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How fire forged human civilization

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Fire Forged Humanity. Now It Threatens Everything

Ancient prophecies of worlds destroyed by fire are becoming realities. How will we respond?

By Stephen Pyne

In this image and those below, photographer Kevin Cooley captures the power and allure of fire. Kevin Cooley

When I was 18, a few days after graduating from high school, I found myself on a forest fire crew at Grand Canyon National Park in Arizona. I returned for 15 seasons, 12 as crew boss, and I became a pyromantic. For those years I lived one life at a university and another on the canyon’s North Rim. On a fire crew, you quickly learn how fires can shape a season and how seasons can shape a life. I found a way to reconcile my two lives and became a scholar on fire.

My first fire, in June 1967, was a lightning-blasted snag on Powell Plateau, an isolated mesa in the Grand Canyon. Fifty-six years later

I’ve written works about fire on every continent, among them primary histories for the U.S., Canada, Mexico, Australia and Europe, including Russia. My focus has been to chronicle the relationship between fire and humans, an alliance that has remade, and unhinged, the planet. Here’s how that happened—and how I think we can restore balance.

Earth is a fire planet, the only one we know of. Earth has fire because it has life. Life created the oxygen fire needs; life created and arranges the fuel it requires. Even the chemistry of fire is a biochemistry: fire takes apart what photosynthesis puts together. As long as terrestrial life has existed, so has fire.

Fire takes on some properties of the living world it depends on. In ways, it resembles a virus—something not truly alive but that requires the living world to propagate. And like a virus, fire propagates by contagion.

The one requirement of fire that life did not furnish was ignition. That changed with the appearance of a genus, now a single species, that could start fire at will: ours. Humans became unique fire creatures. We used fire to remake ourselves, and then we and fire remade Earth.

We developed more compact guts and big heads because we learned to cook food. We went to the top of the food web because we learned to cook landscapes for hunting, foraging, farming and herding. And we have become a geological force because we've begun to cook the planet. Becoming the keystone species for fire made us the keystone species for Earth. Not only can we start (and, within limits, stop) fire, but fire serves as a fulcrum for our desires, good and bad. The fire stick became an Archimedean lever with which we move the world.

Our relationship with fire grew as we domesticated it. Fire had to be birthed, fed, trained, sheltered, tended—we even have to clean up after it. For many intellectuals, from Roman architect Vitruvius to 20th-century French anthropologist Claude Lévi-Strauss, fire control separates the civilized from the barbaric. Fire is also a core technology and a foundation for chemistry. With fire we turn mud into brick and pottery, limestone into cement, sand into glass, ore into metal; fire always seems to exist somewhere in the life cycle of made things and in built environments. And working fires have illuminated, warmed and powered almost all human activities from religious sacrifices to the forging of weapons.

In a sense, early humans and fire made a pact for mutual assistance: each would expand the realm of the other. People would carry fire to places and times in which it could not have existed otherwise. In return, fire empowered humans to go everywhere and do far more than their primate ancestors could ever have imagined. If humans colonize other planets, they will leave Earth on plumes of flame.


Kevin Cooley

Yet limits existed. People and the flames they sparked were constrained by terrain, vegetative fuels and climate. Anthropogenic fire could alter some of those conditions but not at a planetary scale. That began to change about 12,000 years ago, at the end of the last glacial period. A fire-wielding creature met an increasingly fire-receptive world. With tugs and yanks and positive feedback, a planetary makeover began that is rampant today. The Holocene epoch that followed the last glaciation is an Anthropocene or, given the catalytic role of fire, a Pyrocene.

The Pyrocene, a concept and term I created several years ago, is an interpretation of Earth’s fire history as an amalgam of three fires. I’ll use the U.S. to illustrate this idea.

“First fire” is nature’s fire. Geologists have found fossil charcoal that is more than 420 million years old. Lightning was overwhelmingly the ignition source. Yet by the time the 1880 U.S. census mapped forest fires across the country, there was little overlap between lightning-kindled fires and the many burns on the ground. Humans were responsible for the vast majority of the burning. Indigenous peoples used fire for hunting, foraging, fishing and general land maintenance; fire could render landscapes more habitable. Newcomers, too, had a fire heritage that they hauled across the Atlantic, one embedded in agriculture and pastoralism. With contact between peoples, the fires of the two groups met and merged. Native practices better adapted to local sites were often adopted or modified to accommodate livestock and new crops. But even though people working the land never doubted the value of fire in sustaining their livelihoods, elites in the New World often echoed those of the Old World who distrusted and feared fire as messy, dangerous and wasteful, a stigma of primitivism.

These human-handled fires constitute a “second fire,” which is first fire domesticated, or at least tamed, and used to create a landscape more amenable to human habitation. Compare the 1880 geography of fires to that of human settlement, and you’ll find they overlay almost perfectly.

The new settlers came amid a first wave of European expansion. Usually this sprawl is considered in terms of political and economic imperialism. But there was a parallel expansion of plants, animals, diseases and peoples that rewrote fire regimes. The demographic collapse of Indigenous people in the Americas was particularly catastrophic. Spanish conquistador Hernán Cortés noted in a 1520 letter to Spain’s Holy Roman Emperor Charles V that “not a palm” of land (in central Mexico) was untended. Yet as much as 90 percent of those tenders disappeared during the 16th century. A partly domesticated, often feral land replaced the one they had cared for. This upheaval followed plagues and wars that swept Eurasia. Millions of people died, and millions of trees grew. Researchers are exploring how this global swap might have influenced the Little Ice Age that ended in the 19th century.

A second wave of fire expansion began in the late 18th century. This time, in addition to transporting plants and animals, ships carried ideas about fire that proved mighty in refashioning Earth. A scientific revolution—the discovery of oxygen in 1774—deconstructed fire into a chemical reaction called combustion.

“Fire” lost its siting in landscapes and its mythical status as a fundamental element and became a subdiscipline of physics, chemistry and mechanical engineering. Combustion was rational and modern, landscape fire primitive and backward.

This scientific redefinition aligned with a technological revolution aimed at fashioning new engines of fire, which gave people unparalleled power. Revealingly, the earliest steam engines—such as those created by pioneering inventors Thomas Newcomen and James Watt in the 1700s—were used to pump water out of coal mines, clearing the way to more fuel for the machines. Steam engines and their voracious progeny helped to disseminate Europe’s understanding of fire and the machines that exploited it. Wherever possible, the new firepower replaced the old, much as gas lighting and, later, electric bulbs did candles, and traditional knowledge and practices were condemned, replaced or suppressed. What happened in industrial Europe also happened in its colonies. Thousands of years of empirical fire experience, coded in lore, story, song lines and oral wisdom, were dismissed, in effect dissolving humanity’s hard-won understanding of how fire works in thousands of landscapes.

This conversion to combustion chambers, especially when used to burn fossil fuels, created the “third fire” that dominates the planet today.

The transition from burning living landscapes to burning lithic (fossil) landscapes constituted something new under the sun. Humanity’s quest for fire had always been about finding new stuff to burn and new ways to burn it. Now the issue was not sources; new reserves of fossil fuels kept being discovered (and still are today). The problem concerned sinks: there was no place to put all the effluent. Fire in living landscapes had evolved with checks and balances that could, within limits, be stretched. Third fire had no such ecological fetters. It could burn day and night, winter and summer, through wet and dry spells. Humanity had suddenly unshackled Prometheus. Its firepower was all but unbounded.

The transition toward fossil fuels as a source of primary energy is regarded as a fundamental driver of global change and has birthed an exponentially increasing body of fire scholarship. Yet as dramatic as its consequences seem, third fire is the latest phase change in an unbroken narrative of humanity and fire. This connectedness is part of the value in viewing the Anthropocene through a pyric prism. It is my particular contribution to the thinking about fire.

The competition between first and second fire expanded to include third fire. I call this shift the pyric transition because the demographics of fire seem to have emulated those of people as they underwent industrialization. Humanity has used its firepower to remake all its habitats, one after another. That third fire abolishes open fire has been taken by Western elites as a measure of modernity. To them, flame is slovenly, backward, even atavistic, tolerable only when used for ceremonial purposes. Working fires are those that are housed in machines.

So fire has disappeared in many domestic settings, sublimated into electricity. It has disappeared in urban environments. Historically, cities burned as often as their surrounding countryside; after all, they were made of the same materials and responded equally to drought and wind. Perhaps the best-known example is the swarm of fires that, on October 8, 1871, burned both the city of Chicago and the town of Peshtigo, Wis., amid a million acres of charred forest around Lake Michigan. But modern cities are designed not to burn, made of materials that have already passed through flames to become cement, glass and metal and then been arranged in ways that retard fire's spread.

A similar process has occurred in agriculture. The green revolution is about not just clever breeding but the "inputs" that amplify plant growth. Whereas open fire converted dead biomass into nutrients and purged sites of pests and competing plants, modern agriculture relies on petrochemicals that get cooked into fertilizer and biocides and delivered by pumps, planes and tractors powered by fossil fuels. Fallow—potentially arable land left "idle" during the growing season—fell out of favor. European agronomists and officials had always hated fallow, which they regarded as a waste of good land, and burning of these fields added insult. Yet fallowing contributed to agriculture's biodiversity.

Most spectacularly, the pyric transition extended into remote lands—forest reserves, nature preserves, the distant bush, the outback. Officials applied the new counterforce made possible by third fire and sought to abolish flame in wildlands as they had in other habitats.

There are good reasons to eliminate flames (and their inevitable smoke) in houses and cities. Few residents would want them back except as an occasional amenity. But pushing that change into the countryside and backcountry is different. The provocation was a wave of megafires during the late 1800s and early 1900s that were larger and more lethal than those of previous decades. Locomotives opened land to logging and clearing, which covered landscapes with combustible slash, over which trains scattered sparks from their smokestacks and brakes with abandon. The wreckage unleashed by fire and axe inspired state-sponsored conservation—a global project to protect landscapes, especially forests, from destruction. Between 1891 and 1905 the U.S. began reserving forests, granted them a charter and established an institution, the U.S. Forest Service, to administer it all.

The consensus wisdom was that such fires were intolerable. Bernhard Fernow, an émigré forester from Prussia who headed the Division of Forestry (predecessor to the Forest Service), dismissed the spectacle as one of “bad habits and loose morals,” unworthy of an aspiring great power. Gifford Pinchot, first chief of the Forest Service, likened the challenge of fire protection to the abolition of slavery. Their views were typical of forestry that had emerged from central Europe, which saw fire as a metric of social behavior. They regarded fires as they might malaria or banditry: the world would be better off without them.

As emissaries of modernity, foresters dismissed traditional fire knowledge and practice. Fire control became foundational to conservation, a global project that ranged from the Rocky Mountains of North America to the Central Provinces of India.

Foresters in the U.S. made “systematic fire control” their special contribution to world forestry.

Kevin Cooley

They went at it with extraordinary verve and resolve. Burned area decreased sharply, especially after World War II, aided by immense stocks of war-surplus hardware converted for firefighting. Industrial-scale fire protection thus became another marker in the Great Acceleration in global change. In the U.S., the burning of living landscapes plunged as the burning of lithic landscapes bolted upward. The period between the mid-1940s and the mid-1980s was a sweet spot in which technology and active suppression shrank free-burning fires to a pittance. Third fire overwhelmed first and second fire.

By the 1960s the ecological blowback was apparent. Wildlands are not cities; fuels build up, threatening to stoke uncontrollable conflagrations. Ecosystems rot, choked by the absence of fire’s renewing spark. Between 1968 and 1978, federal agencies reformed their policy from suppression-only to a mixed program centered on restoring good fire.

Note that all this happened before any wide concern about climate change. Since then, global warming, like a performance enhancer, has added energy to fire’s expression, and it has globalized the consequences. Even places that have not attempted the pyric transition feel its effects.

Like the pyric transition, the shift in fire-management approach happened quickly. After the Great Fires of 1910—which burned three and a quarter million acres in northern Idaho and western Montana, part of five million across the West—the U.S. spent 50 years trying to take all fire out of its landscapes and then another 50 trying to put good fire back in. The aftershocks promise to continue for a long while.

Let’s widen our aperture and consider fire’s big history. As long as Earth has had terrestrial vegetation, it has had first fire. Second fire appeared in the Pleistocene epoch, competing with first fire. During the Holocene epoch, which began approximately 11,700 years ago, people used fire to recode the patches and pulses of fire across the planet. Third fire arrived over the past two centuries. Its geography is different because it includes an axis of deep time. We are taking stuff out of the geological past, burning it in the present and loosing its effluent into the future. Initially third fire competed with first and second fire; more recently, as a result of humans’ overloading the atmosphere with greenhouse gases and promoting changes in land use, third fire has amplified any kind of fire on the land.

Earth is dividing into two realms of combustion. One burns living landscapes; the other burns lithic landscapes. Satellite views of Earth at night show the two realms clearly: countrysides aflame, cities aglow. Consider the two Koreas, a cameo of Earth’s pyrogeography. South Korea has made the pyric transition and is ablaze with electric lights at night, whereas North Korea is dark but shows abundant landscape fires during the day. South Korea is also now experiencing the wildfires typical of industrial nations, which it is fighting with third-fire-powered machines.

Plenty of disasters can occur when the two realms of combustion meet; think of power lines that start blazes. My favorite contrast is

Biosphere 2, a glassed-in, self-contained habitat in Arizona that could be plunked down on Mars. The geodesic structure has a zero-tolerance policy for fire, yet it sits at the base of the Santa Catalina Mountains, which experience fires that are both essential and inevitable (85 percent of the mountains burned in 2003 and 2004). What may be most striking in this scene, and many others like it, is the absence of any middle—a middle ground or a middle narrative that shows humans exercising their historic role as a fire agent and mediating between these two otherwise exclusionary visions.

Widen the aperture further. The Pleistocene's serial ice ages remade entire landscapes, created continental shifts in biogeography, dramatically changed sea level and spawned serial extinctions. Boosted by the pyric transition, fire is assuming the position previously held by ice. Climate change fomented by third fire is driving off ice and remaking landscapes; it's causing continental shifts in biogeography, changes in sea level and a wave of extinctions. Instead of outwash plains, we have heat domes, and instead of permafrost, permathaw. The ice of the Pleistocene has yielded to the fires of a Pyrocene.

And the humans? Consider the inhabitants of Fort McMurray in Alberta, Canada. They live in a modern city established to mine tar sands but sited in a boreal forest. In 2016 a fire, most likely ramped up by global warming, bolted out of the bush, burned through the town, shut down Suncor's mining operations and then continued untrammeled by any efforts to contain it. The residents fled in their petrol-powered vehicles. Fort McMurray—a creation of our fire age. Fort McMurray—a place that burned both ends of its combustion candle. Fort McMurray— a portal to the Pyrocene.

Today we live in a fire age in which ancient prophecies of worlds destroyed and renewed by fire have become contemporary realities, even for people living in modern cities. In the summer of 2023 millions of residents of New York City and other metropolises saw dark-orange daytime skies thick with smoke palls from Canadian wildfires—and breathed in the effluent. Mythology has morphed into ecology. We're witnessing a slow-motion Ragnarok—a story from Norse mythology in which a great battle burns the world. Climate history is becoming a subnarrative of fire history.

Kevin Cooley

In the 21st century experts in lots of disciplines have proposed ways to cope with fire challenges. Let me close by proposing three responses—a fire triangle for the Pyrocene.

