on degraded coastal land. Fiaxor clings to the inside rim of a large saltwater lagoon along Ghana’s southeastern coast. The little town is a collection of low, concrete block buildings straddling a narrow spit of flat sand jutting into the deep lagoon. Pygmy goats munch stubby grass that grows in muddy patches between tightly packed houses.

The population of about 300 relies on fishing for its livelihood, which has become so tenuous because of overfishing and excessive algae growth that many young people have moved away. To generate new income, around 2004 the village allowed a salt-mining company to create salt flats at its northeastern end. The hope was to harvest the mineral and earn money from the land lease so the village could cash in on Ghana’s booming, but often exploitative, salt-export business. The process stripped away the island’s protective vegetation, including mangroves. The business folded in 2014, and Fiaxor was left with barren land, making it more vulnerable to storms, flooding and sea-level rise.

Seawater Solutions set up shop in late 2020. Raphael Ahiakpe, the company’s Ghana director, told me that one early idea was to train farmers to grow halophytic crops for human consumption. He then grinned and said residents quickly informed him that his *Sarcocornia fruticosa* was food for goats, not people. Rather than trying to convince people to eat something they don’t want, Fiaxor is incorporating the sarcocornia, a hardier, perennial version of salicornia, into what the people need: fish feed.

The company now employs several Fiaxor residents and has planted thousands of mangrove saplings on the land the village had leased to the salt company. Next to one stand, Ahiakpe walked me around an artificial fishpond, about 8,600 square feet, where tiny tilapia were growing for the village to harvest when fishing in the saltwater lagoon didn’t net anything. Beside the pond, fronting the lagoon, sarcocornia was about to be transplanted from a plot that’s thriving at the company’s headquarters, about half an hour away.

Salicornia grows thick in a protected salt marsh on Spain’s Mediterranean coast. The succulent stalks can be eaten raw or cooked.
Rachel Parsons

Fish effluent from the pond will fertilize the halophytes, and the halophytes will feed the fish; their seeds make a protein- and oil-rich fish meal. The village is making money by leasing the land to the company. And Seawater Solutions has received accreditation from an organization to sell carbon credits for the root-level carbon sequestration that the sarcocornia and mangroves will provide. The company says it splits the income with the village.

Doris Atitsogbui, the site manager and a lifelong resident, told me the village was “happy and excited” when Seawater Solutions proposed its project because there were no jobs in Fiaxor. She’d like to see similar sites spread throughout the Volta Delta region, which is teeming with hundreds of other fishing villages. The salty plants could help solve a variety of societal challenges.

The science of halophytes is also being applied to traditional crops. Researchers at King Abdullah University of Science and Technology in Saudi Arabia grew cultivars of the currant tomato, a small, wild relative of the common tomato that thrives in Peru, and found five cultivars that did well in highly salty environments. The scientists are investigating genes in those varieties that they could breed into other tomatoes. Researchers at the University of

California, Davis, are trying to devise transgenic alfalfa, pearl millet, peanuts and rice that will grow in salty conditions.

Yet there are still plenty of obstacles. Some halophytes produce oxalic acid, which is toxic to the kidneys when eaten in large amounts. Many of the plants are “includer” halophytes, meaning they absorb sodium from their environment. This trait makes them high-salt foods, which can be a concern for people with high blood pressure. (“Excluder” halophytes can deal with salty environments by blocking sodium from entering their roots.) Agronomists have learned, though, that sodium levels in many of the harvested crops can be reduced significantly through cooking.

Growing the crops also can be tricky because many still need some amount of fresh water. Salicornia, for example, needs lower salinity to germinate in the spring. “What I say to other farmers in my region,” Janse explains, “is that the availability of fresh water at the right moment is even more important than for fresh crops.”

Perhaps the biggest challenge for farmers, according to Janse, is that demand for halophytes is low outside regions like his. Most people have never heard of them. If the foods are around at all, they tend to be grown on small farms and be offered in upscale supermarkets or restaurants—an irony not lost on advocates who argue that adding more halophytes to the global diet could tackle hunger and food insecurity in low-income countries.

To raise public awareness, some agronomists have become test-kitchen chefs, realizing that if the vegetables are to spread, people need to try them. What the proponents are finding is that the more consumers know about the environmental impacts of agriculture, the more open they are to halophytes. In March 2024 a team at the University of Florence ran a small, qualitative study to assess the viability of *Tetragonia tetragonioides*, a species of dark, leafy green halophyte, as an alternative to spinach. Spinach is relatively salt-tolerant, but tetragonia can be reliably cultivated in a greenhouse at a much higher ratio of salt to fresh water—up to about twice what spinach can handle.

Participants were not told how the plant was grown before they ate it. A small percentage of them said they would pay more for tetragonia than spinach simply because they preferred it. But that percentage nearly tripled when the people were told tetragonia was grown sustainably with less fresh water. (The study results have not yet been published.) It's easy for people to say they would act a certain way, says Mozzo, who worked on the study, but the outcome supports the idea that people can be sold on these plants. Halophyte evangelists like to remind listeners that prior to the 2010s, few consumers outside of South America knew quinoa. Then, in 2013, the U.N. declared the International Year of Quinoa and funded an awareness campaign targeting farmers and consumers.

Still, agricultural policies may present "bottlenecks and obstacles" to broader uptake of halophyte farming, says Kate Negacz, a saline-agriculture policy researcher at Vrije University in Amsterdam. In many countries or states, governments pay subsidies primarily for conventional crops; if a subsidized corn farmer wanted to switch to ice plant because salty water was seeping into her land, she'd be unlikely to get a subsidy for it. And in many jurisdictions, water use is controlled by local water boards, which would need to be convinced that halophytes are viable. Some hope may come from Europe, where policy conversations related to saline-agriculture practices are becoming more frequent. "Things are starting to move," Negacz says.

In Ghana, as in the Netherlands and Spain, the lesson for researchers, entrepreneurs and farmers is that halophytes work when they fit cultural and economic needs. In the Netherlands, Janse says, it's normal to see halophytes on the dinner plate. In Ghana, the plants serve a different but no less important function, providing fish food and local income.

In an increasingly salty world, there is an urgent need for diverse applications of these plants. Agronomists, soil scientists and ecologists on almost every continent are working to address agricultural salinization, and halophytes already grow in a wide array of climates. And as the participants in the University of Florence taste test of tetragonia proved, people may be ready to eat these foods even if they don’t know it yet.

Rachel Parsons is a Los Angeles-based multimedia journalist whose work focuses on climate, environment and human ecology. Her work has appeared in *New Scientist*, *DeSmog*, *Fort Worth Magazine*, *PBS NewsHour* and Reuters. Follow her on Twitter @RachelDParsons

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https://www.scientificamerican.com/article/the-future-of-food-may-depend-on-crops-such-as-quinoa-that-thrive-in-salty-soils

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Animals

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  There are fewer than 500 Ethiopian wolves, and they may be the first large carnivore known to act as a pollinator
- ## Penguins Help to Map Antarctica’s Growing Mercury Threat
  Molted penguin feathers record mercury infiltrating Antarctica’s food web

Nectar-Eating Wolves May Be Pollinating Flowers

There are fewer than 500 Ethiopian wolves, and they may be the first large carnivore known to act as a pollinator

By Meghan Bartels edited by Andrea Thompson & Sarah Lewin Frasier

An Ethiopian wolf (*Canis simensis*) feeding among blooming Ethiopian red hot poker flowers (*Kniphofia foliosa*).
Adrien Lesaffre

An Ethiopian wolf’s diet is pretty basic: its proverbial meat and potatoes consists of a large rodent called a giant mole rat (which *is* meat but looks more like a fuzzy potato). But it seems that the endangered canid also has a sweet tooth. It regularly laps up sugary nectar from a tall, fiery-hued flower that adorns the animal’s high-elevation ecosystem. In the process the wolf may be serving as a pollinator, a role usually occupied by insects, birds and flying mammals—not large carnivores.

That hypothesis comes from a team at the Ethiopian Wolf Conservation Program, which published its observations in the journal *Ecology*. For years the group’s monitors have noticed the occasional wolf drinking nectar from a local flower called the

Ethiopian red hot poker (*Kniphofia foliosa*), which blooms from June to November and looks something like a large, furry matchstick set aflame. (Its nectar is also popular with children and baboons, says study co-author Sandra Lai, an ecologist at the University of Oxford and the Ethiopian Wolf Conservation Program.)

Despite the reports of nectar drinking, Lai and her colleagues were surprised by what they learned through systematic observation. Wolves "spend a lot of time actually foraging on the flowers," Lai says. "They can stay, like, an hour and a half, going from flower to flower. We've seen one individual going consecutively to 30 flowers." The scientists also observed the behavior among members of different packs, suggesting that nectar feasting is a widespread habit, not a local quirk.

An Ethiopian wolf (*C. simensis*) licks nectar from an Ethiopian red hot poker flower (*K. foliosa*) (*left*), and its muzzle is covered in pollen after feeding on the nectar (*right*).
Adrien Lesaffre

The new report doesn't surprise Anagaw Atickem, an ecologist at Addis Ababa University in Ethiopia. He was not involved in the research but has studied how domestic dogs compete with Ethiopian wolves, and he says he has noticed that the dogs have a taste for this same nectar. Based on the new study's finding, he wonders whether sharing the flowers may even spread diseases between the two species.

Both Atickem and Lai say there's a lot more to learn about the behavior and its importance. The wolves end up with a muzzle covered in pollen, raising the possibility that they could transport it between flowers and pollinate them in the process. If they did, the wolves would be among the first known large carnivores that facilitate plant reproduction in this way. Pollination is more commonly associated with flying creatures, Lai says; scientists are only beginning to consider ground-bound mammals such as mice, squirrels, monkeys, lemurs and civets as potential pollinators.

Biologists require intricate experiments to determine whether an animal really is pollinating a specific species of flower, however; they need to confirm not only that the creature can transport pollen but also that the interaction results in fruit. "It is not impossible, although it is quite challenging," Lai says, adding that a first step toward understanding the relation between wolf and flower might be to catalog all the animal species that appear to visit the red hot pokers.

The wolves' sweet treats also raise conservation questions, given the challenges that the region is facing. Both the wolves and the red hot pokers are native to Ethiopia's afroalpine ecosystem, found only in mountains some 3,000 meters above sea level. But as the nation's human population grows, people and livestock are venturing to higher altitudes. Meanwhile climate change is raising temperatures in these highland areas.

Atickem now wonders whether the nectar provides a crucial nutrient. If so, it would underscore the need to keep the flower on the landscape as the habitat shrinks and warms. "Even small amounts of nectar may be helpful," Atickem says. "The conservation of these flowers may be very relevant for the Ethiopian wolf."

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/nectar-eating-wolves-may-be-pollinating-flowers

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Penguins Help to Map Antarctica’s Growing Mercury Threat

Molted penguin feathers record mercury infiltrating Antarctica’s food web

By Gayoung Lee edited by Sarah Lewin Frasier

Gentoo penguins have a wide geographic range, making them good targets for follow-up research.
David Merron Photography/Getty Images

When Philip Sontag first visited Antarctica as a Ph.D. student, he brought back an unusual souvenir: a huge bag of penguin feathers. And now, after a decade-long analysis, Sontag and his colleagues have figured out how to use such feathers to create a living map of the mercury contamination that increasingly threatens Southern Hemisphere wildlife.

Mercury is a common by-product of gold mining, a growing industry in several southern countries. The toxic metal accumulates as it moves up the food chain by binding with amino acids in animals and then infiltrating their central nervous systems, where it can inhibit neural growth. Tracking mercury exposure is crucial for monitoring an ecosystem—but merely sampling rocks, ice or soil for its presence tells little about how much is actually entering the food web.

Many predators, including penguins, have evolved ways to dispose of mercury. The chemical builds up in feathers that the birds regularly molt in large quantities. Sontag, now a polar researcher based at Rutgers University, and his colleagues hoped to use molted feathers to determine where penguins picked up the toxic substance. The scientists were surprised to find a very clear correlation between the feathers' levels of mercury and of a carbon isotope called carbon-13; the latter varies based on geographic location and thus acts as an indicator of "where the penguins are feeding or where their breeding grounds are," Sontag says. These findings, published in *Science of the Total Environment*, confirmed this connection in seven penguin species scattered across the Southern Ocean—a pattern suggesting they're exposed to more mercury farther north, where the comparatively warmer environment leads to higher carbon-13 levels.

These findings suggest that penguins could function as mercury bioindicators: living trackers of environmental pollutants, says the study's senior author John Reinfelder, a marine biologist at Rutgers. Rather than measuring the chemical itself in a snapshot of time and place, he says, measuring penguin feathers' mercury levels tracks the substance's movement through the oceanic food web. For instance, penguin species known to reside near one another had varying mercury and carbon-13 levels because of their different migration and feeding patterns. These data could be modeled into a maplike database to help guide future projects on conservation and polar science research.

Scientists consider penguins promising candidates for such bioindicators, says marine scientist Míriam Gimeno Castells, a Ph.D. student at the Institute of Marine Science from the Spanish National Research Council, who was not involved in the study. The animals are midway through the food chain. They breed in colonies, so researchers can easily scoop up feathers from many different individuals. Additionally, every breeding season they undergo dramatic molts; the feathers they lose “will contain the mercury that has accumulated during the nonbreeding season,” Gimeno Castells says.

Sontag’s next steps are to collect newer feathers to experiment with, across different species, and to measure mercury in penguins’ blood and prey to compare with levels of the substance in their feathers.

And how are the penguins themselves doing with their current mercury levels? “We don’t believe penguins have been exposed to toxic levels as of yet,” Reinfelder says. “Yes, the penguins will be okay.”

Gayoung Lee is *Scientific American*’s current news intern. A philosopher turned journalist, originally from South Korea, Lee is interested finding unexpected connections between life and different science, particularly in theoretical physics and mathematics. You can read more about her here: https://gayoung-lee.carrd.co

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https://www.scientificamerican.com/article/penguins-help-to-map-antarcticas-growing-mercury-threat

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Artificial Intelligence

- **Why This AI Gazes into Goat Faces**
  AI-based systems can help identify livestock's early signs of distress

Why This AI Gazes into Goat Faces

AI-based systems can help identify livestock's early signs of distress

By Lucy Tu edited by Sarah Lewin Frasier

Nitin Prabhudesai/Getty Images

The patient grumbled and grimaced, but he refused to speak to his doctor.

The patient was a goat.

Recognizing animal pain is notoriously difficult. To do so, humans must rely on subtle body language or behavioral changes. But a new artificial-intelligence model automates this process by identifying pain in goats—using only their facial expressions. The model, described in *Scientific Reports*, achieved 80 percent accuracy and offers a promising avenue for automatically monitoring livestock health.

Traditionally, detecting animal pain involves analyzing photos or videos by hand for specific cues—a raised lip, a flared nostril—and creating pain scales tailored to individual species. But as humans, we both detect and interpret animals' pain through a biased lens, says University of Florida veterinary anesthesiologist Ludovica Chiavaccini, the new study's lead author. When detection is automated, "the computer just picks up the patterns."

Chiavaccini and her team videotaped 40 goats of various breeds and ages with different medical conditions at a veterinary hospital, generating more than 5,000 fixed frames. Using a behavioral pain scale, clinical history and physical exams, they classified each goat as in pain or not. The team tried three approaches, training an algorithm on different groupings of images while reserving others to test that training. The most balanced model, similarly adept at detecting pained and not-pained goats, was trained on four fifths of the frames, fine-tuned using the remaining fifth and tested on videos of two additional goats. Repeating this process five times with varying groupings yielded an average accuracy of 80 percent. Such training "essentially builds 30 years of clinical experience in 30 minutes," Chiavaccini says.

Similar AI tools exist for cats, which have better-established expression-based pain scales, but the only such pain scale for goats had been validated solely in young, healthy males undergoing castration. Chiavaccini was inspired by the lack of goat pain scales, in addition to a graduate student's enthusiasm for the animals after presenting them at an agricultural show.

AI-powered tools built with similar methods could someday help veterinarians make quicker and more accurate diagnoses or alert farmers to early stages of livestock distress. "This study shows the potential for broader adoption of AI in animal care and highlights the need for further exploration across diverse species," says University of Glasgow computer scientist Marwa Mahmoud, who specializes in human and animal behavioral AI.

Expression-based pain-assessment tools already exist for nonverbal human patients, but these systems' effectiveness can be limited by poor image quality or suboptimal camera angles. “Many of the engineering problems we solved, like adapting to messy, real-world conditions, could be helpful to human medicine,” Chiavaccini says. “Doctors worry about perfect lighting or head alignment. Meanwhile I’m out here racing after a goat with my camera.”

Lucy Tu is a freelance writer and a Rhodes Scholar studying reproductive medicine and law. She was a 2023 AAAS Mass Media Fellow at *Scientific American*.

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https://www.scientificamerican.com/article/why-this-ai-gazes-into-goat-faces

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Arts

- **Poem: ‘(origins, positrons)’**
  Science in meter and verse

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Poem: ‘(origins, positrons)’

Science in meter and verse

By Julia Nelsen & Fabiano Alborghetti edited by Dava Sobel & Clara Moskowitz

Masha Foya

Elementary particle compositions
silent sidereal peals
hailing from space
          energy
distributed across fourteen orders of magnitude
or of beauty if we believe it all begins with the sun
                          a nova, supernova
                    or a quasar, punctiform
and forms, footprints, equal amounts of matter
and its mirror.
                    Vertigo
always favors the grace of emptiness, indeed
but it all builds up, don’t you see?
zygote, blastomere, morula
          and from this sum, forever
anti-particles, atoms, the positive and negative

everything that exists
          that decays
                    and reproduces
in ever new collisions. Electrons. Positrons.
A stellar nucleosynthesis.

Julia Nelsen is a translator and researcher of Italian literature based in Berkeley, Calif.

Poet **Fabiano Alborghetti** lives in Canton Ticino, Switzerland. He is author of eight poetry collections and winner of the 2018 Swiss Literature Award.

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https://www.scientificamerican.com/article/poem-origins-positrons

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Biotech

- **‘Hot Potato’ Plants Engineered to Flourish in Heat Waves**
  A genetic tweak keeps potatoes efficient in the heat

‘Hot Potato’ Plants Engineered to Flourish in Heat Waves

A genetic tweak keeps potatoes efficient in the heat

By Julian Nowogrodzki edited by Sarah Lewin Frasier

Thomas Fuchs

When a scorching heat wave struck Illinois in June 2022, crop physiologist Katherine Meacham-Hensold hoped her team’s new bioengineered potato variety would survive it—but she was astonished by just how well it thrived. The plant yielded 30 percent more of its large red tubers than a normal, unengineered plant in the same conditions, according to a recent study in *Global Change Biology*.

“This study is particularly noteworthy because it shows real benefits in a field setting with a staple crop,” says biochemist Edward Smith of the University of Oxford, who was not involved in the research. “There’s no reason this technology couldn’t be applied to more crops.”

To engineer the potato, Meacham-Hensold and her colleagues at the University of Illinois Urbana-Champaign focused on an inconvenient heat-triggered process in most plants called photorespiration, in which a key photosynthesis enzyme known as RuBisCO gets sidetracked and begins making a toxic by-product. RuBisCO molecules need to bind to carbon dioxide to carry out photosynthesis, but about a quarter of the time they grab oxygen instead—and this erroneous process happens more often at high temperatures. This inefficiency can decrease crop yields by as much as 50 percent.

In the new engineered potatoes, a gene inserted into the plant cell's nucleus produced a protein that traveled into the chloroplast, the cell organelle used in photosynthesis. There it broke down the toxic by-product, so the chloroplast didn't need to send it out to other organelles. This saved energy, similar to how eating local food saves the energy of trucking it across the country.

During the engineered potatoes' 2022 growing season in the Illinois test field, an extreme heat wave brought four consecutive days with temperatures higher than 95 degrees Fahrenheit. But the new potato's genetic change which can be passed on to the next generation—boosted yield by almost a third. "We were really shocked," Meacham-Hensold says. The photosynthesis process is a promising target for agricultural engineering, she adds, because it can increase crop yield without the need for extra land use and fertilizer. The results are exciting, Smith says, although he'd like to see data from future growing seasons.

The new technique could help crops adapt to climate change. Similar strategies have been used previously in rice, but this study is the first to show that it doesn't cause a decrease in a food crop's nutritional quality, Meacham Hensold says: the team froze and ground up the tubers to measure their starch, fiber, sugars, protein, calcium, potassium, iron, and vitamins B_6 and C.

Next the researchers are working on soybeans and cowpeas; the latter is “a hugely important food-security crop in African countries,” Meacham-Hensold says. A high-yield soybean variety with the same genetic change will hit the field this year.

Julian Nowogrodzki is a science writer based in Boston.

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https://www.scientificamerican.com/article/hot-potato-plants-engineered-to-flourish-in-heat-waves

Chemistry

- **The World’s Smallest Pasta Is Not Very Tasty**
  Researchers seeking better bandages are creating extremely thin fibers of starch

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Chemists Seeking Better Bandages Make World’s Smallest Pasta

Researchers seeking better bandages are creating extremely thin fibers of starch

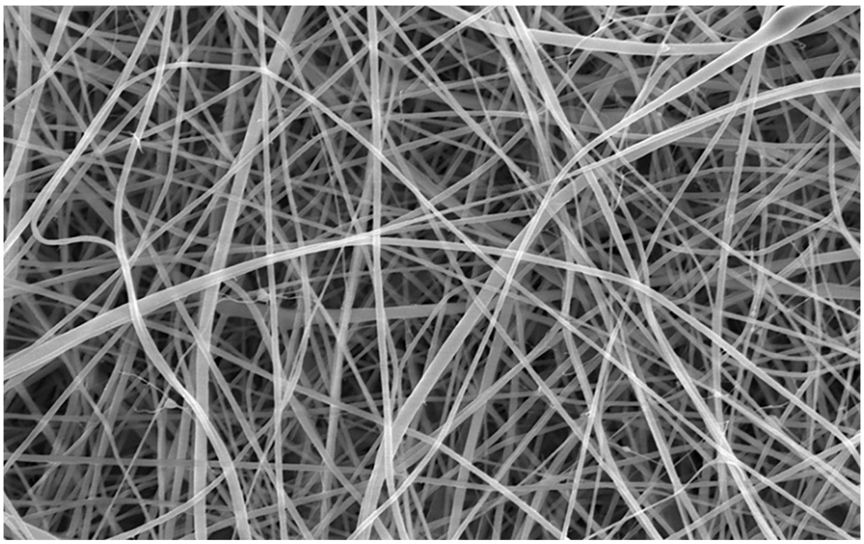
By Ben Guarino edited by Sarah Lewin Frasier

A bowl of plain noodles (a strand of the world's tiniest pasta, not pictured, is invisible).
Say-Cheese/Getty Images

The skinniest pasta yet made—let’s call it “nanotini”—has an average diameter of 372 nanometers and only two ingredients: flour and formic acid. The latter, a caustic agent typically secreted by agitated ants, is why researcher Adam Clancy sniffed the creation before he tried eating it.

It is generally inadvisable to consume things pickled with formic acid, because ingesting as little as a tablespoon can be fatal. But Clancy, a chemist at University College London, relied on his understanding of the acid’s odor threshold—the lowest concentration at which the human nose can detect a substance. Clancy trusted that if the finished product was scentless, then it was essentially acid-free. Satisfied, he sampled a wad of nanotini. “I know you’re not meant to self-experiment, but I’d made the world’s smallest pasta,” Clancy says. “I couldn’t resist.”

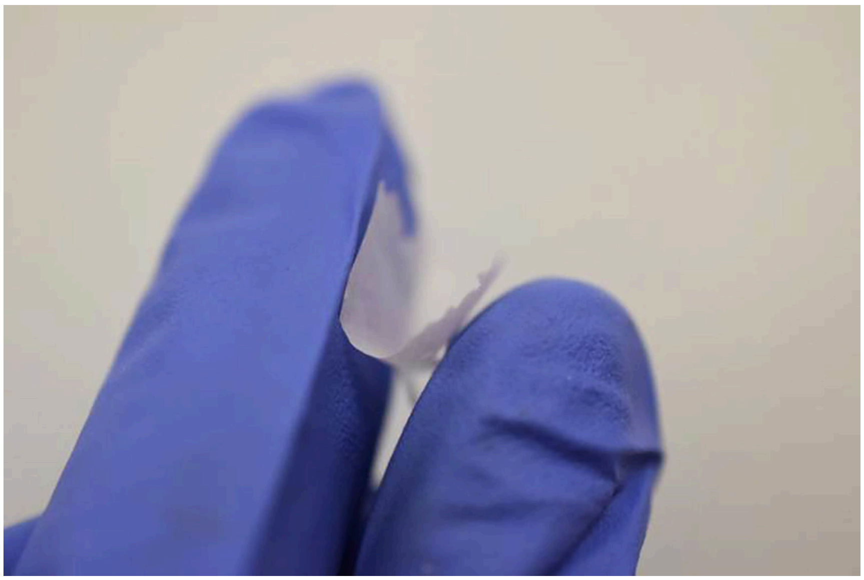
Clancy and his co-authors, who recently published their pasta recipe in *Nanoscale Advances*, aren’t trying to whip up a menu item; they are investigating starch nanofibers for their potential as next-generation bandages. Mats of these fibers have pores that let water pass through but are too small for bacteria, Clancy says.



The team used a scanning electron microscope, scanning the mat with a focused beam of electrons and creating an image based on the pattern of electrons that are deflected or knocked-off. Each individual strand is too narrow to be clearly captured by any form of visible light camera or microscope.
Beatrice Britton/Adam Clancy

Ideal wound dressings aren’t simple barriers. They should also speed recovery, says Cornell University graduate student Mohsen Alishahi, who studies nanofiber bandages made with starch derivatives and wasn’t involved with the nanotini project. “Using a natural material such as starch to develop the wound dressing can help the wound heal more quickly,” Alishahi says. Starch should encourage cells around an injury to grow because the fibers resemble the body’s microscopic structural network, called the extracellular matrix. And starch has another natural advantage: it is made by every species of green plant and is one of the most common organic compounds on the planet.

Previous nanofibers had been built with purified starch from corn, potato and rice. This is the first time anyone has done so with plain white flour—thereby, Clancy claims, meeting the definition of the world's smallest pasta. To make it, his team first dissolved the flour in acid, which uncoiled its starch clumps so the molecules could be stretched into skinny threads.



The nanofiber mat held between two fingers.
Beatrice Britton/Adam Clancy

The researchers employed a delicate sequence of heating and cooling to prepare the starch. This process is "the most interesting" aspect of the new research, says Pennsylvania State University food scientist Greg Ziegler, who studies starch nanofibers as possible scaffolds for cultured meat and wasn't involved with the new paper. Despite the impurities of supermarket flour, the resulting liquid had the "proper viscosity for spinning," Ziegler says, referring to the technique used to make the pasta.

Pasta makers typically slice dough or push it through small holes to give it shape. But in this case, the starch molecules were "electrospun"—pulled by electrical charge through a hollow needle tip. The liquid whipped out of the needle horizontally, attracted to a grounded plate a few centimeters away. As the acid swiftly dried in flight, the starch chains formed solid but invisible threads; their width was too small to be seen by the unaided eye. What could be seen were the off-white mats that formed when fibers amassed on the plate. These bendy mats looked a bit like tracing paper, but instead of wood pulp, it was exceptionally tiny pasta all the way down. As for the flavor? “I can confirm it needs some seasoning,” Clancy says.

Ben Guarino was formerly 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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https://www.scientificamerican.com/article/the-worlds-smallest-pasta-is-not-very-tasty

Culture

A Fascinating Sparrow, Aha! Moments and Local Flowers

Astronomers search for missing planets, a salty food movement takes hold, and it may be time to redefine the second

By Jeanna Bryner

Scientific American, March 2025

The best stories are those that draw you in with intrigue, visuals and characters, leaving you with a new perspective on the world and your place in it. My take on flowers is forever changed after reading science journalist Maryn McKenna's deep dive into the chemically laden, international floral industry, where loose to nil regulations on insecticides and fungicides allow farms to create the perfect blossom. These chemicals are used at such high levels on flower farms in countries such as Ecuador and Ethiopia that they lead to cognitive and physical ailments for workers, neighbors living nearby, and even people handling the blooms thousands of miles away. The good news: Farms across the globe are bringing pesticide-free flowers with local character into fashion. For me: I'm letting go of my love for perfectly round and bright peonies.

Cute little White-throated Sparrows hold a treasure trove of mind-shifting qualities. Contrary to conventional wisdom, the flashier figure in a mating pair is sometimes male and sometimes female. Referred to as "the bird with four sexes," the sparrows come in four varieties based on their sex organs and color morph (white-striped or tan striped). Regardless of biological sex, the white-striped morph aggressively defends territory, and the drab tan striped morph is the nurturing parent. Neuroscientist Donna L. Maney reveals the fascinating genetics underlying these morphs, ultimately challenging the idea that life fits into binary boxes of male and female. I hope your binocular view of backyard birds is a little more spectacular after reading Maney's article.

Astronomers looking at the heavens through behemoth telescopes have found something missing from the parade of planets discovered since 1995 outside of our solar system: a dearth of worlds a tad larger than Earth but quite a bit smaller than Neptune. Astrophysicist Dakotah Tyler says that some atmosphere-stripping force could be preventing intermediate-size planets from forming or keeping their middleweight girth. The answers not only will resolve an astronomical puzzle but also could enlighten our view of Earth's (and our own) place in the universe.

Our cover story tells in wondrous detail how, after more than a century of searching, scholars have discovered the neurological and psychological sources of insight. Psychologist John Kounios and writer Yvette Kounios describe why insightful thinking is beneficial and feels good. If you are struggling to solve a puzzle or dilemma, anxiety, lack of sleep and the modern drive for productivity can be your enemies: Find somewhere you can relax and allow your brain to loosen its grip on old ways of thinking. You may be surprised at what you can imagine.

Journalist Rachel Parsons delivers a compelling case from farmers and researchers who are part of the salty food movement. It's not an endorsement of potato chips. These foods are made from halophytes, which are adept at growing in highly saline soils resulting partly from drought and sea-level rise. The salty conditions have eliminated millions of acres of crops from production. Will such salt-tolerant plants be the answer? The primary barrier seems to be humans' narrow view of what counts as delicious food.

I'll leave you with a question you might need a minute to wrap your head around: Should humanity redefine time or, more specifically, the second? That's what physicists are grappling with in science writer Jay Bennett's feature. As atomic clocks advance, scientists can measure a second tens of thousands of times more accurately than with the standard method using cesium atoms. The implications of the decision could have timely and interesting repercussions.

Jeanna Bryner is managing editor of *Scientific American*. Previously she was editor in chief of Live Science and, prior to that, an editor at Scholastic's *Science World* magazine. Bryner has an English degree from Salisbury University, a master's degree in biogeochemistry and environmental sciences from the University of Maryland and a graduate science journalism degree from New York University. She has worked as a biologist in Florida, where she monitored wetlands and did field surveys for endangered species, including the gorgeous Florida Scrub Jay. She also received an ocean sciences journalism fellowship from the Woods Hole Oceanographic Institution. She is a firm believer that science is for everyone and that just about everything can be viewed through the lens of science.

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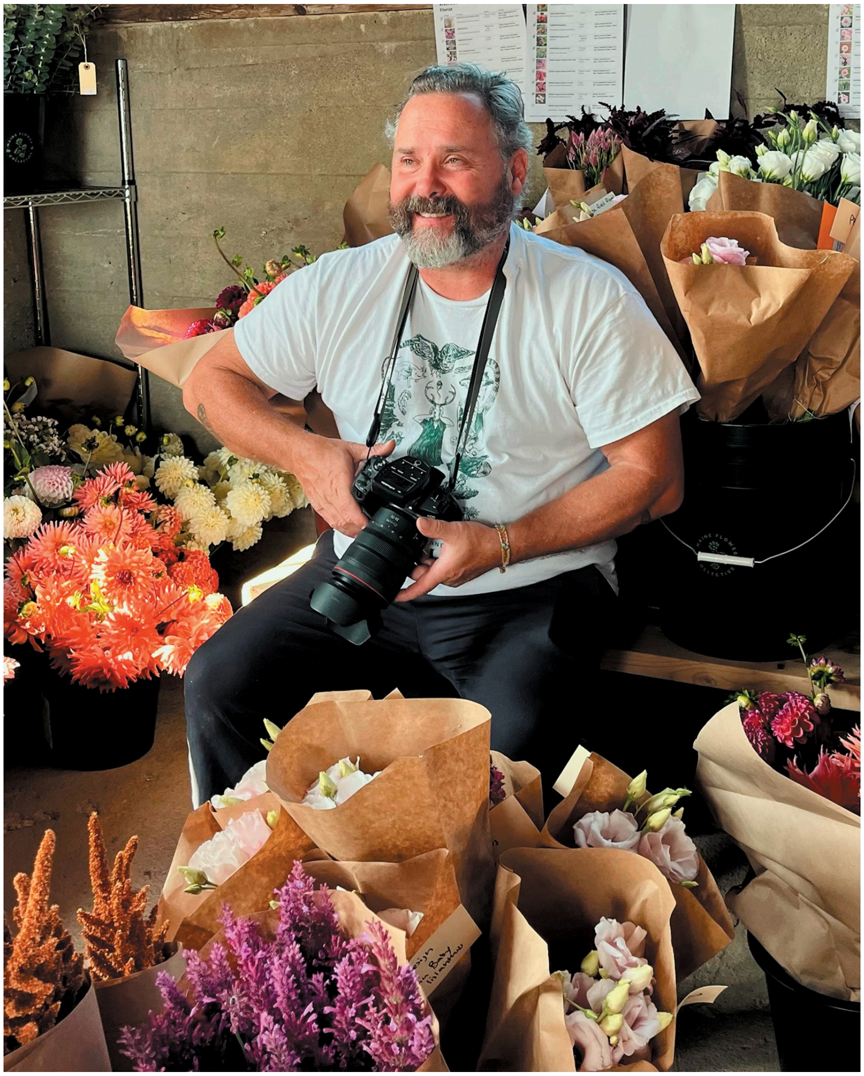
https://www.scientificamerican.com/article/a-fascinating-sparrow-aha-moments-and-local-flowers

Contributors to *Scientific American*’s March 2025 Issue

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

By Allison Parshall edited by Jen Schwartz



Jesse Burke.
© John Hesselbarth

Jesse Burke
The Imperfect Bloom

For Jesse Burke (*above*), photographing a flower farm was a dream assignment. “When you send me to a farm,” he says, “you’re sending me to my favorite place ever to talk to my favorite people ever.” Burke felt a “kinship” with the Maine-based flower farmers he photographed for this issue’s story on sustainable floriculture, written by journalist and *Scientific American* contributing editor Maryn McKenna. He and his family have dubbed their home in Rhode Island “Sweet Bean Farm”; they raise chickens, potbellied pigs and pet Flemish giant rabbits (“imagine a Boston Terrier [in size], but it’s a bunny with giant ears”).

Burke’s photography often fuses the worlds of science and art. For this shoot, he brought a macro lens to get detailed photos of the blossoms’ structures. Close up, the flowers’ centers almost look like fireworks, he says. He specializes in something he calls environmental portraiture, or capturing people in nature, and is known for his photo series *Wild & Precious*, which documents trips to beaches, mountains, forests and canyons with his young daughter. This kind of photography is “sort of raw and wild,” he says. “It was a great tool for creating this relationship between my kids and nature and between me and my kids.”

Maryn McKenna
The Imperfect Bloom

When journalist Maryn McKenna began living part-time in Maine, she became intrigued by the local flower growers at farmers markets. “I wanted to know how they make it work when there’s this dominant, incredibly lucrative and incredibly inexpensive product that sort of saturates the world,” she says. In her feature story for this issue, she investigated the harms linked to the perfect blossoms you might find at the grocery store, and she followed the movement of small farmers who are instead growing sustainable flowers with local character.

McKenna began covering public health in the 1990s, when she investigated cancer clusters surrounding a former nuclear weapons plant in Ohio. She's learned an important lesson in her reporting: "Most of the time there are not villains in the world," she says. "Most of the time people are doing things for what seem like good reasons at the time," but their actions have unintended consequences, she adds. Take, for instance, the overuse of lifesaving antibiotics—the subject of two of her books—which has created legions of resistant "superbugs."