The first side of the triangle: We have too much bad fire. We have too many fires that kill people, destroy communities and trash valued landscapes. In trying to abolish fire, we killed off many of the good fires that make bad ones easier to fight.

But modernity has shaped communities that are particularly vulnerable to fire. The problem of urban fire was solved a century ago. Watching towns burn today is like watching the return of polio or smallpox. Partly, the issue is a matter of definition. We defined the wildland-urban fire from the wildland side, viewing it as wildland fire complicated by houses. We should have defined the problem as urban fire complicated by peculiar landscaping. Define the problem as wildland fire, and it's nearly unsolvable. Define it as urban, and we know exactly what protective measures need to be taken.

The second side: We have too little good fire. Restoring fire is tricky. As is true of reintroducing any lost species, it's much easier to take fire out than to put it back in. We need to recover a lot of traditional knowledge while adapting it for current conditions. We can send people with drip torches along old trails, burn cropland set-asides as fallow, and create hybrid management schemes that alloy suppression and prescribed burning of single fires, especially those in nature preserves and in the backcountry.

Note, however, that replacing fossil fuels with renewables as a primary energy source will not be enough. If we use renewables to sustain the same landscapes we have now, we will have the same fire problems, though perhaps tamped down by lessened global warming. The U.S. still has a major fire deficit. As we ratchet down our burning of lithic landscapes, we'll have to ratchet up our burning of living landscapes. We have a lot of fire in our future.

The third side: We have way too much combustion overall. We must shut down the burning of fossil fuels. We can mitigate its effects only so much.

Here let me leave the U.S. for Victoria, Australia, and the saga of the Hazelwood power station. Hazelwood was erected to burn brown coal from an adjacent open-pit mine. In 2009 power lines in the area kindled fires in the Black Saturday bushfire outbreak. A few years later bushfires ignited the open-pit mine. The two realms of fire were turning on each other. It’s common for open-pit mines to consume the communities around them; in this case, the bush consumed the mine. What parable will we extract from this saga?

As we approach our fire-informed future, I’m reminded of the Old Testament prophet Ezekiel, who declaimed, “They shall go out from one fire, and another fire shall devour them.” We hold a species monopoly over fire. It’s what we do that no other creature does; it’s our role in the great chain of being. For us, fire is not just an ecological process or a tool; it’s a relationship. Through greed and a lust for power, we have turned our ancient companion from our best friend into our worst enemy.

Good fire made us. Bad fire may break us. The choice is ours.

Stephen Pyne is an emeritus professor at Arizona State University, where he worked for more than 30 years. He is author of *The Pyrocene* (University of California Press, 2021) and *Fire: A Brief History* (second edition, University of Washington Press, 2019). He has received a Fulbright Fellowship, a National Endowment for the Humanities Antarctic Fellowship and a MacArthur Fellowship.

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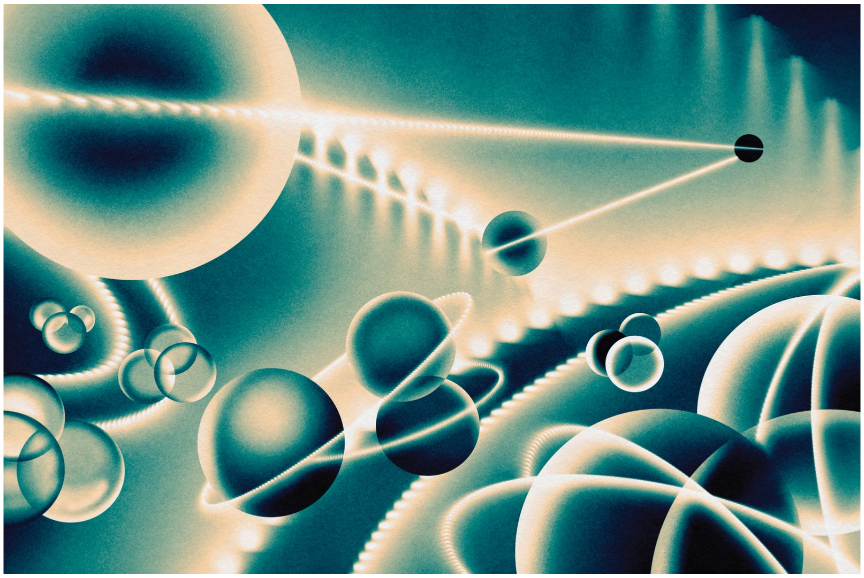
The Secret to the Strongest Force in the Universe

New discoveries demystify the bizarre force that binds atomic nuclei together

By Stanley J. Brodsky, Alexandre Deur & Craig D. Roberts

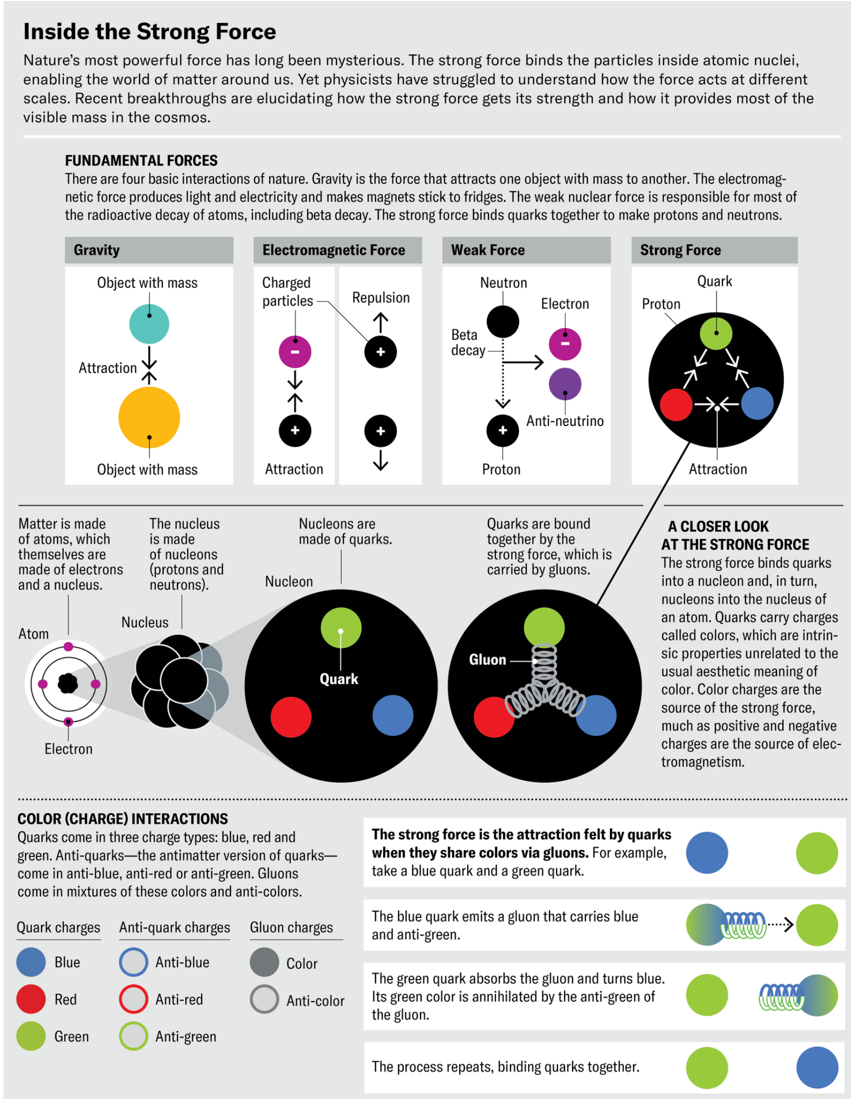


Deena So'oteh

The strongest force in the universe is called, aptly, the strong force. We never get to witness its fearsome power because it works only across subatomic distances, where it binds quarks together inside protons and neutrons and joins those nucleons into atomic nuclei. Of the four basic forces of nature, the strong force is by far the most potent—it's 100 trillion trillion trillion times stronger than the force of gravity. It's also the most mysterious.

Despite knowing roughly how it compares with the other forces, scientists don't know precisely how strong the strong force is. The other three forces—gravity, the electromagnetic force and the weak nuclear force (responsible for some radioactivity)—are much better measured. The strength of electromagnetism, for example, denoted by its "coupling constant," has been measured with the same precision as the distance between New York and Los Angeles, to within a few hair breadths. Yet the strong force's coupling constant, called α_s ("alpha s"), is by far the least understood of these quantities. The precision of the best measurements of α_s is 100 million times worse than that of the electromagnetic measurement.

Even this level of (un)certainty is known only in the simplest domain of the strong force theory, at very high energies involved only in some of the rarest and most extreme events in nature. At the lower energies relevant to the world around us, the strong force earns its name by becoming truly intense, and concrete information on α_s in this range is scarce. Until recently, no one had made any experimental measurements of α_s at this scale. Theoretical predictions for its value were unhelpful, covering the entire span from zero to infinity.



Jen Christiansen

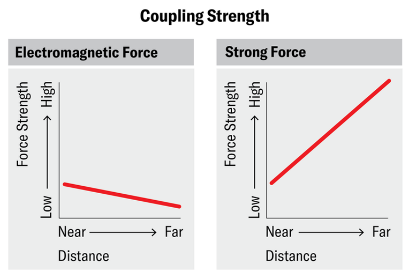
The strong force's might makes it difficult to study in lots of ways. The theory describing how it works, called quantum chromodynamics, is so complicated we can't use it to make direct calculations or precise predictions. One of the reasons for this complexity is that the carrier of the strong force—a particle called the gluon—interacts with itself. Electromagnetism, in comparison, is simple because its carrier, the photon, is chargeless. But the gluon carries the strong force's version of charge, called color, and its self-interactions quickly get out of hand. So despite its importance to nuclear physics and building the material world, the strong force is not unconditionally loved by researchers. Instead many look at the domain where the strong force is truly strong as a "Terra Damnata," a realm to avoid at all costs.

Yet understanding the strong force is essential for explaining the complexity of the matter around us. In fact, the strong force accounts for the origin of around 99 percent of the mass in the visible universe. (The remaining 1 percent comes from the Higgs boson.) And now, after half a century of effort, scientists have finally begun revealing some of the strong force's secrets. One of us (Deur) recently made the first measurements of how α_s changes within Terra Damnata, and two of us (Brodsky and Roberts) independently developed new theoretical predictions that explained the data. Terra Damnata is looking more welcoming than ever before. And now that we can explore this terrain, we stand to learn much more. We at last have the ability to analytically calculate aspects of quantum chromodynamics from first principles. Furthermore, exploring this range of the strong force could help us understand proposed unifying theories of the universe, as well as the question of how many dimensions exist in space and time.

Magnets direct particles through the Continuous Electron Beam Accelerator Facility (CEBAF) at the Thomas Jefferson National Accelerator Facility.
Courtesy of Jefferson Lab

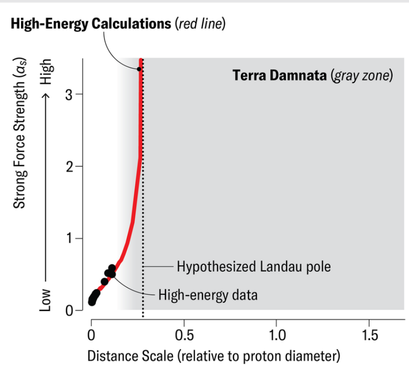
If α_s is a constant, how can it change? The answer has to do with the concept of quantum loops, also known as vacuum polarization. Quantum theory revealed that the "vacuum" of space is actually full of tiny particles that are constantly appearing and disappearing in fluctuating clouds. Interactions with these virtual particles can cause a force to depart from its classical behavior because of what's called a quantum loop. When the notion was first introduced, quantum loops were an unpleasant surprise because they predict infinite quantities—a clear sign that something is wrong. But eventually physicists figured out how to tame these infinities and absorb all the corrections from quantum loops into the equation describing the carrier of the force. Thus, in quantum chromodynamics (QCD), quantum loop corrections affect the gluon's behavior and determine how much α_s changes with the distance between quarks. With this new distance dependence from quantum loops lodged within the coupling constant, these quantities lost their constancy. So we'll just call them "couplings" from now on.

For most of the forces, the couplings change slowly with distance. For instance, from the tiniest scales ever probed by humans to everyday scales, α_{em}, the electromagnetic coupling, decreases only by about 10 percent of its value. For the strong coupling, α_s, however, the change is huge: even within the domain where physicists are comfortable calculating α_s (that is, far from Terra Damnata), its value changes by several orders of magnitude. Another difference, far more important, is that the electromagnetic coupling decreases as the distance grows. For the strong force, however, α_s increases with distance. If you try to pull two quarks within a proton apart from each other, the attraction between them becomes stronger. In fact, it grows so powerfully that it's essentially impossible to pry quarks away from each other—the strong force keeps them "confined," and you can never find a single quark by itself. The same rule applies to interactions between quarks and gluons and between gluons and gluons. The flip side is that these interactions are weak at short distances: the closer you zoom in on a quark, the more loosely it's bound. The smallness of α_s at small distances is called asymptotic freedom, and its discovery in the 1970s eventually won its pioneers the 2004 Nobel Prize in Physics.



Jen Christiansen

At short distances, where α_s is small, physicists can perform calculations using the same methods that we use for the electromagnetic and weak forces. But these methods don't work for QCD at longer distances—say, the size of a proton. This length is, by everyday standards, still very small (the proton, being one-50,000th the size of an atom, has a radius of roughly a millionth of a billionth of a meter). Yet it represents an expanse in particle physics. The problem is that α_s grows too quickly. Before we can reach a fermi, α_s becomes too big for the standard calculation method to be applicable. This is why the (not even very) long-distance domain became Terra Damnata.



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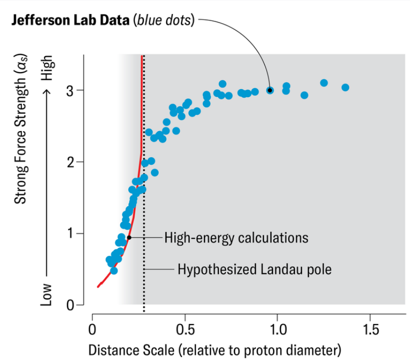
With the usual calculation method unavailable, physicists tried other strategies, but they were either less well tested or imprecise and predicted a long-distance limit for α_s that could lie anywhere between zero and infinity. The usual short-distance calculation method predicts an infinite value of α_s at long range. But this infinity, referred to as the Landau pole after physicist Lev Landau, reveals only that the computational method has failed rather than telling us about the strong force. It was crucial to determine what α_s does at a distance.

A breakthrough has finally emerged from a wide-ranging effort by many physicists. The tale unfolds in three stages, and one of us played a part in each.

The first step was fortuitous. In the late 1990s Deur was a Ph.D. student taking data at the Thomas Jefferson National Accelerator Facility (Jefferson Lab) in Virginia, which houses a particle accelerator. His measurements spanned the transition between short distances and Terra Damnata. At the time, he knew of the Landau pole but not that it was bogus. He was puzzled to see that nothing seemed to happen at the distance where α_s should noticeably change (or so he thought). The data were completely smooth, with no sign of the blowup he had been led to expect. The measurements didn’t seem to bother more experienced scientists, who were accustomed to collecting data in this region, and there are only so many naive questions that students can ask before exhausting their welcome. So he added this issue to the long list of things that he didn’t understand about the world, to be answered (maybe) later, and moved on.