The use of these drugs in flower agriculture has mostly flown under the regulatory radar. "We forget that flowers are a crop," she says—and not a frivolous one. From funerals to weddings to holiday celebrations, flowers are often the centerpieces of our most important cultural traditions. "The beauty embodied in flowers is actually very important to our lives."

Dakotah Tyler
The Missing Planets

As a Division I football player in college, Dakotah Tyler lived a life structured by his sport. Then he got injured. "Not having that passion and that purpose created sort of a void," he says. But in its absence, a new fascination emerged. While watching astronomy documentaries, Tyler became enchanted by the idea of worlds outside our solar system. "I remember thinking that there was probably a planet made just totally out of glass and maybe one that was completely diamonds," he says. Now finishing his Ph.D. in astrophysics at the University of California, Los Angeles, Tyler studies the mysterious rules that govern planetary formation, which he wrote about for this issue.

Exoplanet research is full of surprises. Take a class of planets called hot Jupiters, for example. At one time "we didn't even think that those were possible," he says, yet "they're everywhere." The mysteries still to be resolved by exoplanet research continue to capture his imagination. Even if the universe wouldn't create a planet of glass, could it create one with frozen ice clouds blanketing an unreachable surface, like a fictional planet in his favorite movie, *Interstellar*? It's not as far-fetched as it once seemed, Tyler says. Reality is often "much more complicated and much more interesting" than we think.

Jen Christiansen
Infographics

After graduating from college with degrees in geology and studio art, Jen Christiansen had a simple goal: "to not choose one at the expense of the other for as long as possible." To this day, she still hasn't. Christiansen has been working for *Scientific American* for 19 years and currently oversees many of the data visualizations and explanatory graphics in each issue. Usually that means assigning projects to other researchers and artists. But this month she had the opportunity to craft many of the graphics herself, including visualizations of atomic clocks, salt-tolerant plants, creative intuition and our knowledge of knots. "It was a treat to be able to see [these projects] to the end," she says.

Turning complex science into digestible graphics can be like a puzzle—and Christiansen finds the hardest ones the most rewarding. Those usually involve the fields of physics or chemistry, where "there's very rarely anything for you to look at," she says. But she's also learned that even tangible, physical objects can stretch our intuitive abilities. In this issue's Graphic Science column, written by space and physics senior editor Clara Moskowitz, Christiansen demonstrates how bad we are at judging the strength of knots. They're "kind of like optical illusions," she says, ones that defy our physical reasoning abilities—and remind her to "slow down and question" how people might interpret her illustrations differently than she does.

Allison Parshall is an associate editor at *Scientific American* covering mind and brain. She writes the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, she

contributes to *Scientific American*'s podcast *Science Quickly*. Parshall's work has also appeared in *Quanta Magazine* and Inverse. She 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-march-2025-issue

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Readers Respond to the November 2024 Issue

Letters to the editors for the November 2024 issue of Scientific American

By Aaron Shattuck

Scientific American, November 2024

VACCINES AND IMMUNITY

“No More Needles,” by Stephani Sutherland, describes new nasal spray vaccines. It was very helpful to learn about mucosal immunity, an aspect of the immune system about which there has been very little press. But the article did not discuss the effect of nasal vaccines on immunocompromised or immunosuppressed individuals.

My wife is a heart-transplant recipient and is on a lifelong regimen of immunosuppressants. Recently we received an alert from her transplant team that transplant patients should not take FluMist, a spray vaccine against influenza that received U.S. Food and Drug

Administration approval last September. It also said such patients shouldn't be in the same room as another person receiving an inhaled dose of FluMist or have any contact with a person who has taken the vaccine for seven days. Why is this?

ANDREW WRIGHT *BASKING RIDGE, N.J.*

THE EDITORS REPLY: *FluMist is made with a weakened (attenuated) flu virus to stimulate immunity. A normally functioning immune system can keep that virus in check. A suppressed immune system, however, may not be able to stop the weakened virus from creating a real infection. People who have received an organ transplant usually have a suppressed immune system, so live, attenuated vaccines are not recommended for such individuals.*

> "We shouldn't abandon the leap second out of a misguided quest for simplicity!" —Agatha Mallett, *Via E-mail*

SECOND OPINION

"Should We Abandon the Leap Second?," by Mark Fischetti and Matthew Twombly, questions whether the leap seconds we add or subtract to time kept by our atomic clocks are worth the effort.

We should maintain the leap second. It is the basic link between UT1 (essentially mean solar time) and atomic clock time, also called international atomic time (TAI). Their combination, coordinated universal time (UTC), gives the advantages of both: accurately ticking seconds, as defined by the International System of Units, but still respecting the day-night cycle that is foundational to everyday human life.

Jumps in UTC turn out to be the only reasonable way to make this elegant and useful correspondence. Every alternative involves sacrifice: reduced accuracy, reduced human relevance or long-term failure. Moreover, removing the leap second would actually make computerized timekeeping much harder, not easier, so there is simply no reason to do it.

UTC is the sole time standard that is ideal for the needs of both humans and machines, and leap seconds are crucial to implement it. We shouldn't abandon the leap second out of a misguided quest for simplicity!

AGATHA MALLETT *VIA E-MAIL*

BABY TALK

"The Evolution of Music," by Allison Parshall, Duncan Geere and Miriam Quick [Graphic Science], notes three worldwide trends in song: they tend to be slower than speech and to have a higher and more stable pitch. It occurs to me that this pattern is the same one we see when adults "speak" to infants (at least in the Western world). If this is correct, is there a connection between song and the most basic infantile communication? And further, is this link the basis for the evolution of adult speech?

DENNIS MONASEBIAN *ARMONK, N.Y.*

PARSHALL REPLIES: *Recent research does support the idea of infant-directed speech, or "baby talk," sharing characteristics such as higher pitch and slower tempo across cultures. One could hypothesize that the same features that make baby talk attention-grabbing and appealing to infants also make adult song attention grabbing and appealing to adults, although it's also possible that they evolved separately for different reasons.*

FINDING HELP FOR ADDICTION

As someone who has struggled with addiction, I was very interested in Maia Szalavitz's article on "The Traumatic Roots of

Addiction" [October]. But I was dismayed by her portrayal of 12-step programs, particularly Alcoholics Anonymous (AA). To classify them as "social support" groups is not correct. AA's meetings may provide social support, but that is not the basis of the program.

Further, Szalavitz comments on the rigidity of 12-step programs and people telling newcomers to "shut up and listen," but this is not the case in AA. It is simply a suggested program of recovery. Some groups did decide to veer away from the established program and basically create their own. As noted in the article, AA has no opinion on outside matters, including therapy. Therapy in conjunction with AA has helped many people—and has made a difference in my life. One without the other would mean incomplete treatment. Whenever a given group tells me what I must do in a rigid way, I simply find another meeting. The program can work for anyone who wants it to.

"MIKE H." *VIA E-MAIL*

SZALAVITZ REPLIES: *It is not possible to write about 12-step programs without encountering pushback from members who claim misinterpretation. Research shows that participation in 12-step groups is most likely to be beneficial for people who attend them voluntarily and find them helpful. But because both the social support aspect and the steps themselves can be harmful to some (as I discuss), they should not be mandated. Still, 12-step participation is the foundation of most American addiction treatments. To help the majority of people with addiction who have suffered from childhood trauma get evidence-based care, this must change.*

MOTIVATED DELAY

I have some responses to Javier Granados Samayoa and Russell Fazio's fine article on procrastination ["How to Beat

Procrastination”; Mind Matters], but I just haven’t been able to find time to jot them down. Perhaps I’ll do so next month.

TIM JOHNSON *SARASOTA, FLA.*

ULTRASOUND LESSONS FOR ADHD

I was intrigued by Lucy Tu’s Advances article on a study that enhanced mindfulness with ultrasound stimulation of the brain’s default mode network (DMN) [“Ultrasound Meditation”; October]. I recall a video by YouTube personality Jessica McCabe in which she talked to psychiatrist Edward Hallowell about how the DMN can act up and lead to rumination in people with attention deficit hyperactivity disorder (ADHD). They also discussed strategies for how to get the DMN to relax. I wonder if ultrasound stimulation would be a viable treatment for those of us whose brain wants to go full speed all the time or if lessons from studying ADHD could become useful in determining how ultrasound stimulation could be helpful.

“VIVIANA H.” *VIA E-MAIL*

ERRATA

“Better Measures,” by Cassandra Willyard [Innovations in Solutions for Health Equity], should have described creatinine as a molecule, not a protein.

“Defogging Data,” by Jyoti Madhusoodanan [Innovations in Solutions for Health Equity], should have said that the Office of Management and Budget defined the single Asian or Pacific Islander category in 1977 and that a 1997 revision to the standard required that group to be split into two categories. In addition, the article should have given Joseph Keawe‘aimoku Kaholokula’s full name and described him as a health disparities researcher.

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

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

Ecology

- **How Corals Fight Back against Warming Seas**
  Most corals can’t relocate, but they’re finding ways to beat the heat

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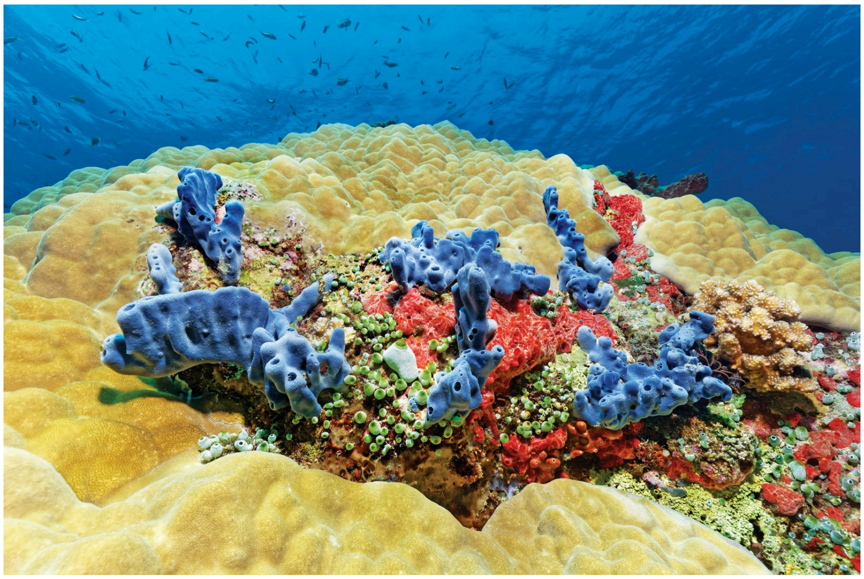
How Corals Fight Back against Warming Seas

Most corals can’t relocate, but they’re finding ways to beat the heat

By Rohini Subrahmanyam edited by Sarah Lewin Frasier



Many corals have creative ways to fight the dangers of warming seas. imageBROKER.com GmbH & Co. KG/Alamy Stock Photo

Deep underneath the eastern tropical Pacific Ocean lies a dazzling landscape of undulating coral reefs colored by photosynthetic algae, from which corals get their energy. But in the early 1980s an aquatic heat wave caused by the El Niño climate phenomenon led to a record-breaking mass-bleaching event, turning more than 90 percent of these corals a pale, lifeless white. The algae—which had thrived inside their coral hosts for millions of years—could no longer bear to live within them.

Strong El Niño events warmed up the same Pacific waters in the late 1990s and again in 2015–2016, but scientists noticed that these heat waves didn’t affect the reefs as badly as the first. Diving after the latest event, University of Miami marine biologist Ana Palacio saw that some of the corals seemed to be resisting or recovering from the bleaching. Maybe, Palacio thought, they’ve found a way to adapt.

Many adult corals are tethered to the reefs they build. Swimming to cooler waters is not an option, making them particularly vulnerable to the changing climate. But corals are also resilient, and scientists are discovering how they adapt. Some corals switch out their algal tenants for more heat-resistant species. Others can use rows of tiny hairs on their bodies to “fan” away excess harmful oxygen released by stressed-out algae. And certain baby corals modify their own metabolisms to withstand the warming waters. Scientists hope to use such natural adaptations in the race to preserve these crucial ecosystem anchors.

When Palacio and her team examined coral reefs after the 2015–2016 heat wave, they found that particular corals called *Pocillopora*—the main reef-building coral species in the eastern tropical Pacific—seemed to have expelled the algae that usually reside within them and taken in other species that were more tolerant to the heat.

“They start changing their [algae] community as the water becomes warmer and warmer, and they associate more and more with this thermotolerant algal symbiont called *Durusdinium glynnii,*” Palacio explains. This species’ name comes from the Latin word *durus*, meaning “rough” or “tough.” Most symbiotic algae produce toxic levels of oxygen under heat stress, forcing the corals to evict them. But *Durusdinium* keeps its levels tolerable.

Yet the corals don’t always rely on their algal guests to avoid excessive oxygen, researchers have found; sometimes they can take matters into their own “hands.” Rows of cilia—tiny, hairlike projections—can act like corals’ own personal ventilation system by fanning excess oxygen toward spots that lack it.

In 2022 marine biologists Cesar O. Pacherres and Soeren Ahmerkamp, then at the University of Bremen in Germany, showed that these fast-beating cilia create microscopic whirlpools in the water, swirling the oxygen around and preventing it from harmfully accumulating in any one spot. All corals have this ventilation system, but how much they use it can vary between species. The scientists now plan to test if and how some vulnerable corals—such as those in the Great Barrier Reef—beat their cilia faster in response to higher temperatures.

And corals aren't always stuck in place; their larvae float freely through the ocean before settling, which offers crucial opportunities for a species to shift to more hospitable waters or spread its heat-tolerant genes. That's why Ariana Huffmyer, a marine biologist at the University of Washington, is particularly interested in how baby corals adapt to higher temperatures. She and researchers at the Hawai'i Institute of Marine Biology recently showed that coral larvae, if exposed to warm water for as little as three days in the laboratory, alter their own metabolism to cope with heat stress and avoid bleaching.

Corals typically provide a small amount of nitrogen to their resident algae, and in return they get carbon, which they use as an energy source. "To maintain [the algae's] own survival and give the nutrients required to the host, there's a really intricate, delicate and very complex nutritional relationship between the two," Huffmyer says. Under stress, corals produce too much nitrogen. This excess causes the algae to go into hyperdrive and divide a lot more—hoarding the carbon and keeping it from their hosts. Huffmyer discovered that baby corals exposed to short periods of heat stress learn to keep the excess nitrogen to themselves and don't overshare with the algae, maintaining a stable symbiosis.

Pacherres cautions that such adaptations can protect an organism only to some extent. "They have the tools to withstand certain things, but past that limit there's not enough they can do. For example, if it's hot, we [humans] can sweat to alleviate the heat. But if it gets too hot, we die," he says. "At one point sweating is not enough."

But whatever heat-beating tools corals do have can help scientists develop protection strategies. Baby corals that can withstand stress are especially important for conservation efforts because they can travel between reefs and potentially share heat-tolerant genes in new locales. "The larvae from those reefs are already preadapted to some degree to rising temperatures, so we need to protect them because they're in some ways the source of the future," says Madhavi Colton, a conservation scientist who researched science-based tactics to save corals at the nonprofit Coral Reef Alliance.

Natural coral adaptations can also aid direct interventions like stress-hardening corals in nurseries before planting them back into ocean reefs. "You need to grow corals that are more likely to survive than the corals that died before," Palacio says. If researchers can persuade corals to adopt heat-resistant algae or if they activate genes that can deal with heat stress, it raises the corals' chance of surviving future ocean heat waves.

"When you dive and see a beautiful healthy reef with these colorful corals ... I still feel this euphoria of being in this whole alien underwater world," Huffmyer says. "It's hard to go back after a bleaching event and see it dead. But that does give you the motivation to want to use whatever your skill set is, whatever your passion is, to try to help."

Rohini Subrahmanyam is a biologist turned science journalist. She loves writing about interesting creatures on our planet. Subrahmanyam received a Ph.D. from the National Center for Biological Sciences at the Tata Institute of Fundamental Research in India. Follow her on X (formerly Twitter) @rohsubb and on LinkedIn, and see her portfolio here.

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https://www.scientificamerican.com/article/how-corals-fight-back-against-warming-seas

Evolution

- ## Why Do Wild Cats Have So Many Different Eye Colors?
  The Internet's vast cat resources help researchers chart cat eye evolution

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Why Do Wild Cats Have So Many Different Eye Colors?

The Internet's vast cat resources help researchers chart cat eye evolution

By Zane Wolf edited by Sarah Lewin Frasier

Snow leopard's colorful eye.
Picture by Tambako the Jaguar/Getty Images

Wild cats showcase a stunning diversity of eye colors, proving a mystery for researchers because most wild species are known to have narrow eye color schemes (usually black, brown or yellow). Eye color's evolution is notoriously hard to track: fossils don't preserve it, taxidermy specimens have fabricated eyes, and most books illustrate only one example per species. Now scientists have harnessed the Internet's abundant wild cat photographs to chart the transition from brown eyes to colors such as green and blue—and found something of a gray area.

Any animal's eye color is determined by its levels of two melanin pigments: eumelanin, which makes brown-black, and pheomelanin, which makes red-yellow. Eye colors vary according to the amounts of each, with different combinations leading to colors such as blue, green and gray.

For a paper in *iScience*, Harvard University biology graduate student Julius Tabin and his co-author, Katherine Chiasson, used a process called ancestral state reconstruction to determine the eye colors of extinct wild cat species based on those of their living descendants. The authors analyzed the clearest images submitted to the database iNaturalist.org, then classified each cat's eye color and mapped the data to the cat family tree, using an algorithm to find each common ancestor's possible eye colors. The algorithm accounted for the likelihood of certain changes and figured in the time since species diverged in order to generate the likeliest colors at every split.

"It's a way we can actually look into the eyes of the felid ancestor," Tabin says. "The ancestor develops gray eyes, and then the eye color diversity just explodes." Once an eye with moderate amounts of both eumelanin and pheomelanin appeared (producing gray eyes), blue and green were not far behind.

The scientists next tried to connect the discovered eye colors with numerous factors, including habitat, fur color and hunting behavior, to help explain why those shades had evolved. But they found little correlation. "Huskies have those bright blue eyes because we wanted them to" and bred them accordingly, Tabin says, but in wild cats, "I have no idea what's going on here." Sexual selection is plausible—perhaps cats prefer particular eye colors in mates—but it would be challenging to test.

Eye color is "a very overlooked trait, and it's a pity because it's probably important ecologically and evolutionarily," says University of Glasgow evolutionary biologist Arianna Passarotto, who is not affiliated with the new study. She is skeptical of using photos taken in uncontrolled conditions, but she describes the study as “ambitious” and “absolutely very novel.”

As Juan José Negro, an ecologist at the Spanish National Research Council also not affiliated with the study, puts it, “the eye is the last frontier for [studying] coloration.”

Zane Wolf was formerly a graphics intern at *Scientific American*. She has an interdisciplinary research background, including animal behavior, soft robotics and astrophysics, with a current focus on data storytelling as it pertains to scientific communication.

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https://www.scientificamerican.com/article/why-do-wild-cats-have-so-many-different-eye-colors

History

- **March 2025: Science History from 50, 100 and 150 Years Ago**
  Color blindness; the end of fire

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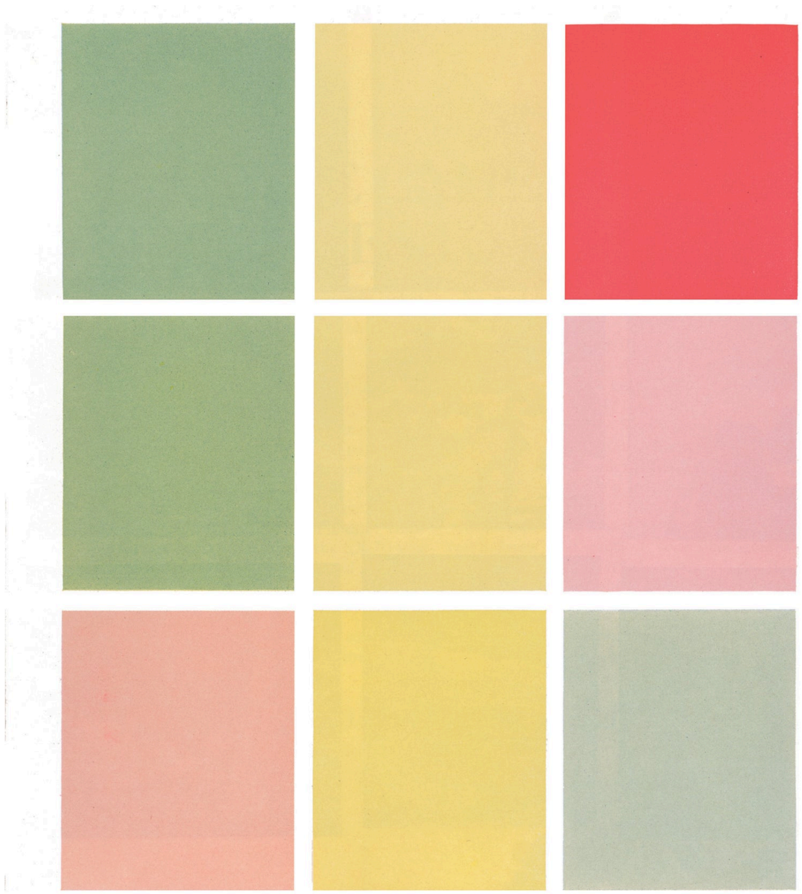
March 2025: Science History from 50, 100 and 150 Years Ago

Color blindness; the end of fire

By Mark Fischetti



1975, Color Blindness: “People with protanopia cannot distinguish between green and red or colors in between. Color blocks *(top row)* simulate the appearance of lights that they judge as identical. People with deuteranopia also cannot distinguish between red, green or colors in between. Color blocks *(middle row)* simulate lights they regard as identical. People with anomalous trichromacy can sense red, green and blue to match all colors but require unusual proportions (*bottom row*); when asked to match a yellow *(center)*, they may select a pink *(left)* or a green *(right)*.”
Scientific American Vol. 232, No. 3, March 1975

1975

Chemical Warfare Ill Defined

“Biological weapons have been negotiated out of the arsenals of most of the world’s major military powers, and poison gas may be on the way out. In January the U.S. acceded to the Geneva Protocol of 1925, banning any first use of gas and bacteriological weapons, and to the Biological Weapons Convention of 1972. This month the Conference of the Committee on Disarmament is scheduled to meet in Geneva to take up proposed treaties that would move the world toward actual chemical disarmament. That will involve troubled issues of verification and inspection, however, and a major difference in definition: the U.S., unlike the rest of the world, has held that riot control gases and herbicides—both of which the U.S. deployed in the Vietnam war—are not agents of chemical warfare.”

Tokamak Fusion by 1980

“The Ford Administration has decided to include in the Federal budget for fiscal year 1976 a request for some $7.5 million to start work on a major new fusion-power test facility at Princeton University. If the funds are approved, detailed design of the proposed installation could begin almost immediately, with component fabrication and site construction scheduled to get underway late next year. The machine would be a plasma-confinement system known generically as a tokamak. Assuming that everything goes according to plan, the experimental fusion reactor, the first U.S. system of its kind that is expected to reach the ‘breakeven’ threshold for net power output, would be finished and ready for operation by 1980, at a projected cost of approximately $215 million.”

The Tokamak Fusion Test Reactor began operation in 1982. It produced significant energy output but never reached breakeven. It was shut down in 1997.

1925

The End of Fire

“Great changes in human affairs take place inconspicuously. The substitution of iron for bronze, of the printing press for the scribe and of mechanical power for human labor, occurred so gradually that probably people hardly appreciated its significance. A cultural change is now in progress that promises to be as profoundly revolutionary—the gradual abandonment of humans’ most ancient tool: fire. The first effective step toward a fireless future was the substitution of the electric lamp for a flame for illumination. Next came the electric motor in the place of small steam engines. The next step, and the one in which the electrical industry is at present particularly interested, is the substitution of electricity for fire in producing heat for industrial purposes.”

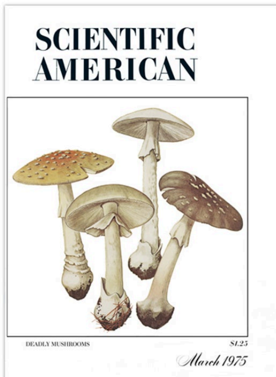
1875

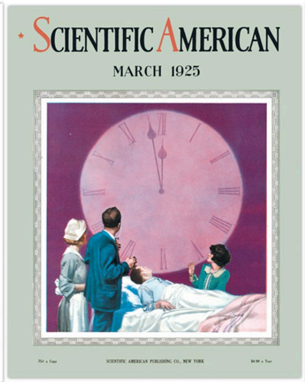
Postage Inequality

“The Congress has again looked after its own interests. By amending the postal law, the speeches of members and other stuff are to be sent free, while the postage charged to the public is doubled. There is little doubt that this tax upon the people is due to lobbying influence of the express companies. The express charge for the smallest package sent from New York to San Francisco is 75 cents; the post office carries one weighing a pound for 16 cents. The measure affects the reading public. Three cents postage must be paid on *Scientific American* and other large papers. A person is charged three cents to send this paper across the river from New York to Brooklyn but two cents to forward it over the ocean to London.”

Snowflake Hitchhikers

“It is difficult to believe that the pure white snowflake, which settles noiselessly upon the earth, is, after all, a scavenger of the atmosphere that absorbs into its porous substance the myriads of microscopic bodies which form atmospheric dust near the surface of the earth. M. Gaston Tissandier states that, in a drop of water obtained from a single flake and magnified 500 times, he found pieces of coal, cloth fragments, grains of starch, sandy matter and an immense variety of other substances, not a fragment of which exceeded in diameter three ten-thousandths of an inch."





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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Language

- **Science Crossword: Creative Bursts**
  Play this crossword inspired by the March 2025 issue of Scientific American

Science Crossword: Creative Bursts

By Aimee Lucido

This crossword is inspired by the March 2025 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 makes crosswords part-time for several outlets and writes trivia full-time for Bloomberg's news quiz, Pointed. She is also the author of several books for kids, including *Emmy in the Key of Code*, *Recipe for Disaster*, and *Pasta Pasta Lotsa Pasta*. Lucido lives with her husband, daughter and dog in New York.

https://www.scientificamerican.com/article/science-crossword-creative-bursts

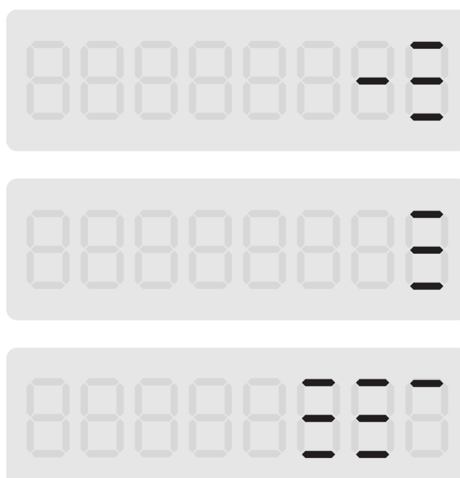
Mathematics

- **Math Puzzle: Follow the Calculator Clues**
  Decode the clues from a broken calculator in this math puzzle
- **Math's 'Hairy Ball Theorem' Has Surprising Implications**
  Here’s what the hairiest problem in math can teach us about wind, antennas and nuclear fusion

Math Puzzle: Follow the Calculator Clues

By Heinrich Hemme

An old calculator uses a seven-segment display, in which numerals are represented by different patterns of vertical and horizontal line segments. But the device is faulty and no longer shows any vertical segments. Someone types a number into this calculator, and the display shows the horizontal segments visible in the top image. Next the person presses the multiplication key and types in a second number. The display now shows the horizontal segments in the middle image. After the user presses the equal key, the display shows the horizontal segments in the bottom image. Which two numbers were multiplied with the calculator?



The last digit of the product must be 7. Because the last digits of the two factors can be only 2, 3, 5, 6, 8 or 9, one factor must end in 3 and the other in 9. The tens digit of the first factor can be only 4. Thus, the product could be 49 × 3 = 147 or 43 × 9 = 387. But the first possibility is ruled out because the hundreds and tens digits of the product can be only 2, 3, 5, 6, 8 or 9—leaving us with the second solution.

All three numbers can, however, still have a leading 1 that would be invisible. With a maximum of one leading 1 per number, there are three more possible solutions: 143 × 9 = 1,287, 49 × 13 = 637 and 149 × 13 = 1,937. It is easy to check that for all factors with more than one leading 1, the product does not consist entirely of 1’s apart from the three final digits.

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.

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https://www.scientificamerican.com/article/math-puzzle-follow-the-calculator-clues

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Math’s ‘Hairy Ball Theorem’ Has Surprising Implications

Here’s what the hairiest problem in math can teach us about wind, antennas and nuclear fusion

By Jack Murtagh edited by Jeanna Bryner

olindana/Getty Images

You might be surprised to learn that you can’t comb the hairs flat on a coconut without creating a cowlick. Perhaps even more surprising, this silly claim with an even sillier name, the “hairy ball theorem,” is a proud discovery from a branch of math called topology. Juvenile humor aside, the theorem has far-reaching consequences in meteorology, radio transmission and nuclear power.

Here “cowlick” can mean either a bald spot or a tuft of hair sticking straight up, like the one the character Alfalfa sports in *The Little Rascals*. Of course, mathematicians don’t refer to coconuts or cowlicks in their framing of the problem. In more technical language, think of the coconut as a sphere and the hairs as vectors.

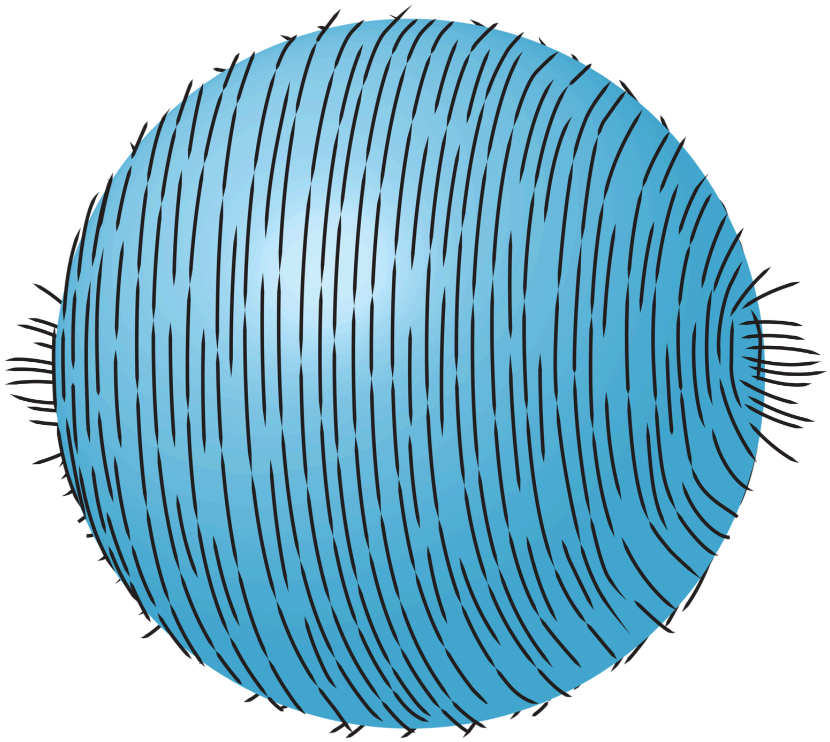
A vector, often depicted as an arrow, is just something with a magnitude (or length) and a direction. Combing the hair flat against the sides of the coconut would form the equivalent of tangent vectors—those that touch the sphere at exactly one point along their length. Also, we want a smooth comb, so we won't allow the hair to be parted anywhere. In other words, the arrangement of vectors on the sphere must be continuous, meaning nearby hairs should change direction only gradually, not sharply.

If we stitch these criteria together, the theorem says that any way you try to assign vectors to each point on a sphere, something ugly is bound to happen: there will be a discontinuity (a part), a vector with zero length (a bald spot) or a vector that fails to be tangent to the sphere (Alfalfa). In full jargon: a continuous nonvanishing tangent vector field on a sphere can't exist.

> The hairy ball theorem automatically applies to hairy cubes, hairy stuffed animals and hairy baseball bats.

This claim extends to all kinds of furry figures. In the field of topology, mathematicians study shapes, as they would in geometry, but they imagine these shapes are made from an ever elastic rubber. That rubber can be molded into other forms, but it is incapable of tearing, fusing or passing through itself. If one shape can be smoothly deformed into another without any of these things happening, then those shapes are equivalent as far as topologists are concerned. This means the hairy ball theorem automatically applies to hairy cubes, hairy stuffed animals and hairy baseball bats, which are all topologically equivalent to spheres. (You could mold them all from a ball of Play-Doh without violating the rubbery rules.)

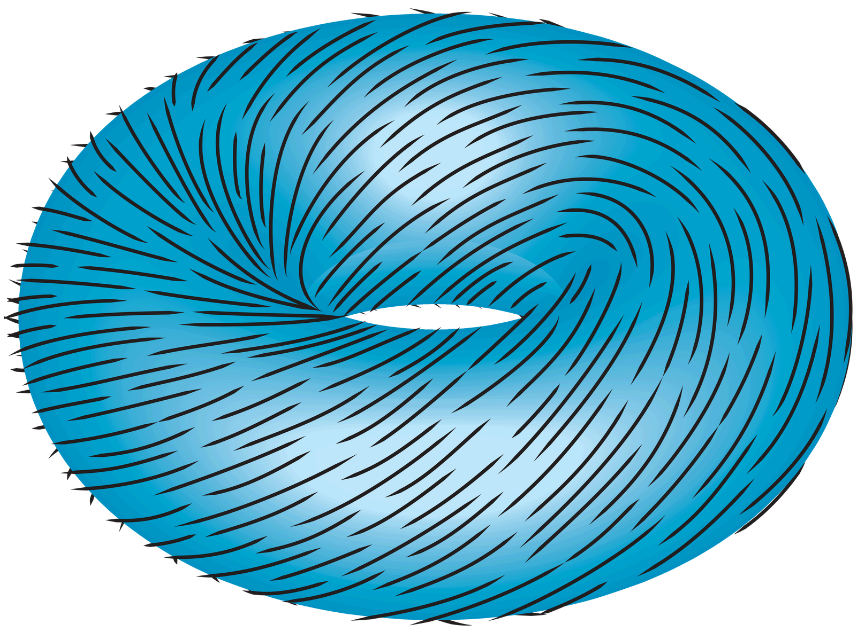
Something that is not equivalent to a sphere is your scalp. A scalp on its own can be flattened into a surface, and hair on it can then be combed in one direction like the fibers of a shag carpet. So, sadly, math can't excuse your bedhead. Doughnuts are also distinct from spheres, so a hairy doughnut—an unappetizing image, no doubt—can be combed smoothly.



Tufts on either side demonstrate the hairy ball theorem. This sphere is covered in small lines resembling hairs that are all combed in the same direction.
Buckyball Design

Here's a curious consequence of the hairy ball theorem: there will always be at least one point on Earth where the wind isn't blowing across the surface. The wind flows in a continuous circulation around the planet, and its direction and magnitude at each location on the surface can be modeled by vectors tangent to the globe. (Vector magnitudes don't need to represent physical lengths, such as those of hairs.) This adheres to the premises of the theorem, which implies the gusts must die somewhere (creating a cowlick). A cowlick could occur in the eye of a cyclone or eddy, or it could happen because the wind blows directly up toward the sky. Programmer Cameron Beccario has created a neat online tool (earth.nullschool.net) that depicts up-to-date wind currents on Earth and clearly shows the swirly cowlicks.

To observe another weird ramification of the theorem, spin a basketball any which way you want. There will always be a point on the surface that has zero velocity. Again, we associate a tangent vector with each point based on the direction and speed at that point on the ball. Spinning is a continuous motion, so the hairy ball theorem applies and assures a point with no speed at all. On further reflection, this conclusion might seem obvious. A spinning ball rotates around an invisible axis, and the points on either end of that axis don’t move. What if we bored a tiny hole through the ball exactly along that axis to remove the stationary points? It seems that then every point would be moving. Does this example violate the hairy ball theorem? No, because drilling a hole transformed the ball into a doughnut! Even doughnuts with unusually long, narrow holes flout the rules of the theorem—contradiction averted.