Jen Christiansen

A few years later he used his data and other measurements from Jefferson Lab to measure a quantity called the Bjorken integral, named after James Bjorken, one of the pioneers of strong force studies. The Bjorken integral has to do with the direction of quark spin inside protons and neutrons, and as a bonus, it also provides a relatively easy way to calculate α_s, as long as you stay away from Terra Damnata. So Deur was able to measure α_s on the sure-footed domain of short distances. Being curious and inclined to experiment, he also checked what the formula would predict for long distances. This experiment was just for fun, and he knew very well that he wasn't supposed to take the answer seriously. But his analysis showed that, far from drastically changing as the distance grew, α_s stopped growing and became constant.

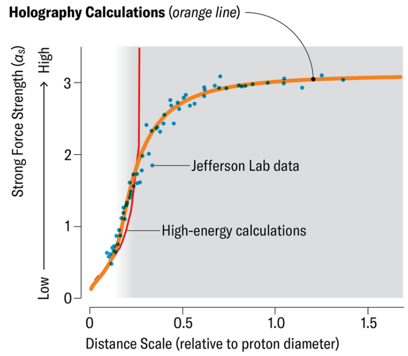
Deur shared this alarming finding with his Ph.D. mentor, Jian-Ping Chen, a Jefferson Lab staff scientist, who remarked that this α_s looked like predictions he'd seen before. Digging into past studies, Deur found other instances of coupling calculations becoming constant at long distances, much like what he saw in his data. Perhaps his playful α_s calculation revealed the strong force's genuine behavior after all? It was a stroke of luck because, although no one had realized it yet, the Bjorken integral is uniquely suited for calculations of α_s at long distances. Whereas most measurements probe interactions among many quarks (because quarks are never found alone), the Bjorken integral manages to filter out most of the multiquark processes and separate out effects on individual quarks. It turns out, this calculation of α_s would not have worked with almost any other type of nucleon data.

Because Deur's α_s possibly made sense, he wondered whether he could show it at physics conferences without too much risk of ridicule. He worried, though, because his measurements seemed to contradict the prevailing wisdom that the intensity of the strong force would keep growing. But he decided to risk it. As it happened, Brodsky attended one of these conferences and helped Deur put the work on firmer theoretical footing. This meeting was the beginning of a fruitful collaboration that continues to this day.

While Deur was exploring α_s experimentally, Brodsky was working with Guy de Téramond Peralta and Hans Günter Dosch to develop a new method to compute QCD properties at long distances. Their strategy uses a mathematical device known as holography (often used to study black holes and gravity) to infer how the strong force behaves with large values of α_s in our four-dimensional spacetime (three space dimensions plus one time dimension) using results from calculations for gravity done in five dimensions. (Whether the extra dimension that underlies this method represents actual physics or is simply a mathematical tool to simplify the problem, much like the use of imaginary numbers in classical physics, no one knows.) This novel approach to the physics of the strong force, so-called light-front holography, can determine α_s at long distances and predict the interactions that confine quarks and gluons within nucleons.

Brodsky had long been acquainted with α_s and knew that attempts to find a unified theory of the electromagnetic, weak and strong forces seemed to require that α_s become finite at long range. In fact, he expected such an outcome because quarks are confined within nucleons, which means quark and gluon quantum loops cannot grow larger than the size of the proton. No more loops means no more evolution of the coupling. So although Deur's measurements of α_s did not surprise him, he was delighted to see that it was, in fact, possible to measure α_s at long distances and that the result showed constancy.

Brodsky and de Téramond Peralta contacted Deur to discuss how to compute α_s using their light-front holography method and went on to calculate it. The result, published in 2010, was gratifying: their α_s matched Deur's experimental data exquisitely. It was all the more remarkable because the calculation had no adjustable parameter. They neither fiddled with settings nor messed with "fudge" factors.



Jen Christiansen

Of course, holography is an exciting, novel approach to quantum chromodynamics (and quantum gravity), but it's not the same as using QCD itself. But we know that it at least models QCD very well, suggesting future physicists might be able to prove some kind of equivalence between the behavior of gravity and the strong force. Still, to feel comfortable saying we'd truly calculated α_s at long distances, we needed a QCD-based computation. A natural approach is to solve the theory's equations of motion, which in QCD describe how all strong force quantities evolve as spacetime changes.

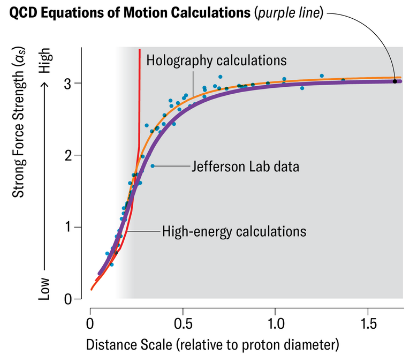
Deur published his first results on α_s in 2005, almost 20 years ago. At the time, Roberts puzzled over them, asking himself what relevance this coupling measurement, seemingly associated exclusively with a single QCD process, could have to the theory's equations of motion. Such equations need a universal coupling that's the same for all processes. He put this question aside and moved on.

Nine years later, during a 2014 meeting that he and colleagues organized at the European Center for Theoretical Studies in Nuclear Physics and Related Areas in Trento, Italy, he returned to Deur's α_s. Until this point, theorists had employed two parallel strategies to use QCD's equations of motion to understand the theory of the strong force. The "top-down" approach tried to predict α_s through the properties of gluons. The "bottom-up" approach aimed to use directly measurable quantities to infer α_s by comparing predictions with experimental data.

At that 2014 meeting, a prominent colleague pointed out that the two approaches were delivering vastly different results that couldn't be reconciled. That colleague, however, was unaware of recent progress with the bottom-up approach that Roberts had made with his collaborator Lei Chang. Within 24 hours, spurred by the challenge, the two had results in hand for the bottom-up coupling estimate. They shared them with two leading players in the top-down area who were also at the meeting, Daniele Binosi and Joannis Papavassiliou, and together the group established that the top-down and bottom-up results for α_s were mutually compatible. The parallel streams were merged.

Now we were left with a key question: How do we connect Deur's coupling measurements and the value we compute using QCD's equations of motion? If we can do that, then we will have bridged the final gap.

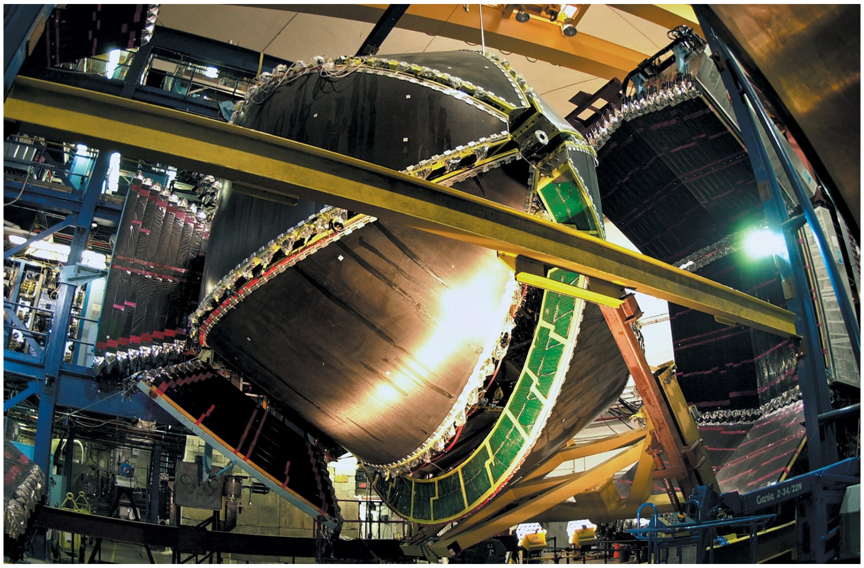
Roberts's next step was to speak with physicist José Rodríguez-Quintero, who had long been working on the top-down approach and had access to results from computer simulations of QCD. After some back-and-forth brainstorming along with Binosi, Papavassiliou and a new team member, Cédric Mezrag, the group arrived at a universal QCD coupling. Amazingly, this result was virtually indistinguishable from both Deur's data and the holography calculation by Brodsky and his colleagues. Moreover, like the holography result, the new prediction was parameter-free: no nudging or tinkering. That fact meant that the agreement was deeply significant.



Jen Christiansen

Since that time, capitalizing on improved information from the top-down, bottom-up and simulation approaches, the group has updated its theoretical analysis. The scientists found that, outside Terra Damnata, their coupling and Deur's data agree to better than 1 percent. Furthermore, moving into Terra Damnata, they discovered that complex interactions between quarks, which could have upset the connection between these couplings, largely cancel out among themselves because of the physical features of the processes underlying the Bjorken integral. This was Deur's stroke of luck: he had serendipitously chosen the one process whose coupling is most closely related to the universal result derived from QCD's equations of motion.

Now, for the first time, we have both compelling data and calculations of α_s that cover the entire length-scale range, including Terra Damnata, the previously unreachable territory. The key finding is that as the distance grows greater, the coupling stops growing, and the inconstant constant becomes constant once more. This discovery has profound implications.



The CEBAF Large Acceptance Spectrometer took some of the measurements that helped to define the strong force at a scale never possible before.
Courtesy of Jefferson Lab

First, knowing α_s at all distances is practically important: physicists can now analytically predict numerous quantities that were previously out of reach. Most phenomena relating to the strong force in nature, from the deepest structure of the atoms within us to the inner workings of neutron stars, are determined by the strength of α_s. Because this coupling is dominated by its long-range behavior, which we now know to be finite rather than infinite, we have opened up a new world of possible calculations.

At a deeper level, the solutions of QCD’s equations of motion help to reveal the origin of 99 percent of the visible mass in our universe. This mass comes from atoms, and most of the mass of atoms is in their protons and neutrons (electrons are relatively light). But where does proton and neutron mass come from? The quarks that constitute them also have very little mass of their own. But at the scale of a proton, our revelations about α_s suggest that quarks gather clouds of gluons around them that generate much of the mass of the proton. In essence, the powerful binding energy that the strong force exerts to bind quarks together contributes almost all of the mass (remember, Albert Einstein revealed that energy and mass are two sides of the same coin). Therefore, if you weigh 160 pounds, then more than 158 of them come from quantum chromodynamics, specifically because of the mechanism that freezes α_s into a constant. The Higgs boson contributes only the small remainder—the tiny mass the quarks and electrons possess on their own.

Even more significantly, the static nature of α_s at long distances means that QCD is the first full quantum field theory that predicts only finite quantities. All the other known quantum field theories, including quantum electrodynamics (which describes the electromagnetic force), run into infinite Landau poles at very high energies. As such, QCD may lead the way to explaining many phenomena that lie outside our current understanding.

Pursuing this line of reasoning, we may learn, for example, whether string theories with 10, 11 or 26 dimensions of spacetime are necessary to make sense of our universe or whether, instead, a clear understanding of our solidly established four spacetime dimensions will turn out to be sufficient. The excitement right now among nuclear and particle physicists is tangible.

Stanley J. Brodsky is a theoretical physicist and emeritus professor at the SLAC National Accelerator Laboratory at Stanford University.

Alexandre Deur is a research scientist at the Thomas Jefferson National Accelerator Facility in Newport News, Va.

Craig D. Roberts is a theoretical physicist at the School of Physics at Nanjing University, where he leads the Institute for Nonperturbative Physics.

Why Feathers Are One of Evolution’s Cleverest Inventions

Fossil and living birds reveal the dazzling biology of feathers

By Michael B. Habib

Bar-tailed Godwits undertake the longest nonstop migration of any land bird in the world. rockptarmigan/Getty Images

In October 2022 a bird with the code name B6 set a new world record that few people outside the field of ornithology noticed. Over the course of 11 days, B6, a young Bar-tailed Godwit, flew from its hatching ground in Alaska to its wintering ground in Tasmania, covering 8,425 miles without taking a single break. For comparison, there is only one commercial aircraft that can fly that far nonstop, a Boeing 777 with a 213-foot wingspan and one of the most powerful jet engines in the world. During its journey, B6—an animal that could perch comfortably on your shoulder—did not land, did not eat, did not drink and *did not stop flapping*, sustaining an average ground speed of 30 miles per hour 24 hours a day as it winged its way to the other end of the world.

Many factors contributed to this astonishing feat of athleticism—muscle power, a high metabolic rate and a physiological tolerance for elevated cortisol levels, among other things. B6's odyssey is also a triumph of the remarkable mechanical properties of some of the most easily recognized yet enigmatic structures in the biological world: feathers. Feathers kept B6 warm overnight while it flew above the Pacific Ocean. Feathers repelled rain along the way. Feathers formed the flight surfaces of the wings that kept B6 aloft and drove the bird forward for nearly 250 hours without failing.

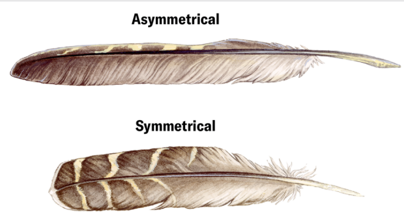
One might expect that, considering all the time humans have spent admiring, using and studying feathers, we would know all their tricks by now. Yet insights into these marvelous structures continue to emerge. Over the past decade other researchers and I have been taking a fresh look at feathers. Collectively we have made surprising new discoveries about almost every aspect of their biology, from their evolutionary origins to their growth, development and aerodynamics.

Among the creatures we share the planet with today, only birds have feathers. It makes sense, then, that for centuries scientists considered feathers a unique feature of birds. But starting in the 1990s, a series of bombshell fossil finds established that feathers were widespread among several lineages of the bipedal, carnivorous dinosaurs known as theropods and that birds had inherited these structures from their theropod ancestors. The discovery of feathered nonbird dinosaurs sent researchers scrambling to understand the origin and evolution of feathers, especially their role in the dawn of flight. We now know many dinosaurs had feathers, and protofeathers probably go all the way back to the common ancestor of dinosaurs and their flying reptile cousins, the pterosaurs. Bristles, fuzzy coverings, and other relatively simple featherlike structures probably decorated a wide array of dinosaurs—many more than we have been lucky enough to find preserved as fossils.

Feathers, such as those of the Lesser Flamingo shown here, are products of hundreds of millions of years of evolution. Robert Clark

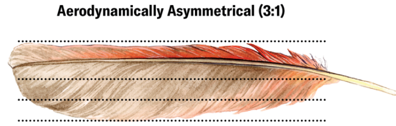
The feathers on nonbird dinosaurs were not limited to bristles and fuzz, however. The flat, broad, flight-enabling feathers we see across most of the wings and much of the body surface of living birds are called pennaceous feathers. (Fun fact: these are the feathers people used to make into quills for writing, hence the word "pen.") It turns out that these feathers, too, appeared before birds. In fact, there is an entire group of dinosaurs comprising birds as well as species such as *Velociraptor* that takes its name from these very feathers: the pennaraptoran clade. Fossils of early pennaraptorans show that they had feathery coverings that would have looked essentially modern at a quick glance.

The flight capacity of these early pennaraptorans has been hotly contested. Some species were clearly not fliers, given the small size of their “wings” relative to their large bodies. For those animals, pennaceous feathers were probably display pieces. But other pennaraptorans, such as the small, four-winged, forest-dwelling *Microraptor*, are trickier to interpret. Many of the arguments about whether this creature could fly have centered on something called vane asymmetry. The two flat “blades” of a feather on either side of the main shaft are called vanes. In living birds that fly, the feathers that arise from the hand, known as the primaries, have asymmetrical vanes: the leading vane is narrower than the trailing one. It stood to reason that vane asymmetry was important for flight. And because fossils of *Microraptor* and its kin show asymmetrical feathers, some researchers argued, these animals must have been able to fly.