This doughnut shape is covered in small lines resembling hairs that are all combed in the same direction, with no tufts resulting.
Buckyball Design

Moving on from toy scenarios—the hairy ball theorem actually imposes tangible limitations on radio engineers. Antennas broadcast radio waves in different directions depending on design choices. Some target their signals in a specific direction, whereas others beam more broadly. One might be tempted to simplify matters and build only antennas that send equal-strength signals in every direction at once, which are called isotropic antennas. There's just one problem: a certain hirsute fact from topology mandates that isotropic antennas can't exist. Picture an orb of waves emanating from a central source. Sufficiently far away from the source, radio waves exhibit an electric field perpendicular to the direction they're traveling in, meaning the field is tangent to the sphere of waves. The hairy ball theorem insists that this field must drop to zero somewhere, which implies a disturbance in the antenna's signal. Isotropic antennas serve merely as theoretical ideals against which we compare real antenna performance. Interestingly, sound transmits a different kind of wave without the perpendicular property of radio waves, so loudspeakers that emanate equal-intensity sound in every direction are possible.

Perhaps the coolest application of the hairy ball theorem concerns nuclear fusion power. Fusion power carries immense promise to—perhaps someday—help ease the energy crisis. It has the potential to generate vast quantities of energy without the climate concerns that plague fossil fuels and with fewer of the radioactive risks associated with traditional nuclear fission reactors. In a nutshell, fusion reactors begin by taking a fuel such as hydrogen and subjecting it to intense heat and pressure, which rips it into its constituent parts to form plasma. Plasma is a cloud of electrons and other charged particles that bop around and occasionally fuse together to form new particles, releasing energy in the process.

There's a fundamental engineering hurdle when building fusion reactors: How do you contain plasma that's 10 times hotter than the sun's core? No material can withstand that temperature without disintegrating into plasma itself. So scientists have devised a clever solution: they exploit plasma's magnetic properties to confine it within a strong magnetic field. The most natural container designs (think boxes or canisters) are all topologically equivalent to spheres. A magnetic field around any of these structures would form a continuous tangent vector field, and at this point we know what befalls such hairy constructions.

A zero in the magnetic field means a leak in the container, which spells disaster for the whole reactor. The leading design for fusion reactors, the tokamak, gets around this problem by using a doughnut-shaped chamber. The International Thermonuclear Experimental Reactor megaproject plans to finish construction of a new tokamak in France by 2025, and those involved claim their magnetic confinement system will be “the largest and most integrated superconducting magnet system ever built.” That’s topology playing its part in our clean energy future.

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https://www.scientificamerican.com/article/maths-hairy-ball-theorem-has-surprising-implications

Microbiology

- **Coffee Boosts Beneficial Gut Bacterium**
  Researchers found a strong connection between coffee and the gut microbiome
- **The U.S. Must Lead the Global Fight against Superbugs**
  Antimicrobial resistance could claim 39 million lives by 2050, yet the pipeline for new antibiotics is drying up. U.S. policymakers can help fix it

Coffee Boosts Beneficial Gut Bacterium

Researchers found a strong connection between coffee and the gut microbiome

By Maggie Chen edited by Sarah Lewin Frasier

Paul Taylor/Getty Images

The thought of a steaming cup of coffee helps to pull many people worldwide out of bed in the morning. Scientists have consistently linked this ubiquitous drink to lowered risks for maladies such as heart disease, colon cancer and type 2 diabetes. But its effects on the gut microbiome—the intestinal bacterial population thought to help mediate between diet and health—are largely unknown.

In the largest-ever study on the relation between coffee and the gut microbiome, published recently in *Nature Microbiology*, researchers looked at fecal DNA from more than 20,000 participants who tracked their daily coffee consumption. The scientists found that regular coffee drinking was linked to the growth of a specific gut bacterium called *Lawsonibacter asaccharolyticus*. “For this, you really need these large dataset approaches that haven’t been possible until recently,” says Peter Belenky, a microbiologist at Brown University who was not affiliated with the study.

L. asaccharolyticus, which was first described in 2018, is a relatively understudied bacterium known to produce butyrate, a marker of adequate gut fermentation that indicates proper digestion and nutrient absorption. “We don’t know too much about this bug,” Belenky says, “but we can place it as likely a fairly good bacterium.”

Studies on diet and the microbiome typically link multiple bacterial species to a specific dietary factor or vice versa. In this one, the researchers discovered that coffee drinking correlated with an increase in several bacterial species, but the correlation with *L. asaccharolyticus* growth was by far the strongest, even with decaffeinated coffee. And feeding coffee to *L. asaccharolyticus* growing on petri dishes made the microbes grow faster. “It’s very unique that we found this very strong, very distinct one-to-one match,” says Harvard University epidemiologist Mingyang Song, a co-senior author on the study.

To find out what this bug might be doing in the gut, the team looked at the metabolites from a few hundred study participants’ blood. They found that an increase in quinic acid, part of a subgroup of polyphenols (antioxidants that can, in the right context, reduce inflammation), was strongly associated with *L. asaccharolyticus* growth. So was hippurate, a compound whose levels indicate greater microbial diversity and therefore better gut health.

Given these results, the scientists are now “trying to link these bacteria and the related metabolites to health outcomes,” Song says. “That can tell us whether the bacteria are really mediating the health benefits of coffee.”

Analyzing these gigantic population-based datasets is an effective strategy to parse out specific relations between things we ingest and the bugs in our gut. “Maybe this will open up a more extensive approach to food research,” Belenky says.

Maggie Chen is a science journalist covering health, biology, and bioengineering.

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The U.S. Must Lead the Global Fight against Superbugs

Antimicrobial resistance could claim 39 million lives by 2050, yet the pipeline for new antibiotics is drying up. U.S. policymakers can help fix it

By Howard Dean

Bacteria such as *Pseudomonas aeruginosa (depicted)* have become resistant to multiple antibiotics. Jennifer Oosthuizen/Science Photo Library/Getty Images

Most Americans could probably guess that heart disease, diabetes and cancer are among the world's fastest-growing causes of death. Yet one rapidly accelerating health threat now lurks under the radar, despite its devastating consequences.

The threat comes from antimicrobial resistance, or AMR, the evolved immunity of dangerous microbes to lifesaving drugs. In 2019 AMR killed 1.27 million people—more than malaria and HIV combined—according to the most recent comprehensive global analysis. A groundbreaking study published in the *Lancet* last

September estimates that, without action, AMR will kill more than 39 million people in the next quarter of a century. Average annual deaths are forecast to rise by nearly 70 percent between 2022 and 2050.

We don't have to stay on this trajectory. But changing direction will require decisive moves from the U.S. government. As the leader in pharmaceutical development, the U.S. has a moral obligation to lead the way on solving this global problem. We need to jump-start research and development on new antimicrobial drugs and shore up the patent system that enables our country to bring so many new medicines to market.

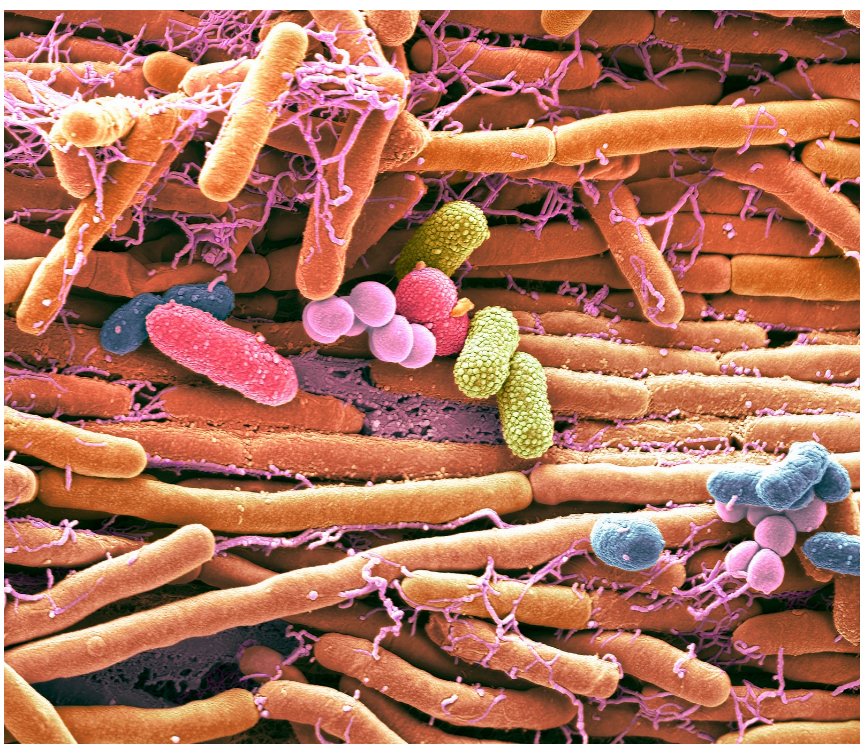
> Without action and investment soon to support the development of new antibiotics, we could be thrown back to the pre-penicillin era, when a simple cut could turn deadly.

AMR occurs when disease-causing microbes—most often bacteria—evolve to evade the drugs created to kill them, turning them into so-called superbugs. Some better-known ones include methicillin-resistant *Staphylococcus aureus* (MRSA), multidrug-resistant *Mycobacterium tuberculosis*, and *Streptococcus pneumoniae*, a bacterium that causes pneumonia and can be resistant to penicillin. In 1993 U.S. hospitals recorded fewer than 2,000 MRSA infections. In 2017 that number had jumped to 323,000, according to the latest data available from the Centers for Disease Control and Prevention. Preliminary data show that cases of another superbug, *Candida auris*, jumped fivefold between 2019 and 2022.

Overuse and misuse of antibiotics are major causes of AMR. The more a bacterium is exposed to a particular antibiotic, the more opportunities it has to acquire mutations and become resistant. The danger is that as these essential medicines stop working, even minor infections will become hard to treat. That will make even routine surgeries and common illnesses much more dangerous—and make it much harder for those who are battling cancer and whose immune systems are compromised to fight off infections. Without action and investment soon to support the development of new antibiotics, we could be thrown back to the pre-penicillin era, when a simple cut could turn deadly.

Yet despite the urgent need for new antibiotics, the pipeline for developing them is drying up. As of today, only four major pharmaceutical companies still work on antibiotics, down from dozens just a few decades ago. The reason is simple: the economics of modern antibiotic development don't work. Creating a single new drug takes an average of 10 to 15 years and costs more than $2 billion. But because antibiotics are typically used for short periods ranging from seven to 14 days and must be used sparingly to limit AMR, their profitability is necessarily low. This built-in roadblock means companies have a hard time justifying the expense and risk.

The *Lancet* study recommends several ways to fight back. One of them, unsurprisingly, is to develop new antibiotics—an area in which the U.S. has an opportunity to show global leadership, expand its influence and make an enormous difference.



Colored scanning electron micrograph (SEM) of bacteria cultured from a mobile phone.
Steve Gschmeissner/Science Source

America has the world's best system of intellectual-property protection, which has made us the frontrunner in biopharmaceuticals as well as dozens of other high-tech industries. IP protections—in particular patents—provide a window of market exclusivity that allows companies to recoup their enormous investments in research and development. Without reliable patents, few businesses would take the risk of developing new antimicrobial drugs.

Unfortunately, over the past several years some U.S. lawmakers have advocated for reducing patent protections as a way to reduce drug prices. But these efforts, though well intentioned, would just make the situation worse. Attacking patents isn't the right strategy, because it would only create another disincentive to invest in novel antibiotic development. This would likely make it harder to combat outbreaks of infectious diseases and superbugs, which are evolving and growing deadlier every year.

There's no single panacea for the brewing AMR crisis. It will require action from all stakeholders and segments of society. Everyday Americans, for their part, need to do a better job of letting respiratory viruses like the common cold run their course rather than asking their provider for antibiotics. Not only are antibiotics ineffective against viruses, but attempting to use them to treat viral infections contributes to resistance. Doctors need to take more responsibility, too. As a physician, I know many of my colleagues could be more judicious in prescribing antibiotics.

Finally, Americans need Congress to be more proactive. One solution to the antibiotic conundrum would be a subscription-type model to incentivize new research and development. Under this kind of system, which is already being tested in the U.K., the government would contract with companies to provide antibiotics for a fixed fee, regardless of how many doses are needed. This would give drug developers a more predictable revenue stream, allowing them to invest in high-risk, high-impact antimicrobial research that extends lives when we need it.

Former secretary of state Madeleine Albright called the U.S. the “indispensable nation,” essential to global progress and peace. Some dispute this characterization, and it’s true that the U.S. can’t solve every problem. But drug R&D is one area where we already lead. Smart policies to tackle AMR can help ensure we maintain this leadership while saving potentially millions of lives worldwide.

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

Howard Dean is a physician, a former chair of the Democratic National Committee and a former governor of Vermont. He is a policy adviser to the Partnership to Fight Infectious Disease.

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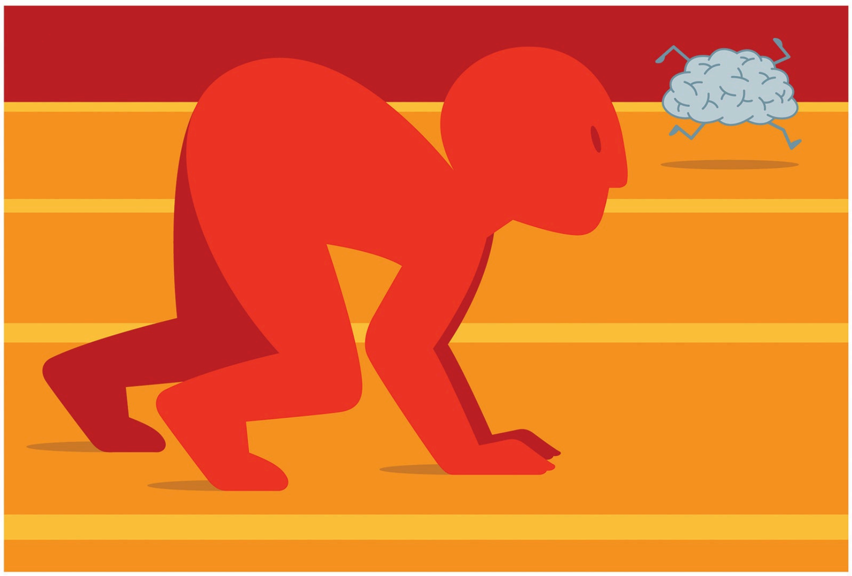
Neuroscience

- ## The Human Brain Operates at a Stunningly Slow Pace
  The brain is sometimes called the most complex machine in the known universe. But the thoughts that it outputs putter along at a trifling 10 bits per second, the pace of a conversation
- ## You Don’t Need Words to Think
  Brain studies show that language is not essential for the cognitive processes that underlie thought

The Unbelievable Slowness of Thinking

The brain is sometimes called the most complex machine in the known universe. But the thoughts that it outputs putter along at a trifling 10 bits per second, the pace of a conversation

By Rachel Nuwer edited by Sarah Lewin Frasier



Thomas Fuchs

People often feel that their inner thoughts and feelings are much richer than what they are capable of expressing in real time. Entrepreneur Elon Musk is so bothered by what he calls this “bandwidth problem,” in fact, that one of his long-term goals is to create an interface that lets the human brain communicate directly with a computer, unencumbered by the slow speed of speaking or writing.

If Musk succeeded, he would probably be disappointed. According to recent research published in *Neuron*, human beings remember, make decisions and imagine things at a fixed, excruciatingly slow speed of about 10 bits per second. In contrast, human sensory systems gather data at about one billion bits per second.

This biological paradox, highlighted in the new study, probably contributes to the false feeling that our mind can engage in seemingly infinite thoughts simultaneously—a phenomenon the researchers deem “the Musk illusion.” Study co-author Markus Meister, a neuroscientist at the California Institute of Technology, says that “the human brain is much less impressive than we might think. It’s incredibly slow when it comes to making decisions, and it’s ridiculously slower than any of the devices we interact with.”

Meister and his co-author Jieyu Zheng, a doctoral candidate in neurobiology at Caltech, also highlight in their paper that our brain can do only one thing—slowly—at a time. Even if Musk managed to hook his brain up to a computer, Meister says, he still wouldn’t be able to communicate with it any faster than he could if he used a telephone.

The new research builds on decades of psychology studies showing that humans selectively perceive just a small portion of information from the sensory experience. “We can only pay attention to so much, and that’s what becomes our conscious experience and enters memory,” Meister says. What has been missing from past research, he continues, is “any sense of numbers.” He and Zheng have endeavored to fill that quantitative gap.

Meister and Zheng collated data from research across different fields, including psychology, neuroscience, technology and human performance. They used this information—from the processing speed of single neurons to the cognitive prowess of memory champions—to run many of their own calculations so they could make comparisons between studies.

From research spanning nearly a century, they found that human cognition has repeatedly been measured as functioning at between about five and 20 bits per second, with a ballpark average of around 10 bits per second. “This was a very surprising number,” Zheng says. Based on this finding, she adds, she and Meister also calculated that the total amount of information a person can learn across their lifetime could comfortably fit on a small thumb drive.

Human sensory systems such as sight, smell and sound, in contrast, operate much faster, the authors found—at about 100,000,000 times the rate of cognition. “When you put these numbers together, you realize there’s this huge gap,” Meister says. “From that paradox comes interesting new opportunities for science to organize research differently.”

The rich information relayed by our senses also contributes to a false notion that we register the massive amount of detail and contrast all around us. But that’s “demonstrably not true,” Meister says. When people are asked to describe what they see outside the center of their gaze, they “barely make out anything,” he adds. Because our eyes have the capability to focus on any detail, he continues, “our mind gives us the illusion that these things are present simultaneously all the time,” even though in actuality we must focus on specific visual features to register them. A similar phenomenon occurs with mental ability. “In principle, we could be having lots of different thoughts and direct our cognition in lots of different ways,” Meister says. “But in practice, we can have only one thought at a time.”