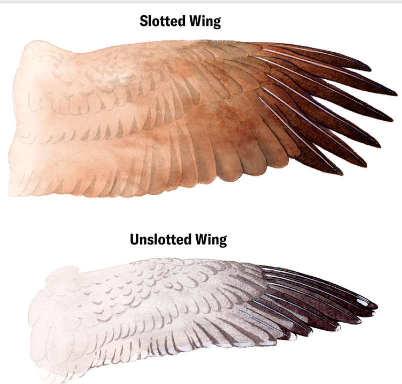
Maria Amorette Klos

Recent work by flight biomechanics experts, including me, has overturned this received wisdom about feather vane asymmetry. Our research shows that feather shape is largely optimized to allow the feather to twist and bend in sophisticated ways that greatly enhance flight performance. Merely being anatomically asymmetrical doesn’t mean much. What matters is that the feather is *aerodynamically* asymmetrical, and for this to be the case, the vane asymmetry must be at least three to one—that is, the trailing blade needs to be three times wider than the leading one. Below this ratio, the feather twists in a destabilizing rather than stabilizing way during flight.



Maria Amorette Klos

Early pennaraptorans such as *Microraptor* didn't have aerodynamically asymmetrical feathers. But that doesn't mean they couldn't fly. The tendency to twist (whether in a stabilizing or a destabilizing fashion) is only relevant if the feathers are separated enough to do so. Keeping feathers in a wing tip tight and overlapping makes them stable, even if they're not asymmetrical. Asymmetry matters only if the flier spreads its primaries apart in flight like many modern raptors do—a feature called slotting. So *Microraptor* and its kin could probably use flapping flight, but their wing shape was necessarily different from that of today's forest-dwelling birds of prey. Specifically, *Microraptor* had relatively long, narrow wings with tight, unslotted wing tips—anatomically distinct from the wings of Cooper's Hawks and other modern-day forest hawks but aerodynamically similar.



Maria Amorette Klos

After considering these findings on vane asymmetry, as well as new data on flight muscles in near-bird dinosaurs, a group of researchers (of which I was the senior biophysicist) led by Michael Pittman of the Chinese University of Hong Kong recently concluded that powered flight—that is, flapping flight rather than gliding flight—probably evolved multiple times in dinosaurs, with just one of those lineages surviving to the present in the form of birds. Yet only in birds did flight feathers attain the degree of shape-shifting we see today. That ability of feathers to twist in just the right way is what enabled slotting, which makes the wing much more efficient at low flight speeds. In essence, a slotted wing behaves as if it is longer and narrower than it is anatomically. Slotting also makes the wing tip very resistant to stall, whereby the airflow separates from the wing, causing a precipitous loss of the lift that keeps the bird in the air. It’s a vital adaptation that underpins an array of aerial acrobatics.

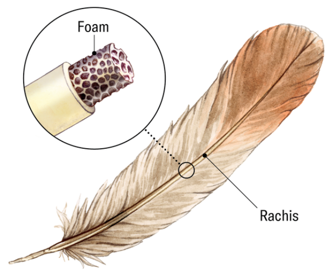
Birds typically need long, narrow wings to soar efficiently—seabirds such as albatrosses and petrels are perfect examples. The advent of wing-tip slots made it possible to soar with broader wings, paving the way for evolution of a diversity of broad-winged soarers, including vultures and hawks. The aerodynamic advantages of slotting also permit the explosive flight performance of sprinters such as grouses, which spend most of their time on the ground but burst into flight for a short distance when startled. And wing-tip slots provide much greater maneuverability for a wide array of birds that live in forests and other cluttered environments, from songbirds to toucans. In fact, the maneuverability made possible by slotted wings might have helped birds compete with pterosaurs and ultimately survive the end-Cretaceous extinction.

The pennaceous feathers we associate with flight aren’t the only type of feather birds possess. Feathers in different regions of the body vary in size, shape and function. You can think of feather form as a spectrum, with the large, relatively stiff flight feathers of the wing and tail at one end and the short, fluffy down feathers that sit close to the body at the other. All of them have a central shaft and softer “barbs” that branch out from the shaft. In flight feathers, the barbs interlock like Velcro teeth to form the smooth, windproof surface of the vanes. In down feathers, the barbs are loosely structured and fluffy to trap heat. Many of the other kinds of feathers combine aspects of these two types. The contour feathers that streamline a bird’s body, for example, have vaned tips like flight feathers and noninterlocking barbs like down ones. The bristle feathers that typically occur on the face and may serve protective and sensory purposes meld the flight feathers' stiff shafts (called rachises) with the down feathers' fluffy base.

The wing of the Greater Prairie-Chicken, a type of grouse, has a slotted tip that helps the bird burst into flight when startled.
Robert Clark

In recent years researchers have begun to piece together the intricate process by which feathers develop. Like scales, spines and hairs, feathers are skin appendages. Scientists have known for a while that they arise from structures in the skin. But how can an animal produce feathers with different anatomies across its body?

My colleagues and I, led by Cheng-Ming Chuong of the University of Southern California, related the developmental biology of various kinds of pennaceous feathers to their mechanical properties. These feathers begin as a tube that essentially unzips along its length, forming the two vanes. Several genes and molecules interact with one another and with the environment to determine the amount of interlocking in the barbs that make up the vanes, the size and shape of the rachises, and whether the shaft is filled with a "foam" that makes it stiff relative to its weight. We found that different feather types have varying specializations in their overall stiffness, their tendency to twist, and the distribution of the foam in the shaft. These variations depend to some extent on the work of different genes, but most of the differentiation is the result of changes in how the genes are regulated—that is, when they are turned on or off or how active they are during feather development.



Maria Amorette Klos

Scientists have also shown a recent surge of interest in another category of feathers: display feathers, the showy feathers that help to attract mates. Display feathers may dazzle an observer with their colors (think of a hummingbird's glittering throat), or they may attain eye-catching proportions, like the feathers that make up a peacock's crest and train. The conventional wisdom about display feathers holds that they are strictly products of sexual selection, in which mate choice drives the evolution of a trait. These days, however, researchers around the globe, me included, are coming to see display feathers not as exclusively sexually selected traits with no mechanical properties of interest but instead as complex compromises between the pressures of social biology and mechanobiology.

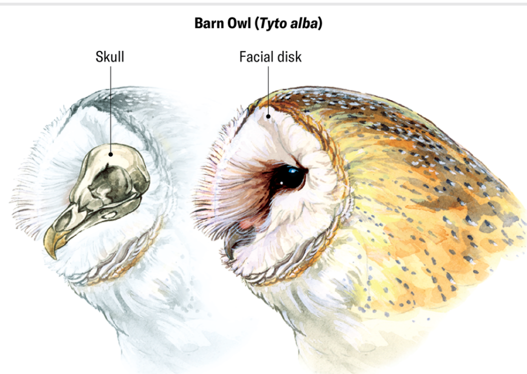
To wit: long display feathers don't grow just anywhere on the body. They most often occur on the lower back and tail, where they interfere comparatively little with flight performance. Take, for example, the Resplendent Quetzal, a small, colorful bird native to the cloud forests of Mexico and Central America with tail feathers that can grow up to three feet long on males during the breeding season. The tail streamers might not be shaped solely by sexual selection. Evidence indicates that the streamers of some birds produce at least a little aerodynamic force, enough to support much of their added weight. The quetzal’s streamers, for their part, lost their tight interlocking structure, making the vanes a pennaceous-downy hybrid that lets much of the airflow pass through without producing much lift. This arrangement is most likely an adaptation to prevent these feathers from being highly destabilizing. These flashy feathers still increase the cost of flying because they add drag, but that cost may well be less than has been assumed.

The Barn Owl‘s primary feathers have features that allow this bird of prey to fly silently.
Robert Clark

The microstructure of display feathers, especially tail streamers, may also be more finely tuned than previously thought. Feather structure provides a balance of stiffness, weight and shape. The feathers must hold their shape well enough, even at extreme lengths, to be effective signals. But they cannot be so stiff as to destabilize the bird during gusty winds or tight maneuvers. There's a particular range of flexibility that shows off the feather to best effect while minimizing detrimental impacts on flight performance.

One of the aspects of feathers that has long fascinated me is their adaptability. Under varying conditions and evolutionary pressures, they can become specialized for everything from speed and maneuverability to insulation or display. Some of the most fascinating adaptations can be found in owls.

Facial disks are an especially conspicuous feature of owls. These broad, semicircular fans of feathers around the eyes and ears give owls their distinctive appearance. The skull of an owl is actually quite long and narrow, but the feathers enveloping it completely change the contours of the animal. These facial disks are not just for looks. They do a remarkably good job of funneling sound to the owl's ears. The disks, along with vertically offset ears and exceptionally sensitive middle and inner ear structures, make owls so good at determining the origin of a sound that they can zero in on prey without seeing it at all (they still use vision to make the final capture, though).



Maria Amorette Klos

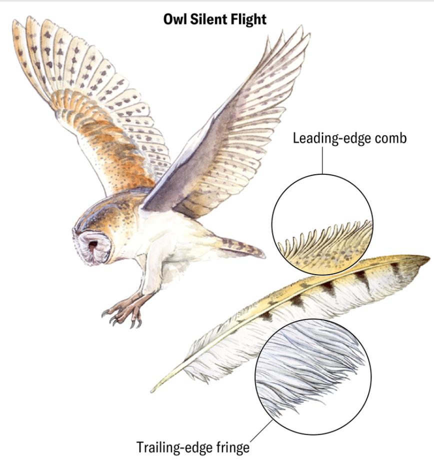
I have worked with quite a few owls over the years, particularly individuals being rehabilitated after injury. One such owl couldn’t be released because a car strike had left him completely blind. Yet if someone tossed food onto one of his perches, the gentle thud of it landing was enough for him to pounce on it perfectly. (Readers may also find solace in knowing that he still flew, having memorized his enclosure, and was regularly taken around for walks and neck scratches.)

Still, that exceptional sense of hearing wouldn’t get owls very far without some additional feather adaptations. Other nocturnal creatures can also hear very well, and an owl whose feathers were rustling in flight would be hard-pressed to get close to its vigilant prey. Furthermore, owls might not hear quietly creeping prey if their own feather sounds covered the faint noises of their targets. Owls solved both problems by evolving feather traits that make them inaudible during flight.

The extremely stiff feathers of hummingbirds such as Anna’s Hummingbird help to support their distinctive, hovering flight.
Kathleen Reeder Wildlife Photography/Getty Images

It is hard to appreciate just how quiet owls are. Even ultrasensitive microphones, if properly calibrated, aimed exactly right and set to maximum sensitivity in a silent space, can just barely pick up sounds from a flying owl ... sometimes. For all practical purposes, owls are silent. They are so eerily noiseless that even if they fly over your head close enough for you to feel their wake, you will still hear absolutely nothing. In a dark space, they are essentially undetectable. All the owl wing sounds you hear in the Harry Potter movies and other films? Those are added in.

Owls achieve this stealth with a few different feather adaptations. To start, their feathers have a "velvety" surface that silences them when they move against one another. More important, the feathers on the leading edge of an owl's wing have a set of comblike structures, whereas those on the trailing edge have fluffy fringes. The leading-edge comb stirs the air in a specific way called micro vorticity. These tiny, swirling streams of air cause the main flow to stick to the wing. In aerodynamic speak, we say the combs "inject vorticity into the boundary layer." When this modified flow then passes through the trailing-edge fringes, the net result is a wake that contains no coherent waves of linear pressure and therefore no sound. Put another way, there are no vibrations from the interactions between feathers and the air capable of producing sound.



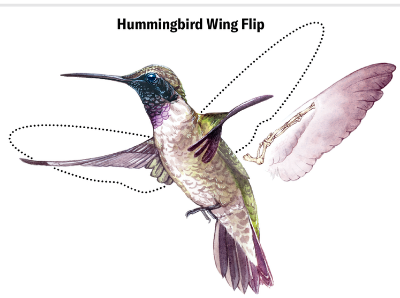
Maria Amorette Klos

These specializations have deep roots. Modern-day owls belong to one of two groups: the tytonids (represented by Barn Owls and Bay

Owls) and the strigids (all other living owls). Their last common ancestor existed at least 50 million years ago. Because owls in both groups exhibit silent flight, this trait probably dates to their common ancestor. In other words, owls have been surreptitiously coursing the night skies for more than 50 million years.

Not surprisingly, some of the most extreme feather adaptations are found in birds with the most extreme ecological specializations. One way feathers can adapt to a particular way of life is by increasing or decreasing in stiffness. Coincidentally, the stiffest feathers are found in two groups of birds that are otherwise as different as can be: hummingbirds and penguins.

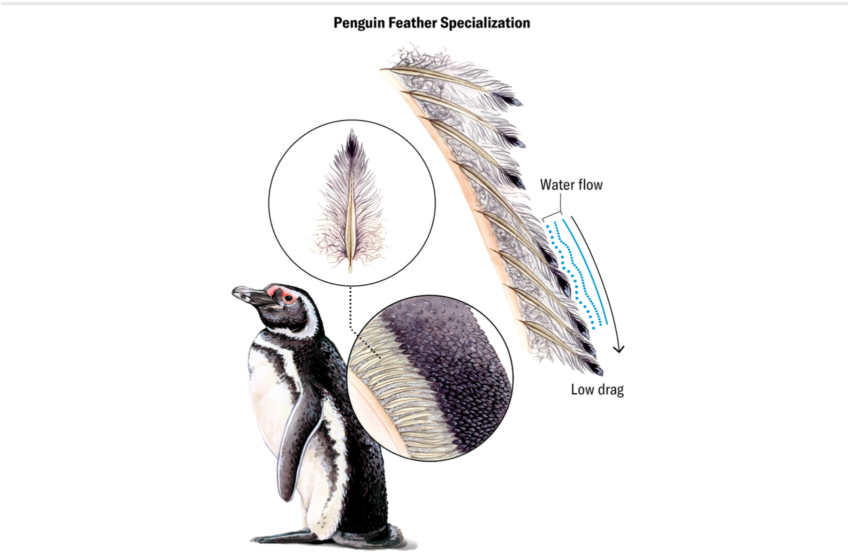
Hummingbirds have ultrastiff feathers as an adaptation to the exceptionally high flapping frequencies and unusual flapping stroke they use to hover in front of flowers while sipping nectar. Unlike most birds, hummingbirds can get a substantial amount of weight support and thrust from their upstroke, not just their downstroke. They do this by rotating their shoulder to flip the wing over completely. The wing needs to be very stiff for this method to work. Reinforcements in the bones of the hummingbird wing provide some of this rigidity; feathers with extremely firm rachises provide the rest.



Maria Amorette Klos

The flightless penguins, in contrast, have adapted to life in the water and on land. They possess some of the most specialized plumage of all, having converted their entire body covering into a densely packed mosaic of tiny feathers. These feathers are individually quite stiff, and together they form a textured surface over the wings and body that regulates the boundary layer of water against them while the penguin is swimming. In essence, they use a rough coat of feathers to catch and hold a smooth jacket of water. The net effect is a reduction in drag and therefore a lower energetic cost of swimming. The dense feathers also trap just enough air to provide some insulation without making the penguin buoyant, supplementing the fat layer that helps to keep the bird warm.

In the absence of any constraints posed by flight, penguins jettisoned the more typical feather accoutrements of their ancestors in favor of a novel suit of drag-reducing, minimum-buoyancy feathers. These feathers are a key part of the package of adaptations that have made penguins the undisputed diving champions of the avian world, capable of reaching depths of more than 1,600 feet in search of krill, fish, and other aquatic prey.



Maria Amorette Klos

Feathers are a fantastic model system for understanding how complex structures evolve and how anatomy and behavior influence each other over time. It’s no wonder that the applied science sector has taken note of feathers’ many brilliant features. Already they have led to successful technological innovations. The Velcro-like mechanism that connects the barbs of pennaceous feathers is the basis for an advanced temporary fastening system. The silencing fringes of owl feathers have inspired ventilation-quieting systems. The surface texture and boundary-layer-control principles of penguin feathers have made their way into robotics, mostly in prototypes.

No doubt feathers will give rise to more clever inventions in the future. We have only to let our creativity take flight.

Long display feathers may be present on the wings, as happens in the Standard-winged Nightjar (*left*) and Pennant-winged Nightjar (*right center*). But they usually grow on the lower back and tail, which minimizes any negative impact on flight, as in the Stephanie's Astrapia (*left center*) and Resplendent Quetzal (*right*).
Robert Clark

Michael B. Habib is a paleontologist and biomechanist at the Natural History Museum of Los Angeles and the University of California, Los Angeles. He studies the anatomy and motion of

pterosaurs, birds and feathered dinosaurs.

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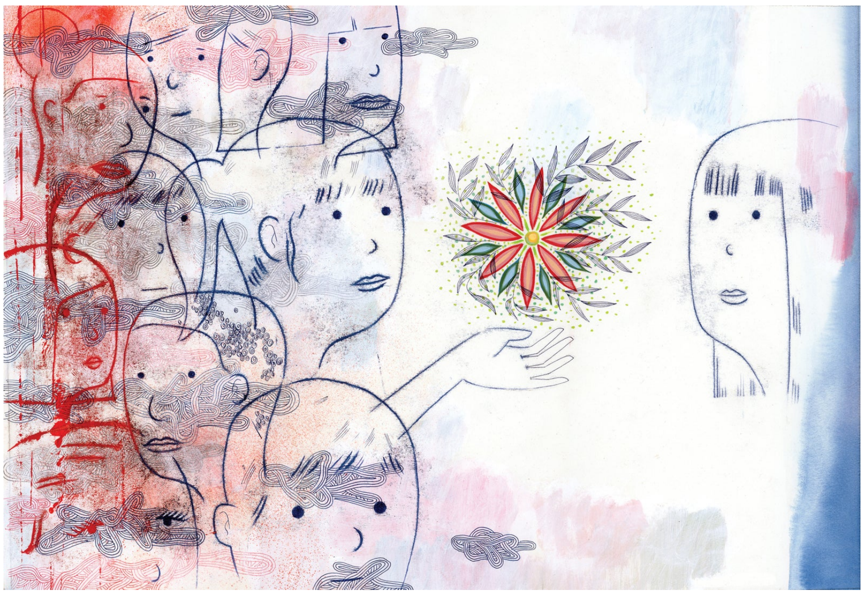
The Science of Reducing Prejudice in Kids

Making schools more welcoming for all can make for a fair and just society

By Melanie Killen



Scott Bakal

Children, like adults, want to be fair and kind. At the same time, they can be quick to reject those they perceive as different. How does this contradiction arise? And how can we help children develop a sense of morality and justice?

“One time—this was, like, a long time ago—I was new in this school, but these people at the school used to judge me because of my skin color and used to disclude me and make fun of me,” Alex, a student of about 10, said to classmates as part of a study my colleagues and I conducted. (Students’ names have been changed for confidentiality.) “I wanted to be their friend. I kind of just, like, ignored them, but they still found a way to get to me. So, like, every single day I went crying to my mom and told her what happened. She just told me to ignore them, but that didn’t help, and it just, like, escalated to the point where I had to see a counselor and stuff.”

For many children, discrimination inflicts anxiety and misery and interferes with their learning. Schools could be far more welcoming than most now are, and I and other developmental psychologists have an idea of how to help them get there.

After decades of investigating children’s moral development, my colleagues and I have come to understand the reasoning children use to deal with the dissonance between their desire to be fair and their need to belong to friend groups. And we’ve figured out how to help them think through and share their views, particularly about what makes social exclusion unfair and why it’s necessary to stand up against stereotypes and biases.

We recently tested our intervention in a randomized, controlled trial, the gold standard for evaluating medical and social treatments, in a Maryland school district. The program significantly improved children’s ability to place themselves in one another’s shoes; enhanced their reasoning in moral conflicts; and helped to foster friendships across boundaries of ethnicity, class and gender. The intervention facilitated Alex’s sharing, after which another student related their experience of exclusion. Responding with empathy and support, the class talked about how to resolve such situations.

Such training and discussions not only help to reduce children's prejudices but also burnish their ability to resolve conflicts and make school less stressful. Most important, they have the potential to make future societies more just and caring. As kids grow into adults, their ideas of "us versus them" too often harden into prejudices—and that has consequences. If George believes as an elementary school student that boys are better than girls at science, it could influence whom he invites to join the science club in middle school, as well as what he thinks as an adult about whether women can be good doctors, scientists or pilots. Our program shows kids how to challenge such stereotypes with the hope of making society better for everyone.

How do people acquire a sense of justice, and how early does it emerge? Pioneering Swiss psychologist Jean Piaget observed children's play in search of answers to such questions. He wanted to understand how they develop precepts such as "do unto others as you would have them do unto you," formalized by philosopher Immanuel Kant as the "categorical imperative." In his 1932 book, *The Moral Judgment of the Child*, Piaget reported that even to children, intentions matter: one kid might injure another, but if it was an accident, no one was at fault. To kids, treating others with equality and respect is a matter of justice.

This robust foundation led to studies in multiple countries on how moral thinking emerges. Developmental scientists now know that it starts early: babies as young as eight months old who witness one puppet trying to climb a hill while other puppets either help or get in the way prefer the helpers to the hinderers. Such preferences, based on early forms of empathy, are not yet explicit moral judgments; those show up a couple of years later. By age three, children understand that hurting others is wrong. By age five, they start to share candy equally. Even some animals have a sense of what is wrong, as ethologist Frans de Waal of Emory University and others have demonstrated. In an experiment de Waal conducted with Sarah F. Brosnan, now at Georgia State University, a capuchin monkey became furious when she got a piece of cucumber as a reward for handing the experimenter a rock while another monkey instead got a real treat: a grape.

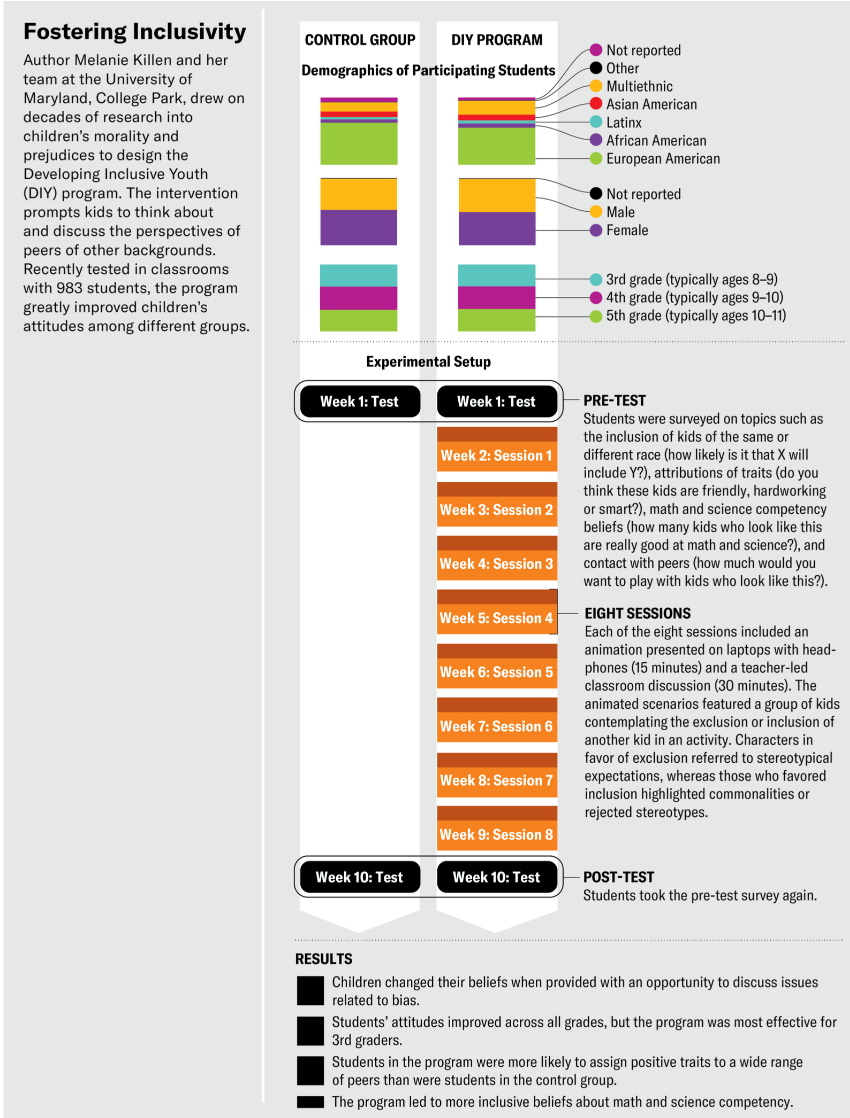
Children, like capuchins, are social beings, but human morality is exceedingly complicated and requires time to fully develop. As kids grow, family, friends, and others can help them understand why fairness and justice matter. My own lifelong interest in social justice may have something to do with my mother, who was active in the Civil Rights Movement in the 1960s, and my grandfather, who was a leader for workers' rights in San Francisco during the early 1950s. Growing up in Berkeley, Calif., I attended schools with almost equal proportions of Black, white and Asian students. When I went to college in Worcester, Mass., to study child psychology and moral development, I was surprised to discover that friend groups and dating circles were often segregated by race and ethnicity. I now think these influences contributed to my desire to understand how morality might win out over prejudice.

As an undergraduate, I worked with developmental psychologist William Damon, then at Clark University, on one of his studies of how fairly children divide up resources. In these experiments, chocolate bars were given to students as a reward for making bracelets. Young children often gave more bars to kids of their own gender and age, but by nine or 10 years old they either divided them up equally or gave more to those who had made more bracelets.

During my graduate studies at the University of California, Berkeley, I learned that adults make decisions about morality in the context of group conventions and cultural rituals. Curious about how children would react when rules and norms conflicted with morality, I worked with my thesis adviser, developmental psychologist Elliot Turiel, to offer children hypothetical scenarios and ask questions. If a team captain has to fetch a runaway ball for their team to stay in a tournament, should they do it even if it means ignoring the fact that a little kid is being bullied nearby? Younger children focused on getting the ball, but nine- or 10-year-olds were more willing to violate a convention—the obligation to take care of the team by retrieving the ball—to help the bullied child. As one student said, “Someone could get hurt, and even though you don’t win anything, it’s still good to see that human beings don’t fight.”

These studies made me wonder what happens when a kid’s friends are doing something wrong—rejecting or harassing another kid because of their ethnicity, for example. At the time, very few researchers were studying prejudice in childhood. Social psychologists began studying prejudice in the 1950s because of the dire need to understand how the Holocaust happened. In his book The Nature of Prejudice (Addison-Wesley, 1954), psychologist Gordon W. Allport argues against the idea of an “evil” leader being singularly responsible for that horror, instead focusing on how most Germans had clustered around a shared national identity to the exclusion of Jews, Communists, and others whom they perceived as different and threatening.

It was group dynamics rather than individual psychology that held the key to understanding prejudice, Allport postulated. He elucidated the mechanisms that fostered and maintained group loyalty (such as propaganda campaigns) and pointed out that intergroup contact based on common goals, cooperation, equal status and the support of authorities could reduce prejudice.



Jen Christiansen; Source: "Testing the Effectiveness of the Developing Inclusive Youth Program: A Multisite Randomized Control Trial," by Melanie Killen et al., in *Child Development*, Vol. 93, No. 3; May/June 2022 (*reference*)

But how do prejudices emerge in the first place? After moving to the University of Maryland in 1994 as a professor of human development, I teamed up with Charles Stangor, a member of the school's psychology department, to study how groups of kids acted when race and gender came into play. Children didn't always apply their ideas of fairness, we found, when they conflicted with the kids' group identity. For example, they thought it was wrong to exclude a boy from a ballet club but also said the other kids "would think that John is strange if he takes ballet." Kids rarely referred to stereotypes when responding to situations of exclusion involving race, however. Clearly, we had to investigate gender- and race-based exclusion differently.

In the early 2000s Martin D. Ruck of the City University of New York, David S. Crystal of Georgetown University and I learned that compared with teenagers who attended homogeneous schools, those who went to more racially diverse schools and had friends of other races and ethnicities were more likely to see race-based exclusion, such as having friends or dates only of the same race, as unfair.

These investigations showed that children identify with groups as early as preschool. These alliances provide social support, camaraderie and protection from bullies. But what happens when being a member of one group means going along with unfair treatment of someone from an out-group? With Adam Rutland of the University of Exeter and Dominic Abrams of the University of Kent, both in England, and my then graduate students Kelly Lynn Mulvey, now at North Carolina State University, and Aline Hitti, now at the University of San Francisco, I started studying how children navigate conflicts between their group affiliations and their sense of justice. When did children and adolescents recognize that their group might be doing something unfair? Would they tell their group that it was wrong, or would they just go along with it?

We showed children of diverse ethnic and racial backgrounds attending Maryland public schools picture cards and asked, for example, whether they thought it was all right for a kid in the picture (named, say, Jordan) to speak up if their after-school club was distributing money unfairly between itself and another club at school. Children between eight and 10 years old were more likely to think that Jordan would tell their friends they were doing something unfair and that those friends would then agree to do the right thing. More important, older children, aged 12 to 14 years, said it was okay for Jordan to tell their friends they were doing wrong, but the group would be unhappy and would probably exclude them. In other words, as they grew older, children came to recognize the cost of arguing against a group norm—a significant obstacle to challenging injustice.

So, for instance, a kid who wants to intervene when their group is teasing a friend of another religion or ethnicity might hesitate to act because they anticipate being kicked out. Further, if they did get rejected, they could be viewed as an outcast by others, adding to the penalty for challenging the norm. Offering hope, however, some kids were skilled at thinking about how to persuade their group to change for the better.

These studies made us wonder whether children would also favor their own group when sharing resources. In one study, led by my then graduate student Laura Elenbaas, now at Purdue University, we asked children whether it was okay that a school attended by Black students got fewer school supplies than a school attended by white students (and vice versa). We also gave them books and other supplies and asked them to divide the items between the schools.

All the kids thought it unfair for one school to get less. But when it came to actually distributing the supplies, younger children had an "in-group bias." Five- to six-year-olds gave more to the schools that had less to begin with, but they were more likely to give when the disadvantaged school was attended by kids of their own race. In contrast, when giving to schools that had less to begin with, the 10- to 11-year-olds gave more supplies to the schools with Black students than to the schools with white students because, as one kid said, "I've often seen that they have less when others have more."