Another problem that contributes to an overinflated sense of our own mind, he adds, is that we have no marker of comparison: “There’s no way to step outside ourselves to recognize that this is really not much to brag about.”

The findings raise questions in many domains, from evolution and technology to cross-species comparisons, the authors write. One of the questions Meister and Zheng are most curious about, though, is why the prefrontal cortex—thought to be the seat of personality and behavioral control—houses billions of neurons yet has a fixed decision making capability that processes information at just 10 bits per second. The researchers suspect the answer might have something to do with the brain's need to frequently switch tasks and integrate information across different circuits. But more complex behavioral studies will be needed to test that hypothesis.

Another important unanswered question, Meister says, is why the human brain can do only one thing at a time. "If we could have 1,000 thoughts in parallel, each at 10 bits per second, the discrepancy wouldn't be as big as it is," he says. Why humans are incapable of such mental multitasking is "a deep mystery that almost nothing is known about."

Anthony Zador, a neuroscientist at Cold Spring Harbor Laboratory in New York State, who was not involved in the new paper but is mentioned in its acknowledgments, says the "wonderful and thought-provoking" study presents what seems to be a newly recognized fundamental truth about the brain's upper limit of "roughly the pace of casual typing or conversation."

"Nature, it seems, has built a speed limit into our conscious thoughts, and no amount of neural engineering may be able to bypass it," Zador says. "Why? We really don't know, but it's likely the result of our evolutionary history."

Nicole Rust, a neuroscientist at the University of Pennsylvania, who also was not involved in the research, says the new study could reshape how neuroscientists approach some of their work.

"Why can our peripheral nervous system process thousands of items in parallel, but we can do only one thing at a time?" she says. "Any theory of the brain that seeks to account for all the fascinating things we can do, like planning and problem-solving, will have to account for this paradox."

Rachel Nuwer is a science journalist and author. Her latest book is *I Feel Love: MDMA and the Quest for Connection in a Fractured World* (Bloomsbury, 2023). Follow her on X @RachelNuwer

https://www.scientificamerican.com/article/the-human-brain-operates-at-a-stunningly-slow-pace

You Don’t Need Words to Think

Brain studies show that language is not essential for the cognitive processes that underlie thought

By Gary Stix edited by Dean Visser & Daisy Yuhas

Shideh Ghandeharizadeh

Scholars have long contemplated the connection between language and thought—and to what degree the two are intertwined—by asking whether language is somehow an essential prerequisite for thinking.

British philosopher and mathematician Bertrand Russell answered the question with a flat yes, asserting that language’s very purpose is “to make possible thoughts which could not exist without it.” But even a cursory glance around the natural world suggests why

Russell may be wrong: No words are needed for animals to perform all kinds of problem-solving challenges that demonstrate high-level cognition. Chimpanzees can outplay humans in a strategy game, and New Caledonian Crows make their own tools that enable them to capture prey.

Still, humans perform cognitive tasks at a level of sophistication not seen in chimps—we can solve differential equations or compose majestic symphonies. Is language needed in some form for these species-specific achievements? Do we require words or syntax as scaffolding to construct the things we think about? Or do the brain's cognitive regions devise fully baked thoughts that we then convey using words as a medium of communication?

Evelina Fedorenko, a neuroscientist who studies language at the McGovern Institute for Brain Research at the Massachusetts Institute of Technology, has spent many years trying to answer these questions. She remembers being a Harvard University undergraduate in the early 2000s, when the language-begets-thought hypothesis was still highly prominent in academia. She herself became a believer.

When Fedorenko began her research 15 years ago, a time when new brain-imaging techniques had become widely available, she wanted to evaluate this idea with the requisite rigor. She recently co-authored a perspective article in *Nature* that includes a summary of her findings over the ensuing years. It makes clear that the jury is no longer out; in Fedorenko's view, language and thought are, in fact, distinct entities that the brain processes separately. The highest levels of cognition—from novel problem-solving to social reasoning—can proceed without an assist from words or linguistic structures.

Language works a little like telepathy in allowing us to communicate our thoughts to others and to pass to the next generation the knowledge and skills essential for our hypersocial species to flourish. But at the same time, people with aphasia, who are sometimes unable to utter a single word, can still engage in an array of cognitive tasks fundamental to thought. *Scientific American* talked to Fedorenko about the language-thought divide and the prospects for continuing to explore interactions between thinking and speaking.

An edited transcript of the interview follows.

How did you decide to ask the question of whether language and thought are separate entities?

Honestly, I had a very strong intuition that language is pretty critical to complex thought. In the early 2000s I really was drawn to the hypothesis that maybe humans have some special machinery that is especially well suited for computing hierarchical structures. And language is a prime example of a system based on hierarchical structures: words combine into phrases, and phrases combine into sentences.

And a lot of complex thought is based on hierarchical structures. So I thought, 'Well, I'm going to go and find this brain region that processes hierarchical structures of language.' There had been a few claims at the time that some parts of the left frontal cortex are that structure.

But a lot of the methods people were using to examine overlap in the brain between language and other domains weren't that great. And so I thought I would do it better. And then, as often happens in science, things just don't work the way you imagine they might. I searched for evidence for such a brain region—and it doesn't exist.

You find this very clear separation between brain regions that compute hierarchical structures in language and brain regions that help you do the same kind of thing in math or music. A lot of science starts out with some hypotheses that are often based on intuitions or on prior beliefs.

My original training was in the [tradition of linguist Noam Chomsky], where the dogma has always been that we use language for thinking: to think is why language evolved in our species. This is the expectation I had from that training. But you just learn, when you do science, that most of the time you're wrong—and that's great because we learn how things work in reality.

What evidence did you find that thought and language are separate systems?

The evidence comes from two disparate methods. One is basically a very old method that scientists have been using for centuries: looking at deficits in different abilities—for instance, in people with brain damage.

Using this approach, we can look at individuals who have impairments in language—some form of aphasia. Aphasia has been studied as a condition for centuries. For the question of how language relates to systems of thought, the most informative cases are cases of severe impairments, so-called global aphasia, where individuals basically lose completely their ability to understand and produce language as a result of massive damage to the left hemisphere of the brain. You can ask whether people who have these severe language impairments can perform tasks that require thinking. You can ask them to solve some math problems or to perform a social reasoning test, and all the instructions, of course, have to be nonverbal because they can't understand linguistic information anymore.

Scientists have a lot of experience working with populations that don't have language—studying preverbal infants or studying nonhuman animal species. It's definitely possible to convey instructions in a way that's nonverbal. And the key finding from this line of work is that there are people with severe language impairments who nonetheless seem totally fine on all cognitive tasks that we've tested them on so far.

There are individuals who have now been tested on many, many kinds of tasks, including ones that involve what you may call thinking, such as solving math problems or logic puzzles or reasoning about what somebody else believes or reasoning about the physical world. So that's one big chunk of evidence from these populations of people with aphasia.

What is the other method?

A nicely complementary approach, which started in the 1980s and 1990s, is a brain-imaging approach. We can measure blood flow changes when people engage in different tasks and ask questions about whether the two systems are distinct or overlapping—for example, whether your language regions overlap with regions that help you solve math problems. These brain-imaging tools are very good for these questions. But before I could ask these questions, I needed a way to robustly and reliably identify language areas in individual brains, so I spent the first bunch of years of my career developing tools to do this.

And once we have a way of finding these language regions, and we know that these are the regions that, when damaged in adulthood, lead to conditions such as aphasia, we can then ask whether these language regions are active when people engage in various thinking tasks. So, you can come into the lab, and I can put you in the scanner and find your language regions by asking you to perform a short task that takes a few minutes—then I can ask you to do some logic puzzles or sudoku or some complex working memory tasks or planning and decision-making. And I can ask whether the regions that we know process language are working when you're engaging in these other kinds of tasks. There are now dozens of studies we've done that look at all kinds of nonlinguistic inputs and tasks, including many thinking tasks. We find time and again that the language regions are basically silent when people engage in these thinking activities.

So, what is the role of language, if not for thinking?

What I'm doing right now is sharing some knowledge that I have that you may have only had a partial version of—and once I transmit it to you through language, you can update your knowledge and have that in your mind as well. It's basically like a shortcut for telepathy. We can't read each other's minds. But we can use this tool called language, which is a flexible way to communicate our inner states, to transmit information to each other.

And in fact, most of the things that you probably learned about the world, you learned through language and not through direct experience with the world. You can easily imagine how it would confer evolutionary advantages: by facilitating cooperative activities, transmitting knowledge about how to build tools and conveying social knowledge. As people started living in larger groups, it became more important to keep track of various social relationships. Also, it's very hard to transmit knowledge to future generations, and language allows us to do that very effectively.

In line with the idea that we have language to communicate, there is accumulating evidence from the past few decades that shows that various properties that human languages have—there are about 7,000 of them spoken and signed across the world—are optimized for efficiently transmitting information, making things easy to perceive, easy to understand, easy to produce and easy to learn for kids.

Is language what makes humans special?

We know from brain evolution that many parts of the cortical sheet [the outer layer of the brain] expanded a lot in humans. These parts of the brain contain several distinct functional systems. Language is one of them. But there's also a system that allows us to reason about other minds. There's a system that supports novel problem-solving. There's a system that allows us to integrate information across extended contexts in time—for example, chaining a few events together. It's most likely that what makes us human is not one "golden ticket," as some call it. It's not one thing that happened; it's more likely that a whole bunch of systems got more sophisticated, taking up larger chunks of cortex and allowing for more complex thoughts and behaviors.

Do the language and thinking systems interact with each other?

There aren't great tools in neuroscience to study intersystem interactions between language and thought. But there are interesting new opportunities that are opening up with advances in AI where we now have a model system to study language, which is in the form of these large language models such as GPT-2 and its successors. These models do language very well, producing perfectly grammatical and meaningful sentences. They're not so good at thinking, which is nicely aligning with the idea that the language system by itself is not what makes you think.

But we and many other groups are doing work in which we take some version of an artificial neural network language model as a model of the human language system. And then we try to connect it to some system that is more like what we think human systems of thought look like—for example, a symbolic problem-solving system such as a math app. With these AI tools, we can at least ask, "What are the ways in which a system of thought, a system of reasoning, can interact with a system that stores and uses linguistic representations?"

What do large language models do to help us understand the neuroscience of how language works?

They’re basically the first model organism for researchers studying the neuroscience of language. They are not a biological organism, but until these models came about, we just didn’t have anything other than the human brain that does language. And so what’s happening is incredibly exciting. You can do stuff on models that you can’t do on actual biological systems that you’re trying to understand. There are many, many questions that we can now ask that had been totally out of reach: for example, questions about development.

In humans, of course, you cannot manipulate linguistic input that children get. You cannot deprive kids of language, or restrict their input in some way, and see how they develop. But you can build these models that are trained on only particular kinds of linguistic input or are trained on speech inputs as opposed to textual inputs. And then you can see whether models trained in particular ways better recapitulate what we see in humans with respect to their linguistic behavior or brain responses to language.

Gary Stix, formerly senior editor of mind and brain topics at *Scientific American*, edited and reported on emerging advances that have propelled brain science to the forefront of the biological sciences. Stix has edited or written cover stories, feature articles and news on diverse topics, ranging from what happens in the brain when a person is immersed in thought to the impact of brain implant technology that alleviates mood disorders such as depression. Before taking over the neuroscience beat, Stix, as *Scientific American*'s special projects editor, was responsible for the magazine's annual single-topic special issues, conceiving of and producing issues on Albert Einstein, Charles Darwin, climate change and nanotechnology. One special issue he oversaw on the topic of time in all of its manifestations won a National Magazine Award. With his wife Miriam Lacob, Stix is co-author of a technology primer called *Who Gives a Gigabyte? A Survival Guide for the Technologically Perplexed*.

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https://www.scientificamerican.com/article/you-dont-need-words-to-think

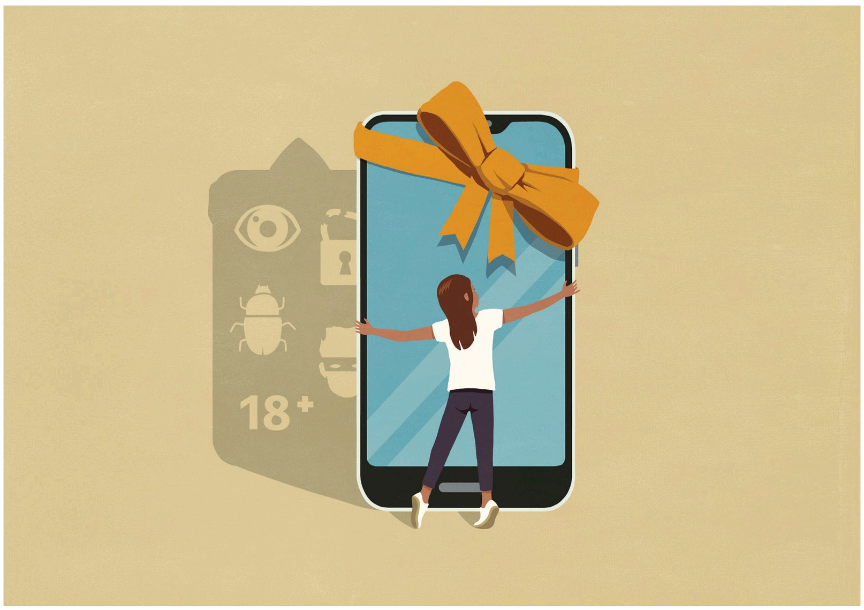
Parenting

- ## When Should Kids Get a Smartphone?
  Teens’ use of smartphones has been blamed for all manner of societal ills. So when should parents take the plunge and equip their kids with these devices?

When Should Kids Get a Smartphone?

Teens' use of smartphones has been blamed for all manner of societal ills. So when should parents take the plunge and equip their kids with these devices?

By Jacqueline Nesi edited by Jeanna Bryner & Megha Satyanarayana



Malte Müller

This piece is part of Scientific American*'s column The Science of Parenting. For more, go here.*

Mental health concerns. Exposure to pornography. Addiction. Loneliness. Bullying. Adolescents' use of smartphones has been blamed for all manner of societal ills. For parents, the stakes feel impossibly high. Get your child a smartphone, and you risk opening Pandora's box. Hold off, and you risk ostracism from their smartphone toting peers.

When to take the plunge? What's the right age to get your child a smartphone?

As a psychologist studying the role of digital technology in youth mental health and author of the parenting newsletter Techno Sapiens, I find this is one of the most common questions I get from parents.

So here's the bad news: there is no one "right" age. But the good news? We can look to the research to make the "right" decision for *your child* and to help you feel more confident in your decision-making.

Let's start with the basics. When your 12-year-old laments that every other kid in their grade has a smartphone, are they correct? According to nationally representative data from Common Sense Media, 42 percent of 10-year-olds report having their own smartphone. By age 12 that number increases to 71 percent, and by 14 it's 91 percent. Of course, these numbers vary across different communities and settings, but these appear to be the averages.

These numbers can tell us, broadly, the age at which other families are giving smartphones to their children, but they cannot tell us what age is *best* to do so. To really answer that question, we would need a specific type of research study that involved a large group of children. We would randomly assign some of them to get smartphones at age 10, some at age 11, some at 12, and so on. We would then follow them over time to see how they develop emotionally, cognitively and socially. Years later we could compare, for example, the kids who got phones at 12 versus those who got phones at 17.

There are a few reasons this study would not work in the real world. The first is the need for random assignment. Randomly assigning kids to get phones at different ages would allow us to determine whether any differences in outcomes were related to the phones. This is unlikely to happen: few families would agree to have the smartphone decision determined by random chance.

Of course, we can simply compare kids who got phones at age 12 with those who got phones at age 17, but without random assignment it's very possible that the kids getting phones at age 12 were already different from those getting phones at 17. Maybe they came from different family situations or economic backgrounds. Maybe they differed in their social or emotional maturity. These challenges may be why current research findings have been mixed. And some studies suggest that earlier smartphone acquisition negatively affects future well-being, whereas others find no impacts at all.

Just because other kids have phones at a certain age, doesn't mean your child is ready.
GoodLifeStudio/Getty Images

Even if we were able to pull off this type of study, there would be another problem: like all people, kids are very different from one another. Twelve-year-olds vary considerably in their needs, preferences, histories, emotional well-being and social skills. Even if a study were to determine a single, optimal age for kids to get smartphones, this would reflect an average. There would still be many kids for whom that "optimal" age was not the right one.

So how can you determine when to get *your* child a smartphone?

Why do they (and you) want a smartphone?

Digital technology plays a key role in adolescents’ social lives: 69 percent of teens say their smartphones make it easier for them to pursue hobbies and interests, and 80 percent say that social media (typically accessed via a smartphone) makes them feel more connected to what’s going on in their friends’ lives. When a young person asks for a smartphone, the motivation may be that everyone else has one, but the desire also might reflect a legitimate experience of missing out on social connections. If all your friends are making plans to hang out over text messaging, and you’re not in the group chat, you really are left out.

There also may be safety or convenience reasons for wanting your child to have a phone; maybe they are walking to and from school, or you need to coordinate pickups from soccer practices or different households.

At the same time, smartphones come with risks. We know that when phones are present they can distract teens from academic work, interrupt in-person social interactions and interfere with sleep. We also know that smartphones offer an in-your-pocket portal to everything on the Internet—some of which we’d rather they not see.

The best device for your child might be the simplest one that meets your needs. You may find that a “dumber” device—whether it’s a basic flip phone, a kid-friendly smartphone or a smartwatch—gets the job done just fine. Gradually introducing new tech gives you more opportunities to teach them about appropriate use: you might slowly progress from a shared family iPad to a basic mobile phone to a smartphone with strict parental controls to, eventually, a smartphone with access to social media and other apps.

It’s worth noting, too, that it can be a lot easier for parents to delay kids’ smartphone acquisition when other families are following the same path. This is why organizations such as Wait Until 8th, which aim to mobilize communities to delay giving kids smartphones, have gained traction in recent years.

Are they ready for a smartphone?

"Ready" is a tricky word when it comes to smartphones. Is any child ever truly ready for a smartphone? Is any adult ready to navigate one of the most powerful technologies of our time without occasional mishaps and challenges? Determining whether your child is ready for a smartphone means recognizing their unique strengths and vulnerabilities, reflecting on their patterns of behavior, and preparing for a major milestone that will require a lot of scaffolding on your part, not to mention some inevitable hiccups.