Surprisingly, there were no differences based on race and ethnicity of the children when it came to giving more to Black schools. A parallel study with my former graduate student Michael Rizzo, currently at the University of Illinois Urbana-Champaign, similarly revealed that a kid's gender made no difference in how they allocated stickers: they gave more to boys (not girls) who made “blue monster trucks” and to girls (not boys) who made “pink princess dolls.” But as they got older, they allocated more equally.

Regardless of race and gender, kids struggled to prioritize what was right and just over their prejudices and in-groups. The good news was that as children matured, they moved toward what was fair.

Putting together the lessons garnered over decades of research, our team developed what we referred to as the social reasoning developmental model of how children weigh fairness in the context of group dynamics. Morality is more than recognizing that treating someone differently because of their skin color, gender or religion is unfair, we postulated. It requires understanding that systemic biases create disadvantages for certain groups and recognizing when it is necessary to level the playing field.

Using this model, we formulated a set of further questions to understand how to help children become resisters of injustice, or “agents of change.” What factors enabled them to reject unfair treatment of others? And because each child belongs to multiple groups, what happens when these identities come into conflict? It’s not only race and ethnicity but also wealth that confers status, for instance. Which matters more when it comes to exclusion? To answer this question, Amanda R. Burkholder, now at Furman University in South Carolina, and I asked children aged eight to 14 to pick a new member of their club. Children predicted that their peers would pick someone of similar wealth even if they were of a different race, indicating that economic class was a better predictor of common interest than race.

By 2015 we felt we knew enough about children’s moral development to design a program to reduce bias and prejudice, promote friendships across social boundaries and help kids stand up to the unfair treatment of others. Above all, we wanted a program that dealt with children’s own experiences rather than the hypothetical scenarios we’d used in our basic research.

Our intervention program, called Developing Inclusive Youth, offers scenarios involving a morally complex situation and gives children a chance to think through their response and then discuss it with their classmates. After initial testing, we coupled this program with training for elementary school teachers on creating a safe space for classroom discussions so children could think and speak for themselves without being pushed toward any particular ideas.

During the program, elementary school kids between eight and 11 years of age gather in a classroom once a week for eight weeks. Each week they interact with an animated online tool to reflect on and discuss a different type of inclusion or exclusion based on gender, race (Black or white), ethnicity (Asian, Arabic or Latinx), immigrant status or wealth status.

First they get a laptop, put on headphones, then watch 15 minutes of a vignette. As an example, the program might present a situation in which a girl wants to work on a science project with a group of boys. One boy says girls aren’t good at science. Another challenges this notion, saying his sister is good at science. What should they do? After the students watching the program have privately entered their responses, the teacher leads them in a 30-minute discussion while they sit in a circle in the classroom.

During one such session on science and gender, a student shared this story: “I think it was at the University of Maryland summer camp ... we were all inside the dining hall eating dinner, and we saw some older kids do arm wrestles. So [one girl] went up to them and was like—she went up to a boy and was like, ‘Hey, do you want to arm wrestle?’ And then he’s like, ‘You’re a girl; you can’t beat me.’ She ended up crushing him!”

The class yelled in glee, asking how many seconds it took. Then another student offered, “Yeah, at my dad’s work, they’re getting the boys the best jobs and the girls the worst jobs” with less money, after which a third student said, “That’s really unfair!”

The randomized, controlled trial showed that children who went through this program were more likely to view exclusion as wrong; think of children of other groups as nice, hardworking and smart; and have higher expectations about the math and science abilities of children outside their race, ethnicity or gender. Further, they were more eager to play with kids who were different from them and reported fewer social rejections. Many teachers told us they learned new things about their students and became closer to them; the class bonded together more, and, most encouragingly, the students applied what they learned to new contexts, such as when the class read a news article.

Implemented widely, this program has the potential to better equip future generations to stand up to injustice. As one student put it, “No matter who you are, you’re just—you’re part of the civilization. You’re part of humanity. You’re not, like, an alien from another planet.”

Melanie Killen is a professor of human development and quantitative methodology at the University of Maryland, College Park. She studies the emergence of morality and prejudice and is a member of the National Academy of Education.

Quiet! Our Loud World Is Making Us Sick

Experts describe ways to turn down the volume, from earbuds to smartphone apps that detect harmful noise levels

By Joanne Silberner

The Niobrara National Scenic River in Nebraska is a place where people can spend a long time hearing only natural sound at low volumes.
marekuliasz/Getty Images

Ten years ago Jamie Banks started working from her home in the town of Lincoln, Mass. After a couple of months, the continuing racket from landscaping machines began to feel unendurable, even when she was inside her home. “This horrible noise was going on for hours every day, every week—leaf blowers, industrial lawnmowers, hedge trimmers,” she says. The sound of a gas-powered leaf blower outside can be as loud as 75 decibels (dB) to someone listening from inside a house—higher than the World Health Organization cutoff to protect hearing over a 24-hour period. “I started thinking, this can’t be good,” she says. “It’s definitely not good for me. It certainly can’t be good for the workers operating the equipment. And there are lots of kids and lots of seniors around. It can’t be good for them either.”

Banks is a health-care specialist and environmental scientist who has worked most of her life as a consultant on health outcomes and behavior change for government agencies, law firms and corporations. She decided to do something about her situation and got together with a like-minded neighbor to pester the town government. It took the pair seven years to get their town to do one thing—ban gas-powered leaf blowers during the summer. The process was long and frustrating, and it made Banks think about going bigger and helping others.

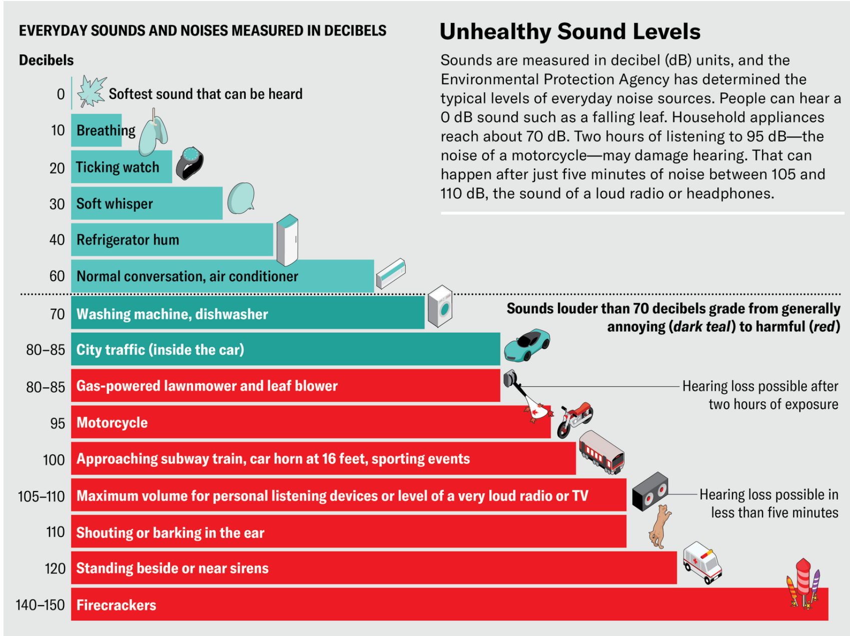
So she did. In June 2023 Quiet Communities, a nonprofit group that Banks founded and runs, sued the U.S. Environmental Protection Agency for not publishing or enforcing rules and regulations to limit loud sounds: unmuffled motorcycles, cacophonous factories, the thunder of an airplane just overhead, the roar of an elevated train, the scream of a soundtrack in a spin class, headphones set too loud. There is a federal law that calls for the EPA to do this, but it hasn't been enforced for more than 40 years.

Banks's idea that loud noise "can't be good" is well supported by science. Noise can damage more than just your ears. Through daytime stress and nighttime sleep disturbances, loud sounds can hurt your heart and blood vessels, disrupt your endocrine system, and make it difficult to think and learn. The World Health Organization calculated that in 2018 in the European Union, 1.6 million years of healthy life were lost because of traffic noise. The organization recommended that to avoid these health effects, exposure to road traffic noise should be limited to below a weighted 24-hour average of 53 dB (the sound of a campfire from about 16 feet away) during the day, evening, and night and 45 dB specifically at night (the sound of light traffic about 100 feet away).

Precise "safe" levels to avoid specific ailments are hard to come by. But in general, research shows, reducing loud noise can reduce the risk of harm. There are several ways to protect yourself. Various organizations have made maps that indicate quiet and noisy places around the U.S. Smartphone apps can tell you if you're in one that's too loud for safety. And noise experts all seem to own earbuds and headphones and use them often to block out the din.

For most of human history, the issue with noise was simply how annoying it can be. The first noise ordinance on record was drafted by Julius Caesar shortly before his assassination in 44 B.C.E., limiting the times that noisy carts and wagons could be on the street. The modern industrial era brought regulations to protect the ears of workers exposed to steam engines, drop forges, and other loud machinery but little information or action on everyday noises. A big moment came in 1970, when psychoacoustics expert Karl Kryter, then at the Stanford Research Institute, published *The Effects of Noise on Man*. The book focused on what loud sound could do to hearing and touched on work performance, sleep, vision and blood circulation.

That noise has biological effects beyond the ear makes sense in evolutionary terms. Noise may signal that a herd of elephants is charging your compound or that a pack of wolves is close by—you need to know, and your body needs to get ready for something unpleasant. As noise and sleep researcher Mathias Basner of the University of Pennsylvania and his colleagues put it in a 2014 *Lancet* review, "evolution has programmed human beings to be aware of sounds as possible sources of danger."



MSJONESNYC; Source: Centers for Disease Control and Prevention (*reference*)

From an evolutionary point of view, sleep was “a very dangerous stage,” a time when you had to maintain attention to your environment, Basner says. But the psychiatrist and epidemiologist, who has spent much of his career studying the effects of airport noise on people sleeping nearby, notes a “watchman function” that leads to night awakenings is for the most part harmful, not helpful, in modern societies.

A lot of people think they sleep soundly despite nearby noise. They should think again. Basner has exposed hundreds of people to noise during sleep studies. He says many would get up in the morning swearing they’d slept through the night without waking, but the data showed they’d had numerous awakenings.

By the early 1970s a poll showed that the public considered noise pollution a serious problem. Formal government recognition came in 1972 with the passage of the Noise Control Act and the establishment of the EPA’s Office of Noise Abatement and Control. The act promised that the government would “promote an environment for all Americans free from noise that jeopardizes their health or welfare.” At the time, the EPA estimated that 100 million Americans experienced daily average sound of 55 dB or over. Fifty-five dB is about halfway between the level of a quiet conversation at home and one in a restaurant or office. Any 24-hour exposure average louder than that, according to the EPA, was loud enough to interfere with activities and cause annoyance.

By this time, studies from universities in the U.S. and Europe were beginning to identify health effects of noise beyond the ear, starting with behavior and learning. In 1973 three U.S. researchers, with funding from the National Science Foundation and two private organizations, studied 73 children in primary school who lived in several 32-story apartment buildings clustered over Interstate 95 where it passes through New York City. Children on the lower floors, exposed to more highway noise, were less able to distinguish sounds and were reading at a lower level than children on the higher floors. There was even a dose-response relation: the longer the child had lived in the building, the lower their scores were likely to be.

In 1975 researchers at the City University of New York looked at school records for 161 primary school students at a school that was 220 feet from an elevated subway, with trains hurtling by every 4.5 minutes. The records showed a three- to four-month reading lag for kids in classrooms on the noisy side of the building compared with those in classes on the quiet side.

Researchers were able to do a natural experiment when the Munich International Airport moved about 25 miles north in 1992. The scientists found that among children living near the old airport site, long-term memory and reading skills improved after the airport closed. But for kids near the new airport, those changes went in the opposite direction, and their stress hormone levels increased.

In the early 2000s Stephen Stansfeld, then a psychiatrist at the University of London, studied kids aged nine to 11 living and going to school near airports in Europe, comparing their blood pressure and learning ability with those of similar children who did not live under flight paths. Airplane noise reached 77 dB(A) at several schools; dB(A) is a decibel scale that emphasizes frequencies the human ear hears best. “We found a straight-line relationship between increasing levels of aircraft noise and children’s reading comprehension,” Stansfeld says. “Noisy schools were not healthy educational environments.” A colleague found the harmful effects lasted into secondary school.

All the while, the U.S. was getting noisier. In 2014 Rick Neitzel, an environmental and occupational health professor at the University of Michigan who has been researching noise for 25 years, and his colleagues estimated that more than 100 million Americans had a continuous average exposure level in 24 hours of greater than 70 dB. Imagine standing next to a washing machine all day or suffering occasional blasts from the gas-powered lawn equipment Jamie Banks could hear inside her house. It was a rise of 15 dB in just a generation, which is the difference between normal conversation and a vacuum cleaner.

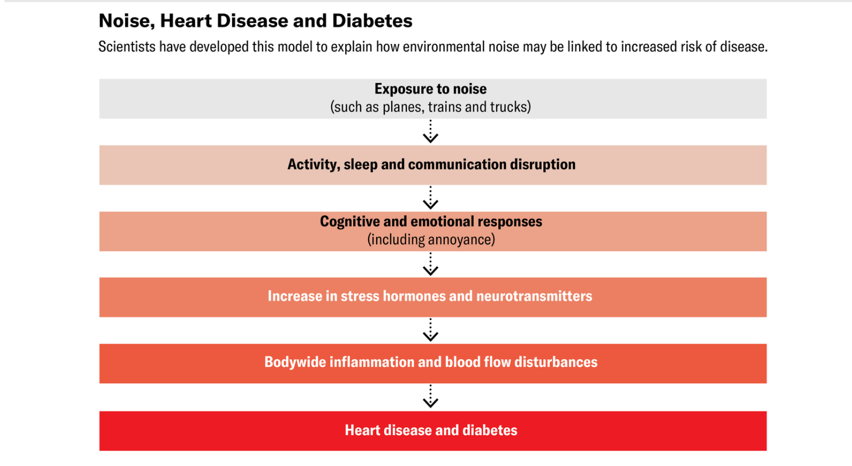
Beyond the brain and cognition, the heart and blood vessels also take a hit from noise—perhaps not surprising given the stressful effects of noise and the impacts of stress on the circulatory system. A slew of epidemiological studies over the years have linked environmental noise, especially nighttime noise, to high blood pressure, heart failure, myocardial infarction (heart attacks) and stroke. The association held true even after researchers controlled for confounders such as air pollution and socioeconomic variables.

Some of the strongest human data come from Denmark, which is an epidemiologist’s dream country because it collects health data on pretty much every resident. Mette Sørensen, an epidemiologist at Roskilde University in Denmark, Thomas Münzel, a professor at Johannes Gutenberg University in Germany, and others teased apart the effects of noise on types of heart disease such as myocardial infarction, angina and heart failure. Looking at 2.5 million people 50 years or older, they found road traffic noise increased the incidence of all three. In a 2021 report on 3.6 million Danes, they showed that an average daily 10-dB increase in sound exposure because of road noise increased the risk of stroke by 3 to 4 percent.