Research consistently demonstrates that the ways in which children respond to technologies are highly individualized to both the child and the specifics of the technology they're using (a phenomenon called "differential susceptibility to media effects"). If your child is emotionally reactive or struggles to fit in socially, these issues may be amplified by a smartphone. If they're responsible, show good judgment and generally follow the rules you've set, the smartphone may be a nonissue. Their prior experiences with technology (like tablets or other screens) can serve as a clue to how they'll respond.

Whatever age you choose, you can set yourself up for success. Have conversations with your child about smartphones early and often. Introduce new tech gradually. Work together with them to set expectations and boundaries around use. Although there is no one "right" age for a smartphone, there can be a right time for *your* family. Trust yourself to know when that might be.

Jacqueline Nesi is a clinical psychologist and assistant professor at Brown University, author of the newsletter Techno Sapiens and co-founder of Tech Without Stress. She holds a Ph.D. from the University of North Carolina at Chapel Hill.

https://www.scientificamerican.com/article/when-should-kids-get-a-smartphone

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Physiology

- **Broken Legs and Ankles Heal Better If You Walk on Them within Weeks**
  Using crutches for months is largely a thing of the past. Early weight-bearing has real benefits

Broken Legs and Ankles Heal Better If You Walk on Them within Weeks

Using crutches for months is largely a thing of the past. Early weight-bearing has real benefits

By Lydia Denworth edited by Josh Fischman


Jay Bendt

Twenty years ago my husband, Mark, broke his left ankle and was in a cast and on crutches for nearly two months. Last year he broke the other ankle. But this time, after surgery, his doctor surprised us by instructing Mark to walk on it two weeks later.

It turns out the standard advice to stay off a broken leg bone for at least six weeks is based less on scientific evidence and more on cultural caution—physicians like to play it safe. But now studies show that complications are no more likely with early weight-bearing than with a long delay. Except in a few complex cases, walking around earlier helps broken bones heal, and it improves quality of life: for example, people can return to work and other activities faster.

If you are fully immobilized, "you come out of the cast with a sort of hairy, withered leg that takes forever to overcome," says orthopedic trauma surgeon Alex Trompeter of St. George's University of London. "The science tells us that the rate at which you lose muscle mass is far faster than the rate at which you gain it." You're slow to build bone, too. Consider astronauts. After six months in zero gravity at the International Space Station, they lose 10 percent of their bone density, and to ward off that loss they do exercises in space that are equivalent to bearing weight.

In the 19th century German surgeon and anatomist Julius Wolff recognized that healthy bones adapt and change in response to the load placed on them. That is why everyone—but especially women, who are more susceptible than men to osteoporosis—should lift weights as they age. It increases bone density.

> Those who walked early on femurs that had broken just above the knee had no higher rate of complications than those who stayed off the leg for six weeks.

When you fracture a bone anywhere in the body, physicians first worry about stability. How much will the bone fragments move if you put weight on them? If the answer is too much, surgery is usually indicated—first a "reduction" to realign the pieces of bone and then "fixation" to hold them in place with screws, plates or rods.

That procedure sets up a bone, which is living tissue, to heal naturally by making new bone and resorbing damaged cells. In the gap caused by a fracture, a healing tissue called callus forms first, which then turns into bone. The right amount of load or movement (here's where Wolff's discovery applies) is critical to this process. Too little results in no callus; too much prevents the bone from knitting back together. "It's all about the strain environment," says orthopedic surgeon Chris Bretherton of Queen Mary's Hospital in London.

Surgical implants hold the alignment until that process is complete. "It's a little bit of a race postoperatively between the bone healing and the fixation breaking," says orthopedic trauma surgeon Marilyn Heng of the University of Miami Miller School of Medicine. In that contest, she roots for the new bone. "Once the body heals and forms bone across the fracture site, the hardware we put in becomes extraneous. The crux of our decisions for weight-bearing status is we want to win that race."

And putting some load on the bones aids that goal. Although the process of bone healing is the same all over the body, bones in the lower limbs such as hips, femurs and ankles bring extra complications because they affect the ability to walk. In patients with hip fractures—predominantly frail, older people—that immobility can lead to dire consequences.

Some patients do not have the dexterity and strength to manage partial weight-bearing while using crutches, so they stay in bed. The lack of movement leads to serious problems such as blood clots and weakening of the lungs. One 2005 study found that nine percent of hip fracture patients died within 30 days of breaking a hip and that 30 percent died within the first year. But more recent studies of healing hips suggest that early weight-bearing decreases mortality rates, and doctors have altered their practices. "The normal standard of care is [now] to fix it and let people walk," Trompeter says.

Breaks in long bones, like the femur in your thigh, can be relatively straightforward to repair with a rod. In a study that looked back at outcomes for a series of patients, Heng and her colleagues showed that those who walked early on femurs that had broken just above the knee had no higher rate of complications than those who stayed off the leg for six weeks.

For ankles, the largest randomized controlled trial to date (480 fracture cases across 23 centers in the U.K.) was published in 2024 in the *Lancet*. Half of the patients were instructed to walk after two weeks, and the other half were told to wait until after six weeks. Any complications, such as infections or broken plates, were equally common in both groups, so early walking didn't pose a greater risk. And the early weight-bearing group reported better function in the ankle at six weeks and at four months postsurgery. "Surgeons just needed a push," says Bretherton, who led the study. He hopes this evidence "gives them that confidence."

As for my husband, he jumped at the chance to get moving sooner. In less than two months, the point at which he was just coming out of a cast last time, his scar was fully healed, he was walking normally and, with a few limitations—no running, no quick pivots—he was exercising again. It seems that he won this race.

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/broken-legs-and-ankles-heal-better-if-you-walk-on-them-within-weeks

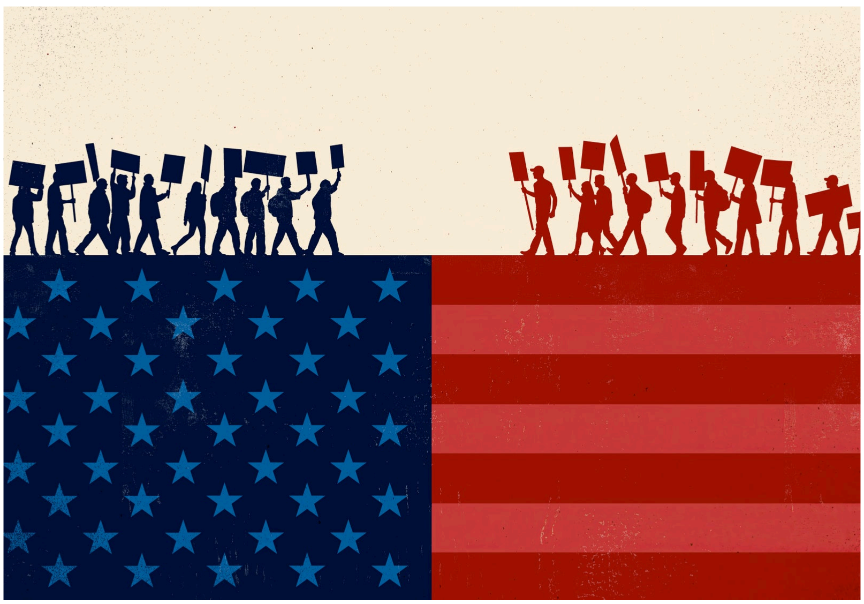
Psychology

- **People Overestimate Political Opponents' Immorality**
  To heal political division, start with common moral ground, a study suggests
- **Which Knot Is Stronger? Humans Aren't Great Judges**
  People are surprisingly bad at guessing knot strength, a study found

People Overestimate Political Opponents' Immorality

To heal political division, start with common moral ground, a study suggests

By Curtis Puryear, Emily Kubin & Kurt Gray edited by Daisy Yuhas



Rob Dobi/Getty Images

How would you describe a member of the opposite political party? Maybe you find them "annoying" or even "stupid." Or you might call them "bigoted" or "immoral." Americans are deeply politically divided, and such harsh language is not uncommon. Large majorities of Republicans and Democrats say the two parties can't agree on basic facts, and members of both report hating political opponents more than they love political allies. Although we lack reliable polling data from the 1800s, some scholars suggest we haven't been this polarized since the U.S. Civil War.

The sources of these divides are varied and include structural features of the U.S., such as the two-party system that pits "us" against "them," and social media algorithms that showcase the most outrage-inducing content from each side. This political environment shapes our beliefs about one another, which can further drive division. Yet research finds that our notions about these things are often wrong. Democrats surveyed in 2015, for example, wrongly believed 38 percent of Republicans made more than $250,000 a year (the real number was 2.2 percent), and Republicans in that same study wrongly thought 32 percent of Democrats were gay, lesbian or bisexual (the real number was 6.3 percent). We also have misconceptions about how much our opponents hate us, wildly exaggerating the other side's animosity.

A common falsehood is that "they"—unlike "us"—lack genuine moral values. "We" are caring people, but "they" are trying to burn everything down. "We" are fighting for goodness; "they" are working for evil. In recent research, we have found that these misperceptions about morality go deep. People think many in the opposing political party approve of obvious moral wrongs.

> Even though people hold varying ideas about specific actions and issues, their core concern in moral dilemmas ultimately boils down to protecting vulnerable parties from harm.

In a national survey, we asked more than 600 participants who identified as either Democrats or Republicans to appraise six basic moral transgressions: wrongful imprisonment, tax fraud, embezzlement, animal abuse, watching child pornography and cheating on a spouse. Almost everyone said they did not approve of these acts. (For some behaviors, a small number of participants—less than 5 percent—said they did approve.) There was no notable difference between the two parties. This finding aligns with past research. In fact, scientists who study moral psychology report that most people actually share a "moral sensitivity." That is, even though people hold varying ideas about specific actions and issues, their core concern in moral dilemmas ultimately boils down to protecting vulnerable parties from harm.

We then asked participants to estimate how likely their political opponents would be to approve of these actions. Our results showed that, on average, Democrats and Republicans thought about 23 percent of their political opponents would approve of basic moral wrongs—despite the fact that the actual percentage was less than 5 for both parties. This pattern persisted even when we tried a variation of our survey with additional participants, to minimize the possibility of purposeful exaggeration. But even when we tried paying participants to be accurate—a common strategy in this kind of research—people still overestimated the fraction of their political opponents who approved of basic moral wrongs.

Further studies demonstrated that these distorted perceptions of the other side's basic morality also drove division. For example, the more immoral people believed their political opponents to be, the more likely they were to agree with language that dehumanized them, such as statements that suggested the other party's members were "lacking in self-restraint, like an animal." People also rejected the idea of talking with or even trying to understand someone from the opposing party, possibly because of their purported immorality.

These distorted perceptions also appear in public conversations about politics. When we examined every post from 5,806 users on X from 2013 to 2021 (about 5.8 million posts), we found that both liberals and conservatives were more likely to use words such as "rapist," "thief," "pedophile," "sociopath" and "murderer" when commenting on posts related to politics than when commenting on nonpolitical topics. In the early 2010s people were about as likely to use these words when they talked about any celebrity or political opponent. But in 2016 hostile language in posts about political opponents began to rise, and it has remained concerningly high ever since.

Can we stop people from acting this way? One simple solution might be to remind one another of our shared moral values.

For example, in our recent research, we found that providing concrete information that highlights someone's basic moral values can increase cooperation across the aisle. In one study, learning that a conversation partner with opposing political views shared a participant's condemnation of wrongs such as tax fraud or animal abuse increased the chances that these people would interact, compared with those who didn't receive this information.

Although this approach clearly cannot resolve all our political divisions, it can still have powerful effects. Sometimes we need a reminder that "they" are like "us." We may disagree on many issues, but underneath those disagreements lies a common moral sense: we all care deeply about protecting our friends, family and communities from harm. Talking about our core principles and values—many of which we have in common—before talking about issues that can easily turn contentious can help our conversations go better.

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.*

Curtis Puryear is a postdoctoral researcher in the Kellogg School of Management at Northwestern University, where he studies how new technologies affect our social worlds, our moral values and political conflict.

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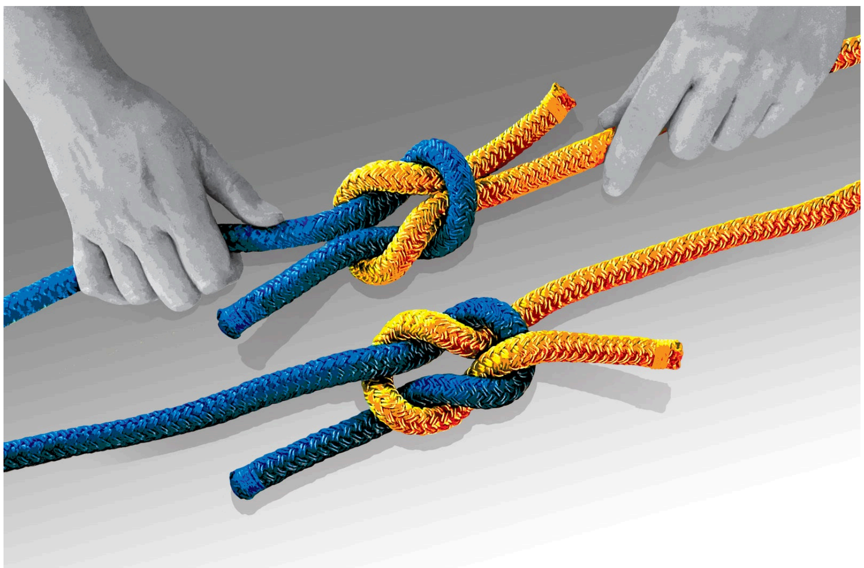
https://www.scientificamerican.com/article/people-overestimate-political-opponents-immorality

Which Knot Is Stronger? Humans Aren’t Great Judges

People are surprisingly bad at guessing knot strength, a study found

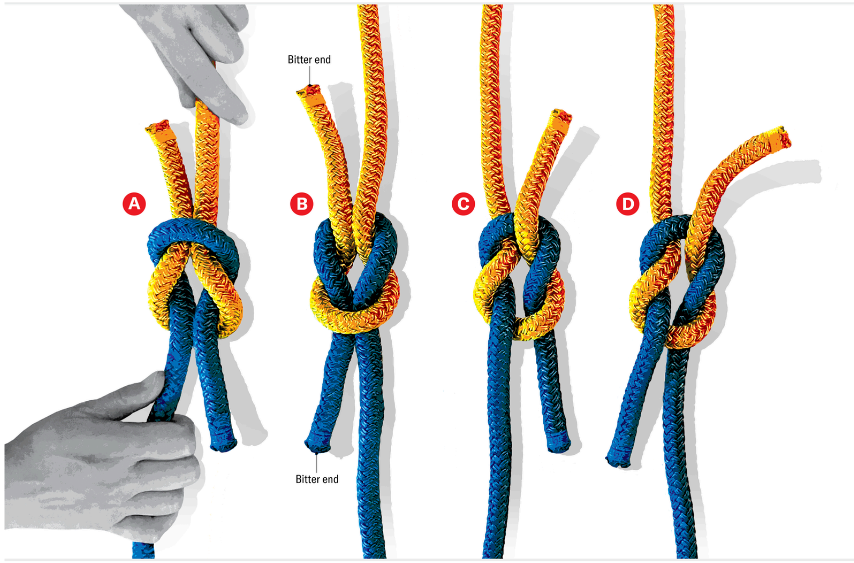
By Clara Moskowitz & Jen Christiansen edited by Clara Moskowitz & Jen Christiansen



Jen Christiansen

Humans are pretty good at guessing whether a towering stack of dishes in the sink will topple over or where a pool ball will go when a cue hits it. We evolved this kind of physical reasoning to navigate our changing and sometimes dangerous environments. But a new study highlights one area of intuitive physics that’s deceptively difficult: judging how strong a knot is.

Take a look at these four knots, which may look similar but are all distinct. Which knot would be hardest to undo if you pulled on the two long ends of its ropes? Rank them in order from weakest to strongest.



Jen Christiansen; Source: “Tangled Physics: Knots Strain Intuitive Physical Reasoning,” by Sholei Croom and Chaz Firestone, in *Open Mind*, Vol. 8; September 2024 (*reference*)

These four knots can be grouped into two pairs of similar configurations: the “thief” (A) and “reef” (B) knots, and the “granny” (C) and “grief” (D) knots. In both pairs, one knot is vastly stronger than the other. The correct weak-to-strong ranking is grief, thief, granny and reef (D, A, C, B).

If you’re surprised, you’re in good company. Researchers recently asked volunteers to look at photographs of these knots and decide which would take more force to undo. The participants consistently misjudged the strength of the ties by wide margins, Johns Hopkins University brain science researchers Chaz Firestone and Sholei Croom report in the journal *Open Mind*.

“Reef and thief knots were rated as similarly strong because they’re visually similar, but the position of the bitter ends”—the shorter, cut-off ends in each knot—“is really significant,” Croom says. “A knot with two bitter ends on opposite sides is a lot weaker than if the two sides are the same. The grief knot, aptly named, is so weak you could sneeze on it and it would fall apart.”

KNOT BASICS

The fact that people are bad at evaluating knot strength is surprising because we encounter them in many situations—from tangled electronic cords to hair braids, knitting stitches to medical suture ties, rock climbing to sailing. “Tying a knot properly can spell the difference between safety and peril,” Croom says. The four shown here are among the simplest knots that can be tied with two lengths of string, and they are prevalent in daily life.

PHYSICAL REASONING

Studying areas where our physical intuition fails helps scientists better understand how our brains perceive the world around us. “Knots might be an interesting case study on constraints around our physical reasoning,” Croom says. “Is it something to do with elasticity? Is it the fact that it’s a soft-body object rather than a rigid-body object?” Figuring out why tangles are so tricky could help scientists predict when people’s snap judgments about a physical situation are likely to be wrong, leading to unsafe reactions.

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.

Jen Christiansen is author of the book *Building Science Graphics: An Illustrated Guide to Communicating Science through Diagrams and Visualizations* (CRC Press) and senior graphics editor at *Scientific American*, where she art directs and produces illustrated explanatory diagrams and data visualizations. In 1996 she began her publishing career in New York City at *Scientific American*. Subsequently she moved to Washington, D.C., to join the staff of *National Geographic* (first as an assistant art director–researcher hybrid and then as a designer), spent four years as a freelance science communicator and returned to *Scientific American* in 2007. Christiansen presents and writes on topics ranging from reconciling her love for art and science to her quest to learn more about the pulsar chart on the cover of Joy Division's album *Unknown Pleasures*. She holds a graduate certificate in science communication from the University of California, Santa Cruz, and a B.A. in geology and studio art from Smith College. Follow Christiansen on Bluesky @jenchristiansen.com

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Society & Policy

- ## Immigration Fuels Innovation in Science to Make the U.S. More Competitive
  The U.S. will need more than one million STEM workers in the next 10 years to stay competitive. Immigrants are critical to that future

Immigration Fuels Innovation in Science to Make the U.S. More Competitive

The U.S. will need more than one million STEM workers in the next 10 years to stay competitive. Immigrants are critical to that future

By The Editors

Rob Dobi

In late December 2024 a social media storm erupted after entrepreneur Elon Musk blasted out support for the iconic H-1B visa. The temporary work visa has long served as a ticket to jobs in the U.S. high-tech industry for skilled foreign-born scientists and engineers. In response, President Donald Trump's nativist backers pushed back immediately. Former Trump adviser Steve Bannon characterized Musk's position as a ploy by tech oligarchs to take jobs from Americans. Headlines proclaimed the outbreak of a MAGA civil war.

Musk's remarks might seem self-serving, but he is right in highlighting the need for more engineering talent from overseas.

Foreign-born tech workers are essential to fuel America's powerhouse economy, one that captures an outsized percentage of global gross domestic product compared with its population. And they will be key for hiring the more than one million additional STEM workers that will be needed in 2033 compared with 2023, according to the U.S. Bureau of Labor Statistics. This increase marks a 10 percent growth rate, almost three times what is projected for any non-STEM industry during the same period.

Immigrants are a big part of what has made America a global leader in science and technology; if Trump's nativist faction prevails and restricts the entry of skilled workers, that will have profound effects on this leadership role, as well as on the U.S. economy.

Closing borders is a mistake. The tech elite know this. Musk, who was born in South Africa and now heads an advisory committee for the Trump administration called the Department of Government Efficiency, is one of many tech magnates who rely on the H-1B visa. Musk's Tesla company received approvals for 742 H-1B petitions for new hires during the 2024 federal fiscal year, more than double the number from a year earlier. Amazon (owned by Jeff Bezos) applied for nearly 3,900 H-1Bs in 2024. Most of the 25 companies that made the most H-1B requests in 2024 are technology firms, including Microsoft, Infosys and Meta, the parent company of Facebook (run by Mark Zuckerberg).

> Cutting off the flow of foreign workers by rejecting H-1B applications can negatively impact local economies and even hurt U.S. workers.

Despite the claims from Bannon and other hard-right MAGA supporters that H-1Bs rob American citizens of skilled jobs, the pipeline for domestic talent alone is unlikely to fill looming employment gaps. U.S. math scores have dropped, and the educational infrastructure at the most basic level is often just not there: only half of U.S. high schools offer calculus, and 60 percent provide physics classes. Both skills are critical for designing quantum computers and achieving innovations in artificial intelligence.

According to study estimates, just 3 percent or so of America's high school graduates join the ranks of STEM workers. Prominent legislation to promote STEM education has not met its funding targets. The Biden administration's CHIPS and Science Act set out to invest billions of dollars in STEM education, but the funding appropriated for the National Science Foundation has been hundreds of millions less than what was originally requested.

In addition to industry jobs, the basic and applied research that takes place at the nation's universities and tech hubs is highly reliant on overseas talent. An August 2024 report from the National Academies of Sciences, Engineering and Medicine (NAS) notes that contributions from the large cadre of international students are critical to sustaining current levels of research in U.S. graduate programs. Foreign-born employees make up 43 percent of U.S. STEM workers who hold doctoral degrees, and this number rises to nearly 60 percent in computer science and certain other fields.

These professionals bring abundant benefits to the STEM workforce. In 2022 more than half of U.S. start-ups with valuations greater than $1 billion had at least one immigrant at their helm—and the value of foreign-born professionals in this country can be witnessed on the global stage at the highest levels of human achievement: 40 percent of American Nobel Prize winners in chemistry, medicine and physics in the past two decades have been immigrants.

Uncertainties about immigration for tech jobs—reflected by the internal strife in the Trump team and among its supporters—could result in fractured policymaking, with foreign-born STEM workers getting placed under the same anti-immigrant policymaking umbrella as undocumented immigrants.

In the fusillades of the MAGA civil war, Trump took Musk's side, saying he has always been a big backer of H-1Bs, although the president has previously said the opposite. He once called the visas "very, very bad for workers." In fact, during Trump's first term his administration set up a partial H-1B blockade. The denial rate for the already short supply of the visas reached 24 percent in fiscal year 2018. It fell back to 2 percent in fiscal year 2022 after courts found his administration's handling of these visas to be unlawful.

Cutting off the flow of foreign workers by rejecting H-1B applications can negatively impact local economies and even hurt U.S. workers. In one 2014 study, researchers looking at this issue found that cities across the nation with high H-1B denial rates experienced a drop in computer-related jobs, and this decline was accompanied by lower wage growth for native-born citizens who lived there.

The U.S. remains a prime destination for foreign-born students and professionals, but the status quo may not hold. Talent-recruitment programs began to emerge in many countries in the 2010s. One prime example is Canada's Tech Talent Strategy, which afforded three-year work permits to as many as 10,000 people in the U.S. who have H-1B visas.

The ultimate fix for the U.S.'s chronically broken immigration system would be to implement a long-sought massive overhaul through congressional legislation. Such comprehensive immigration reform would rationalize the competing demands of border security and the need to equitably regulate both legal and illegal immigration. But this kind of all-encompassing measure has little chance of being adopted during the next four years.

In bringing wider attention to the role of legal immigration, the wrangling over H-1Bs may have an upside. On a podcast last year, Trump remarked that international college students, once they graduate, should be eligible for green cards, which confer permanent residency. His administration could make good on some variation of this idea.

Other steps might raise the caps on H-1B visas granted annually (currently 85,000 in total) and institute much needed reforms to the visa program—especially to ensure that visa holders are not exploited. Employers could do their part by seeking out underutilized programs such as the 0-1A temporary work visa for individuals with “extraordinary ability.”

If nothing is done on H-1Bs and other legal-immigration measures, the desirability of the U.S. as a destination for STEM students and tech workers will fade. The 2024 NAS report notes that between 2019 and 2023, the U.S. fell from first to eighth worldwide in scores for attractiveness to highly educated workers. It will probably slip further.

The anti-immigrant atmosphere ushered in by the Trump administration’s promised mass deportation of undocumented immigrants is also likely to sour foreign students and engineers on coming to the U.S. And this outcome will benefit no one.

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Solar system

- **Ancient Moon Melt Event May Explain 150-Million-Year Gap in Age Estimates**
  The moon may have melted 4.35 billion years ago—explaining a lunar age mystery

Ancient Moon Melt Event May Explain 150-Million-Year Gap in Age Estimates

The moon may have melted 4.35 billion years ago—explaining a lunar age mystery

By Payal Dhar edited by Sarah Lewin Frasier


Javier Zayas Photography/Getty Images

The moon is Earth's closest neighbor in space and the only extraterrestrial body humans have visited. Yet scientists are still unsure exactly when a Mars-size meteorite slammed into early Earth, causing our natural satellite to form from the debris. Lunar rock samples put the event at 4.35 billion years ago, but planet formation models and fragments of zircon from the moon's surface suggest it happened at least 4.51 billion years ago.

A new study published in *Nature* offers a way to explain that 150-million-year gap. Computer modeling and analysis of previous research suggest the 4.35-billion-year-old rock samples may date not back to the moon's formation but instead to a later event in which the moon temporarily heated up, causing its surface to melt and then crystallize.

The moon's elliptical orbit is slowly getting more distant from Earth. As the moon moves it is squeezed and stretched by Earth's gravity, resulting in what is known as tidal heating events—one of which most likely happened 4.35 billion years ago. This early moon would have looked like Jupiter's moon Io, says the study's lead author Francis Nimmo, a planetary scientist at the University of California, Santa Cruz. "It would have had volcanoes all over its surface," he says. This event would have also erased lunar impact basins caused by meteorite strikes, which researchers use to estimate age.

The difference of 150 million years matters a lot to scientists, Nimmo says, especially for learning more about the early Earth. "The moon is moving away from Earth, and the rate at which that happens depends on what Earth was like," he says. "Was it solid? Was it liquid? Did it have an ocean? Did it have an atmosphere?" For instance, very early Earth probably didn't have an ocean—or it would have pushed the moon away too fast. The moon's formation time is crucial to these calculations, and more complex models of tidal heating and the mineralogy involved could help refine our understanding.

"No previous study has synthesized all the available evidence comprehensively," says Yoshinori Miyazaki, a geophysicist at the California Institute of Technology, who wasn't involved with the study. "This paper provides a better view in resolving the discrepancies between different age estimates."

Current hypotheses for when Earth and the moon formed, which put the date at anywhere from 30 million to 150 million years after the sun's birth, suggest vastly different scenarios for planet formation. "Resolving these uncertainties is essential for constructing a consistent picture of solar system history," Miyazaki says.

Payal Dhar (she/they) is a freelance journalist who covers science, technology and society. They write about AI, robotics, biotech, space, online communities, games and any shiny new technology that catches their eye.

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Universe

- **What’s Inside Our Galaxy’s Darkest Place?**
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What’s Inside Our Galaxy’s Darkest Place?

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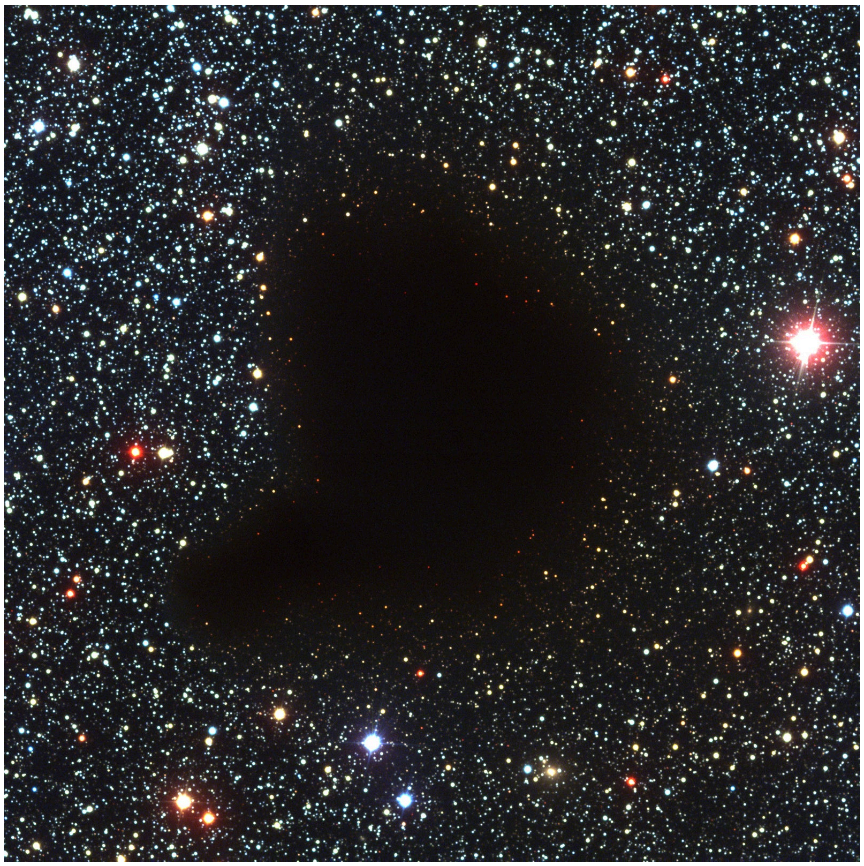

Barnard 68 (B68) is a dark and dusty nebula some 500 light-years from Earth.
ESO

Right now, people who love looking at the wonders of the heavens have it better than ever. Every day brings some new jaw-dropping snapshot from at least one of the myriad observatories now operating on the ground or in space, each offering a new view of alien worlds, exploding stars, colliding galaxies or any number of other astrophysical phenomena. Most of these images are paeans to cosmic forces and inconceivable scales that carve stunning beauty from epic violence.

But not everything in our galaxy (or beyond) is the outcome of such ostentatious chaos. Some of the most visually captivating celestial objects are quiet, steady, even calm—and so dark that they not only emit no visible light but actually absorb it, creating a blackness so profound they seem to be a notch cut out in space.

These shadowy expanses have many sobriquets—dark nebulae, dust clouds, knots—but I prefer to call them Bok globules, a name they received in honor of Dutch American astronomer Bart Bok, who studied them.

A Bok globule is a small, dense clump of cosmic dust; millions of them are scattered around our galaxy. They are cold and opaque to visible light, so much so that until quite recently the only way to see them was in silhouette against brighter background material. Though not as splashy as their star-factory cousins, such as the Orion Nebula, Bok globules can still make stars, albeit in a more artisanal way: they make one or a few at a time that are largely hidden from our prying eyes in the dust's abyssal depths.

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Of all the dark globules we can see with our telescopes, my favorite beyond a doubt is Barnard 68, colloquially called B68. Located about 500 light-years from Earth, it's a vaguely comma-shaped and coal-black cloud a mere half-light-year wide, spanning some five trillion kilometers. We see it easily because it's in the constellation Ophiuchus, with the star-packed center of our Milky Way galaxy as its backdrop. B68 appears to us as negative space, an absence of stars.

Why is it so dark? Although mostly made of hydrogen gas (like pretty much everything else in our galaxy), B68 also has an abundance of carbon. Some of this element is locked up in small molecules such as carbon monoxide, but much of the rest instead resides in long, complex molecules that make up what astronomers generically call dust. One distinguishing (or extinguishing) characteristic of dust is its capacity to block visible light.

And dust clouds can be dark indeed. In the case of B68, any star located on the other side from us will have its light diminished by a factor of *15 trillion*. To put this in perspective, dimming the sun in our sky by this much would reduce it to a fourth-magnitude star difficult to spot in even mildly light-polluted skies. If you were on one side of B68 and the sun on the other, the sun's light would be so attenuated across that half-light-year that it would become invisible to the naked eye.

Such extreme darkness makes B68—and Bok globules more generally—subject to continual mistaken identity. Some years ago astronomers discovered the existence of huge volumes of space largely bereft of galaxies; these are called cosmic voids and can be many millions of light-years across. Alas, I've seen quite a few breathless videos and articles about them illustrated with an image of B68. It's irritating to me as an astronomer to see this mistake because these are very different objects, but it's also rather amusing because the actual voids being discussed are millions of times larger than our friendly nearby Bok globule.

B68's prodigious ability to absorb light relies on a surprisingly modest amount of dust. Even in its center, where it's densest, B68 has less than a million particles of matter per cubic centimeter. That may sound like a lot, but here on Earth it would rate as a laboratory-grade vacuum—at sea level our planet's atmosphere packs about 10^{19} molecules per cubic centimeter, making the air you breathe some *10 trillion times* denser than B68 at its best.

Despite its all-encompassing darkness, we can discern B68's density because, like any cloud, it becomes more tenuous toward its outskirts. This creates an interesting situation: from our viewpoint, we can see some background stars through the relatively thinner material at its edges, but the closer we view to the center, the more that light is absorbed. Stars appear bright at the cloud’s perimeter but grow progressively dimmer as we look closer to the center. Because dust tends to absorb bluer light better than rays of red, which can pass through more easily, such stars don’t just fade; they also redden. And infrared light traverses B68 more easily yet, so telescopes tuned to those wavelengths can see even more stars. Astronomers can use that reddening and dimming to measure how much dust is inside the cloud.

Using other techniques, they can also measure B68’s temperature. Bok globules are terribly cold, and B68 is no exception, registering a bone-chilling –256 degrees Celsius at its edges that drops to only –265 degrees C at its center. This is barely above absolute zero!

Yet that whisper of warmth is enough to support the globule against its own gravity. B68 is not terribly massive, containing only about three to four times the mass of the sun, but that’s still typically more than enough to cause a gravitational collapse. The meager amount of internal heat keeps B68 inflated much like a hot air balloon, however (or, more accurately, a bitterly cold, near-vacuum balloon).

But this fragile impasse can’t last forever. Careful observations of B68 show what seem to be two distinct “cores” of higher-density material, one near its center and another in the stubby “tail” near its southeastern edge (*seen at lower left in photograph*). Radio-wave observations suggest this tail was once a separate, smaller cloud that is now merging with B68, upsetting the delicate balance of gravity inside the cloud. Consequently, B68 may now be collapsing, which means this dark cloud may literally have a bright future ahead: it will form a star.

As the material collapses in on itself, the density in the center would increase and the temperature with it. This would continue for hundreds of thousands of years until, at the cloud’s core, a star is born (perhaps more than one, given there's enough material in B68 to form a couple of sun-like stars). If that happens, almost all the matter remaining in the cloud will be blown away by the light of the newborn star or stars—all, that is, save perhaps for a meager fraction caught in the star's gravitational clutches, which could condense and collapse in turn to create a disk of material destined to form planets.

And who knows? In some few billion years more, perhaps life and eventually intelligence might arise on some of those worlds, so that one day in the far future alien astronomers will peer out and wonder about the universe they see, a vista they could not possibly have glimpsed through B68's youthful, starlight-devouring haze. Perhaps Earth and the sun will be long gone by then, and the galaxy will have transformed into a very different place. But even so, there's comfort to be found in such an end, knowing that once upon a time we began in much the same way; our sun was born in a huge, dust-darkened nebula that eventually lit up with thousands of other stars, a stellar nursery that, like its cosmic children, has long since dispersed.

Everything in the universe is ephemeral and much of it cyclical. We are privileged to be able to observe what we can now, even if what we see is something that is very difficult to see at all.

Phil Plait is a professional astronomer and science communicator in Virginia. His column for *Scientific American*, The Universe, covers all things space. He writes the *Bad Astronomy Newsletter*. Follow him online.

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