They’ve also looked at type 2 diabetes, a condition that had already been associated with chronic sleep disturbance. This link makes sense, Sørensen says: stress such as frequent awakening raises levels of glucocorticoids, which inhibit insulin secretion and insulin sensitivity. Reducing these two things leads to diabetes. In 2013 Sørensen and her colleagues reported an 8 percent increase in diabetes risk for every 10-dB increase in exposure to road traffic noise. Eight years later, looking at 3.56 million Danes 35 years and older, with 233,912 new cases of diabetes, they calculated that road traffic noise could be blamed for 8.5 percent of the cases of diabetes in Denmark and railway noises for 1.4 percent.

Sørensen is aware that those percentages don’t sound very high. But they are meaningful, she says. In Denmark, more than one third of the population is exposed to average daily sound levels above 58 dB. “You have such a huge proportion exposed to this,” she says, “so even though it’s only a really small increase in risk, it’s a large number of people who get diabetes due to noise.”

The physical mechanisms behind these links are still being investigated, but animal studies have highlighted possible culprits. (Researchers cannot deliberately expose people to such potentially harmful noise effects.) Münzel explored some of these connections in mice, for example. In one study, he exposed the rodents to average sound levels of 72 dB over four days and found that the animals had higher blood pressure and levels of stress hormones and inflammation, as well as changes in the activity of genes that regulate vascular health and cell death.



Jen Christiansen; Source: "Environmental Noise and the Cardiovascular System," by Thomas Münzel et al., in *Journal of the American College of Cardiology*, Vol. 71; February 2018 (*reference*)

In the U.S., most research on noise has been done without much help from the federal government, despite the Noise Control Act. In 1981, after Ronald Reagan was elected president on a promise of cutting back the federal government, he appointed Anne Gorsuch as head of the EPA; she eliminated funding for the agency's noise-control office. "She wanted to show the White House that she believed in small government," says Sidney Shapiro, a Wake Forest administrative law professor who has studied the rise and fall of noise-abatement laws. He says noise has never had a well-organized constituency to support it. Responsibility for noise-control research, funding and regulation was left to individual state and local governments.

Today the EPA's noise-control office is still there—on paper. "There is no money to enforce regulations or for research or education," Neitzel says. That's why Quiet Communities is suing. "Not having the EPA doing its job is hugely damaging, not only to the public who are being harmed by noise but also to the research community. We don't have access to a stream of funding that should be there."

Without that information, noise researchers have long struggled to quantify the overall impact of the American din. In 2014 when Neitzel and his colleagues at the University of Michigan wanted to figure out whether reducing noise would have a beneficial effect on cardiovascular disease, they had to resort to prevalence estimates made in 1981. In 2015 they published their findings. A 5-dB reduction in average noise exposure would cut the prevalence of high blood pressure by 1.5 percent and cut heart disease by 1.8 percent. Again, these are low numbers. But because of the high incidence of these conditions to begin with, an average 5-dB reduction would have an annual economic benefit of $3.9 billion. “I was shocked that the numbers were as big as they were,” Neitzel says.

Overall, as with chemical and air pollution, people with lower incomes are being hit the hardest. Their communities may have highways running through them or have factories and airports nearby. “Folks who are already in marginalized communities may be bearing way more than their fair share of noise exposure,” Neitzel says.

In these areas, it’s essential to ground research and solutions in community priorities, says Erica Walker, an epidemiologist at Brown University. Walker founded the Community Noise Lab, which works with communities to study and mitigate the effects of noise and other pollutants. She believes that it’s probably not just the absolute sound level that determines bodily damage—it’s unwanted sound. If the sound is a welcome one, does prolonged exposure to, say, 75 dB (about the volume of street musicians playing trumpets 30 feet away from you) raise stress levels the way that large studies have shown? “We need to know what the difference is between sound and noise from an individual point of view and from a community perspective,” Walker says.

She points to the Shaw neighborhood of Washington, D.C., which has been undergoing gentrification. “The cultural practice was to play go-go music. As the neighborhood began to become gentrified, newcomers had their own acoustical expectations of what the neighborhood should sound like,” Walker says. “If I’m going into a community and I’m measuring noise and I’m saying it’s really loud (based strictly on decibels) and harmful to health, that might be a misclassification.” People already in the community might perceive that noise as comfortable.

Walker and her colleagues are now trying to tease apart unacceptable noise and acceptable sound. In an ongoing study, they’ve been asking volunteers how they feel about different kinds of noise. Then the researchers deconstruct those noises by rearranging them, making them unidentifiable as a specific sound but maintaining the decibel level and frequency spectrum (think high notes and low notes). By the end of this summer, Walker hopes to know whether the deconstructed sound matches up with the recognizable sound. Such information could help distinguish the roles of sound intensity and cultural connotation in human harm.

Whatever your community’s sound tolerance, you can protect yourself from noise that’s intolerable. The simplest way, of course, is to avoid it. Sørensen’s data show that sleeping on the quieter side of a building, away from the street, makes a difference. Or you can move to a quieter area. That is easier said than done, and all the experts I spoke with noted that moving to a more peaceful place, as many of them have, is possible only for people who can afford it. If you plan to move, Basner advises visiting the new area at different times of day.

For noise that can’t be avoided, science may offer some promise, at least for ear effects. Sudden loud noises (think concerts, jet engines, leaf blowers and loud machines) stimulate the delicate hair cells and nerve fibers in the inner ear, resulting in the release of damaging free radicals. Animal work has identified some promising chemicals to sop these molecules up, says Colleen Le Prell, a psychologist and head of the department of speech, language and hearing at the University of Texas at Dallas, who is working on several candidates. There is already a drug for children to prevent chemotherapy-induced hearing loss, but it has significant side effects and isn't approved for general use.

The Montello Foundation's artist retreat in Nevada has been identified by the nonprofit Quiet Parks International as a community without irritating noise.
Stefan Hagen

If you want to get a snapshot of the sound around you, the Internet can help. The National Institute for Occupational Health and Safety has a national map, but it works only on Apple mobile devices right now. The U.S. Department of Transportation has a map for transportation noise, but it doesn't include workplace noise or inside noise. You can see noise across the entire country, albeit at pretty low resolution, on a National Park Service sound map.

To measure sound directly, there are plenty of smartphone apps. Don't be surprised if the numbers are high. Data from Apple watches suggest that one in three adult Americans is exposed to excessive noise and daily averages of 70 dB(A) (the sound of an older washing machine or dishwasher) or greater. Those levels are considered by both the World Health Organization and the EPA as dangerous to the ear. You can see state-by-state results on Apple Hearing Study U.S. maps. Apple watches and iPhones can be set to alert you when sound reaches a particular level.

The data collected from Apple watches come from the Apple Hearing Study, begun in 2019 by Neitzel and his colleagues at the University of Michigan and funded by Apple. The study shows that a quieter world is possible. It took the lockdowns of COVID to prove it. The researchers got smartphone data from about 6,000 volunteers, covering a period from just before the pandemic began in January 2020 through late April of that year, when many businesses and activities had shut down for safety, and lots of people were staying close to home. The data showed a 3-dB(A) drop in noise exposure. Because decibels are measured on a logarithmic scale, that's a halving of sound energy, easily noticeable by the human ear.

Sørensen moved from a city out into the country and checked a noise map first. Neitzel is very intentional about his exposure. "One thing that I absolutely try to do is make sure I've programmed periods into the day that I'm not going to have noise exposure," he says. That means a bike ride through a quiet area or turning the TV off. If he's at a bus stop, he stands back from the street as much as he can, and he routinely wears noise-blocking earplugs or earmuffs—sometimes both—when he's checking out industrial sites.

Neitzel protects his ears at concerts as well. "There's a bit of social stigma around wearing ear protection at a concert," he says, so he wears clear plugs, much like many musicians use. And he's got noise-canceling headphones and earbuds. They seal the ear to limit outside sound, which permits listening at a lower volume. He and his family wear noise-canceling earbuds on planes.

You can ask others to turn sound down. Sharon Kujawa, an audiologist at Massachusetts Eye and Ear hospital in Boston, and her colleagues did an experiment to see whether people in spin classes preferred louder or softer sound. They liked softer. The facility managers were reluctant to make a change, but eventually customer requests got them to agree to a 3-dB decrease in volume.

Fellow ear researcher Le Prell had her children use volume-limiting headphones. The kids were in marching bands in high school, in the percussion section, and she donated earplugs to the entire group.

As for specific levels to aim for, that's a tough one. There's no formula that says *x* hours of exposure to road traffic noise will raise your risk of heart disease *y* percent. The EPA, which established its noise standards in 1974, before the full health effects were so clear, indicates that a 24-hour exposure level of 70 dB or less will prevent any hearing damage, and 55 dB outdoors and 45 dB indoors will prevent activity interference and annoyance. For lack of anything more current, that's the standard used by many noise researchers today.

In terms of protective devices, there are only limited federal regulations on headphones, and there's some concern that the devices go up to volumes that can damage the health (ear and otherwise) of children. Volume limiters on headphones generally have an upper limit of 85 dB, but what the limit should really be, and for how long, is anybody's guess. There's also no solid research on whether devices that produce masking noises help.

Clear, consistent standards for how much is too much, and what works, are unlikely without a revitalization of the EPA's noise-control office. An agency spokesperson wouldn't say whether the lawsuit by Quiet Communities will spur any change. The two sides in the suit "are currently in the midst of filing motions and cross-motions," says Quiet Communities lawyer Sanne Knudsen of the University of Washington. When we spoke, Knudsen expected some kind of agreement would be reached by April and hoped it would be one that got the Office of Noise Abatement and Control up and running again.

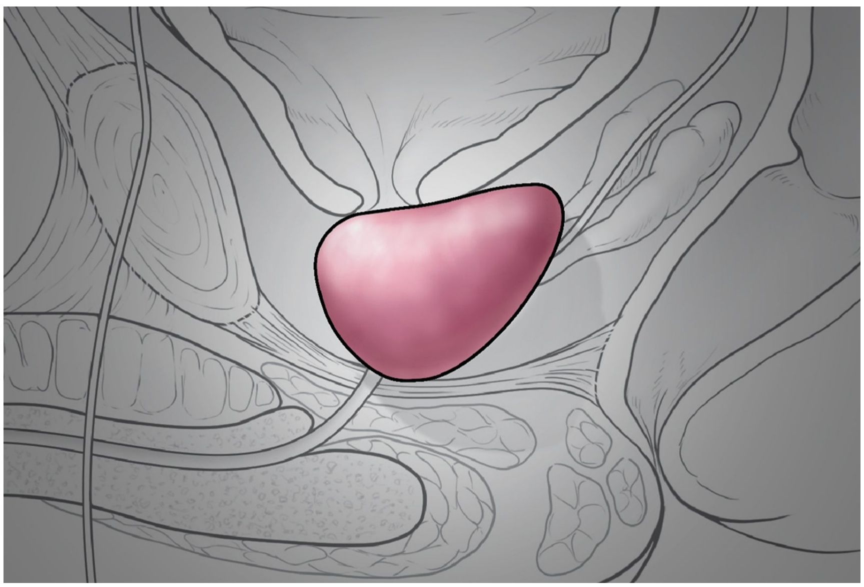
Jamie Banks now spends most of her time in a quiet town in rural Maine, which, she says, is blissfully free of loud lawn equipment and other noise. She is optimistic that a newly active federal noise-control office will establish data-based noise limits and regulations and that the EPA will ensure regulations are enforced. In 1972, when the noise office was established, the Los Angeles Times opined that it wouldn't mean an instant reduction in harmful sound, "but at least a start has been made." Fifty-two years later Banks hopes for not just a start but real progress.

Joanne Silberner, a former NPR health correspondent, has been covering medicine and public health since the start of the HIV epidemic. A co-founder of the Association of Healthcare Journalists, she lives and works on a quiet island in Puget Sound.

New Prostate Cancer Treatments Offer Hope for Advanced Cases

Major discoveries during the past 10 years have transformed prostate cancer treatment, enabling it to proceed even for the most advanced form of the disease

By Marc B. Garnick



David Cheney

Deciding how to diagnose and treat prostate cancer has long been the subject of controversy and uncertainty. A prime example involves prostate-specific antigen (PSA) testing, a blood test for a telltale protein that can reveal cancer even when the patient has no symptoms. After its introduction in the early 1990s, PSA testing was widely adopted—millions of tests are done in the U.S. every year. In 2012, however, a government task force indicated that this test can lead to overtreatment of cancers that might have posed little danger to patients and so might have been best left alone.

While arguments for and against PSA testing continue to seesaw back and forth, the field has achieved a better grasp on what makes certain prostate cancers grow quickly, and those insights have paved the way for better patient prognoses at every stage of the disease, even for the most advanced cases. A prostate cancer specialist today has access to an enhanced tool set for treatment and can judge when measures can be safely deferred.

The importance of these advances cannot be overstated. Prostate cancer is still one of the most prevalent malignancies. Aside from some skin cancers, prostate cancers are the most common cancers among men in the U.S. Nearly 270,000 people in America will be diagnosed with prostate cancer this year, and it is the fourth most common cancer worldwide. Fortunately, the vast majority of patients will live for years after being diagnosed and are more likely to die of causes unrelated to a prostate tumor.

At its most basic level, prostate cancer is a malignancy that occurs in the prostate gland, which produces fluid that mixes with sperm from the testicles to make semen. The prostate is located in front of the rectum, below the bladder and above the penis, and cancer in the gland has four major stages.

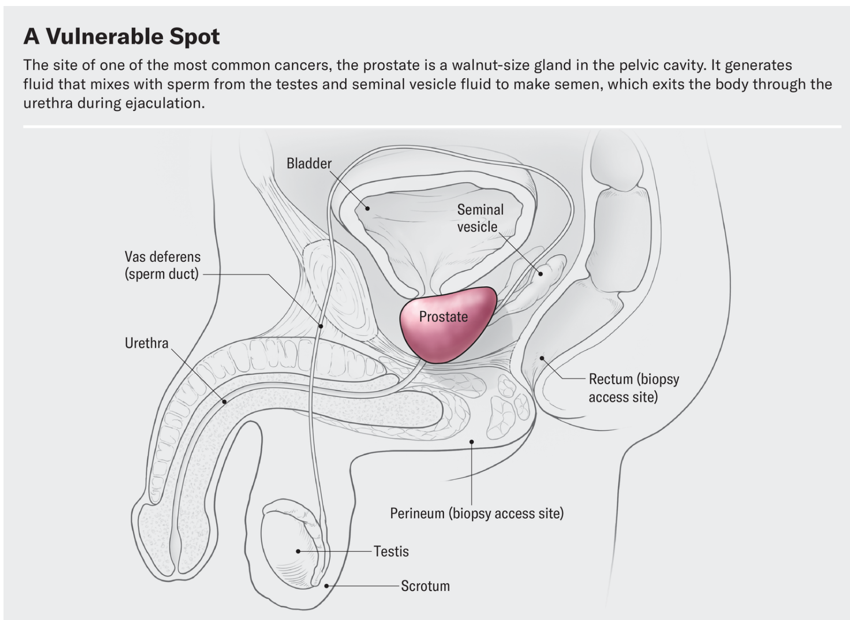
Early on, localized tumors show no evidence of extension beyond the prostate gland. A second, “regionally advanced” form of the disease remains close to the prostate. Then there are metastatic prostate cancers, which spread outside the gland to other parts of the body. Treatment of tumors in this category has benefited from improved diagnostic imaging tests. In fact, with these tests, cancer specialists have characterized the fourth category, oligometastatic prostate cancer, a disease stage on a continuum between localized prostate cancer and more broadly dispersed metastatic disease. Major discoveries in the past 10 years have transformed the way we approach each type of prostate cancer, and these advances are likely to continue for decades to come.

The first treatment steps for people with localized cancer involve risk stratification. Through this process, a physician gauges the likelihood of a cancer's being eliminated or cured by local treatment (usually surgery or radiation) and, if it does abate, of its returning. A physician determines the risk based on PSA results, physical examination of the prostate gland and inspection of cells from the biopsied tumor.

The right course of action for a patient with elevated PSA levels continues to undergo constant revision. Until five to seven years ago, a physician evaluated a person with high PSA by feeling their prostate gland for potentially cancerous abnormalities. Invariably, the next step would be a needle biopsy—an uncomfortable procedure in which the physician obtains snippets of prostate tissue through the rectum.

But we now have a way to biopsy through the perineum—the area between the back of the scrotum and the anal-rectal area. Thanks to technical improvements, it can be done in an outpatient setting without general anesthesia or sedation. The technique reduces the patient's risk of infection and need for antibiotics because it doesn't disrupt the bacterial flora in the rectum. In a recent study, researchers compared outcomes in patients who underwent a transrectal biopsy and received antibiotics with those for people who had a transperineal biopsy with minimal to no antibiotics. They found the two approaches comparable in terms of complications from infections.

Even more exciting is the prospect of eliminating biopsies altogether. When a patient has an abnormal PSA value but their rectal examination shows no obvious evidence of cancerous deposits, physicians can now use magnetic resonance imaging (MRI) to look at the prostate and surrounding tissue. MRI scans are best for identifying clinically significant cancers—those that, if left untreated or undiagnosed, could eventually spread. MRI can also uncover more extensive cancer spread or tumors in unusual locations such as the front of the prostate.



David Cheney

Another benefit of MRI procedures is that they identify fewer clinically insignificant cancers—those that are unlikely to cause problems and might best be left alone. In this case, failure to detect certain cancers is a good thing because it spares people unnecessary treatment. In some medical centers in the U.S. and many in Europe, a physician will perform a biopsy only if the MRI scan does reveal evidence of clinical significance. Studies that have compared the two diagnostic approaches—routine biopsy for all patients with elevated PSA levels versus biopsies based on abnormal MRI findings—found they are similarly effective at detecting clinically significant cancers.

Once a patient is diagnosed with prostate cancer, what happens next? For decades the debate over treatment has been just as contentious as the debate over diagnosis. Fortunately, new research from the U.K. has provided some clarity. Investigators there studied several thousand people with elevated PSA levels whose prostate biopsies showed cancer. These patients were randomized to receive surgical removal of the cancerous gland, radiation treatments or no active treatment at all. At the end of 15 years of comprehensive follow-up, about 3 percent of patients in each group had died of prostate cancer, and nearly 20 percent in each group had died of unrelated causes.

Based on the results of this study and others, more people are now being offered “active surveillance” after a prostate cancer diagnosis, in which treatment is either delayed or avoided altogether. Careful monitoring of patients who have not undergone surgery or radiation is becoming more common; it is now being extended even to those with more worrisome tumors. The monitoring involves a range of measures: PSA testing every three to six months, physical examination of the prostate gland and assessment of the patient’s urinary symptoms. Those tests are followed by repeat biopsies at increasing intervals, as long as there are no significant pathological changes.

If a cancer is identified as having either intermediate- or high-risk features, doctors need to track its progression, usually with bone scans using radiopharmaceuticals and with abdominal-pelvic computed tomography (CT) scans, which may show any spread in the areas to which prostate cancer most often metastasizes. Unfortunately, these techniques are not sensitive enough to reliably detect cancer in structures less than a centimeter in diameter, such as lymph nodes. Consequently, small areas of metastatic disease may go undetected. These cases are said to be “understaged.”

Understaging can now be studied through more precise diagnostic testing. Typically patients whose disease is understaged are not treated until the cancer becomes detectable through symptoms such as urination problems or pain. The disease then may require intensive therapies, and there is less of a chance of long-term remission. One technology that can help address understaging is advanced scanning that combines radiodiagnostic positron-emission tomography (PET) with CT.

These scans can detect molecules commonly found in prostate cancer cells, such as prostate-specific membrane antigen (PSMA). If PSMA is present outside the prostate gland, such as in pelvic lymph nodes, the affected areas can be identified, and a plan can be made for targeted radiation treatments or surgical removal.

Let's consider how PET-CT scanning can be used in clinical practice. One of my patients, a 68-year-old man, was diagnosed with prostate cancer that was localized but had high-risk features. The traditional diagnostic bone and CT scans did not show any evidence of cancer spread outside the prostate. A PET-CT scan for PSMA, however, did reveal the presence of several small deposits of cancer cells in well-defined areas of the pelvis, indicating the cancer had spread to the lymph nodes. This finding prompted treatment that included radiation therapy in the prostate gland and the cancerous lymph nodes, as well as androgen-deprivation therapy (ADT), a treatment that reduces levels of testosterone, the hormone that enables prostate cancer to grow and progress.

The more precise identification of small tumor deposits in a limited number of pelvic lymph nodes—diagnosed as oligometastatic prostate cancer—enabled a new use for an old technology in oncology called metastasis-directed therapy (MDT), which targets cancer-containing lymph nodes or bony areas with radiation. At times, surgical removal of the abnormal lymph nodes may also be incorporated into MDT. Recently published studies on the use of MDT in conjunction with conventional treatments show, in some cases, long-term remission lasting through years of follow-up. Until recently, such a scenario was unthinkable for people whose prostate cancer had spread to their lymph nodes. My patient had the PSMA scan and MDT, as well as a relatively short course of ADT. He is cancer-free for now.

Precise identification of small metastatic deposits has other positive benefits. ADT has for decades been the mainstay for treating many forms of prostate cancer. Patients must continue the therapy for years, sometimes for the rest of their lives. Side effects of ADT are similar to those experienced during menopause. In fact, “andropause” is the term that captures the effects of ADT. Lower levels of testosterone are accompanied by a multitude of symptoms, including but not limited to loss of libido, erectile dysfunction, weight gain, hot flashes, bone loss, cognitive impairment, mood changes, diminished energy, and worsening of preexisting heart and vascular problems.

Studies of MDT for oligometastatic prostate cancer have raised the question of whether ADT could be delayed, administered for a shorter duration or even omitted in patients who otherwise would have required it. By strategically deploying traditional forms of localized treatment—usually surgery to remove the prostate gland or radiation—with added MDT for oligometastatic disease, doctors can significantly shorten the duration of ADT or potentially eliminate it. Such an approach would have been difficult to imagine five years ago. Longer-term follow-up studies will help scientists determine whether some people diagnosed in this fashion can go into an extended remission.

For advanced forms of prostate cancer that have spread to other parts of the body, ADT has been the main treatment. Physicians historically have generally recommended surgical removal of the testicles—the primary source of testosterone—or the administration of other hormones that block the production and action of testosterone. In the mid-1980s I was involved with research on drugs called luteinizing hormone–releasing hormone analogues that lowered testosterone by shutting off the signal in the brain that instructs the testicles to make testosterone. Today newer agents have been added that further lower and block testosterone's action.

The goal of prostate cancer treatment at later stages is to eliminate multiple sources of testosterone. As noted earlier, testosterone in the body comes predominantly from the testicles; the adrenal glands also produce a small amount. But prostate cancer cells can evolve to produce their own androgens. Testosterone and its active form, dihydrotestosterone (DHT), traverse the membranes of prostate cancer cells and interact with androgen receptors in the cytoplasm, a cell's liquid interior. The receptors then transport DHT to the nucleus, where it instructs the cancer cell to grow, replicate and spread.

Traditional ADT does little to affect either the production of testosterone by the adrenal glands or androgen-producing prostate cancer cells, and it doesn't block the activity of androgen receptors. But new approaches to ADT may address these shortcomings. Drug combinations that affect all these processes have substantially improved survival in people with metastatic prostate cancer—and, more important, patients are able to tolerate these more intensive treatment programs.

Instead of just one drug to decrease testosterone, new standards for treatment prescribe combinations of two or even three drugs. In addition to traditional ADT, there are medications such as docetaxel, a chemotherapy, and other new drugs that can block the production of testosterone by the adrenal glands or cancer cells or stop it by interfering with the activity of androgen receptors. All these drug combinations have resulted in meaningful improvements in survival.

Yet another therapy for advanced disease involves the identification of PSMA-expressing cancer cells that can be targeted with pharmaceuticals designed to deliver radioactive bombs. An injectable radiopharmaceutical can be delivered selectively to these cells, leaving healthy cells mostly unaffected. This therapy, lutetium-177-PSMA-617 (marketed as Pluvicto), has been approved by the U.S. Food and Drug Administration for the treatment of prostate cancer that has become resistant to other forms of ADT and chemotherapy. It is likely to become an important therapy for even earlier stages of prostate cancer.

Genetics and genomic testing of patients and cancers have also helped in the quest for improvement of symptoms and longer survival. Some genetic mutations that are known to increase the risk of breast and ovarian cancer have also been associated with a heightened risk of prostate cancer. Testing for such mutations is becoming much more common, and patients who have them can be treated with specific therapies that block their deleterious effects, leading to better outcomes.

An understanding of the type of mutation is also critical—for both patients and their family members. Germline mutations are inherited from a patient's biological parents by every cell in the body. These mutations can be passed along to the patient's children. A somatic mutation, in contrast, is not inherited but develops in the cancer itself. Targeted therapies designed specifically to correct the effects of either germline or somatic mutations have produced significant improvements in patient longevity. Some of the most commonly recognized cancer mutations—either somatic or germline—are those in *BRCA* genes, which have been associated with early-onset breast and ovarian cancer.

When researchers studied cancer in families with *BRCA* mutations, they uncovered many cases of prostate cancer. This finding led to the discovery that *BRCA* mutations appeared in both men and women in these families. The mutations change the way DNA is repaired, introducing defects that can result in cancer formation. Drugs have now been developed that treat cancers linked to the *BRCA* mutations. Several such drugs—those in a class called poly(ADP-ribose) polymerase (PARP) inhibitors—have recently received FDA approval for use as a treatment in people with these mutations. This research has led to more widespread genetic testing of patients with prostate cancer and, when germline mutations are found, family genetic counseling.

All these advances have occurred over the past decade—an incredibly short interval in the context of cancer oncology. Current options for early-stage prostate cancer enable physicians and patients to feel more at ease with conservative choices rather than immediate interventions with negative side effects. For patients whose cancers are advanced at initial diagnosis or progress and become metastatic, the treatment of oligometastases now often leads to long-term remission and requires fewer treatments with harmful systemic side effects. For those with more widespread metastatic disease, their cancer can now be managed with improved therapeutics based on a better understanding of disease biology. These new strategies have begun to transform this once rapidly fatal disease into a chronic condition that people can live with for years or even for their full life expectancy.

Marc B. Garnick is Gorman Brothers Professor of Medicine at Harvard Medical School and Beth Israel Deaconess Medical Center in Boston. He is editor in chief of Harvard Medical School's 2024–2025 Report on Prostate Diseases.

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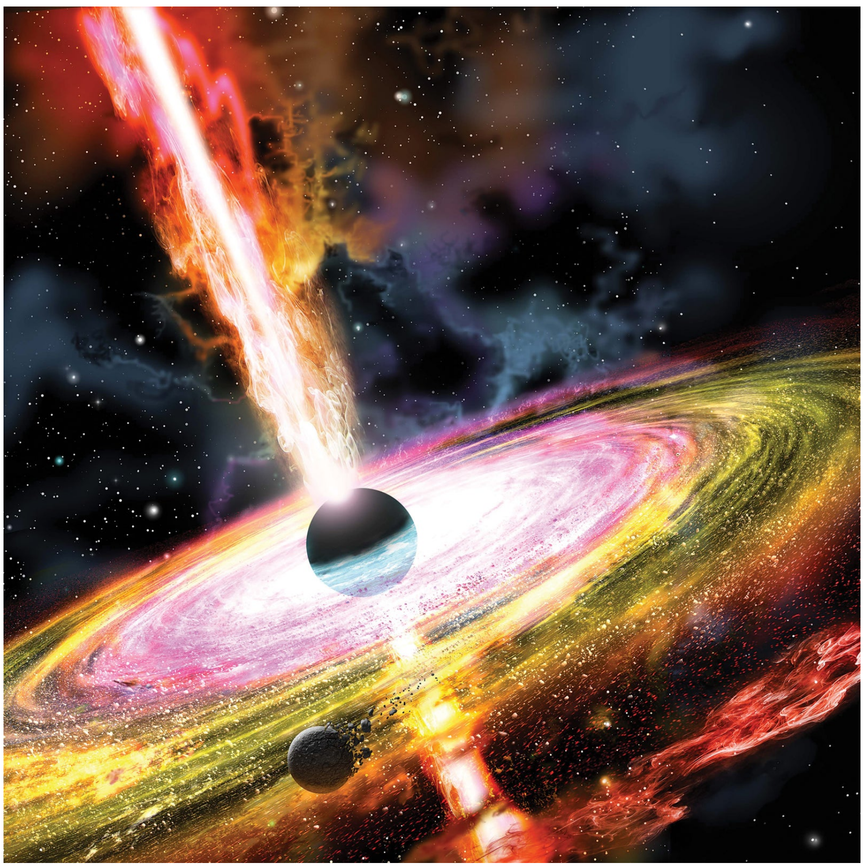
JWST's Puzzling Early Galaxies Bend Astrophysics

Rather than ripping up our fundamental models of the universe, the unexpectedly big and bright galaxies spied in the early universe by JWST probably have astrophysical explanations

By Jonathan O'Callaghan



New observations have found growing galaxies in the early universe to be bigger and brighter than expected, as seen in this artist's conception.
Ron Miller

Ever since it opened its giant infrared eye on the cosmos after its December 2021 launch, the James Webb Space Telescope (JWST) has been finding an overabundance of bright galaxies that stretch back to the very early universe. Their brightness—a proxy for their number of stars and hence their mass—is deeply puzzling because galaxies shouldn't have had enough time to become so bulky in such early cosmic epochs. Imagine visiting a foreign land and finding that many of the toddlers there weigh as much as teenagers. You might have questions, too: Are the children so large because of something in the water, or might it instead be that your grasp of human growth is fundamentally flawed? Theorists who pondered JWST's big, bright early galaxies felt much the same: Was something fundamental amiss in our understanding of cosmology? Namely, was our knowledge of the expansion of the universe after the big bang simply wrong?

The answer, it appears, need not be quite so dramatic. Several studies investigating some of these early galaxies now point toward an astrophysical explanation for the unexpected girth—such as earlier-forming black holes or bursts of star formation—rather than some physics-shattering result. "Most people would put their money on the astrophysical explanation right now," says Mike Boylan-Kolchin, a cosmologist at the University of Texas at Austin. "I'd count myself in that category as well."

Before JWST's debut, its predecessor, the Hubble Space Telescope, held the record for the earliest galaxy ever found. We can see that object, called GN-z11, as it was about 13.4 billion years ago, around 400 million years after the big bang. Once JWST turned its gaze on the universe, however, it repeatedly smashed Hubble's record. Scientists are now studying galaxies stretching back to at least 320 million years after the big bang. And later this year fresh data releases from ongoing JWST galaxy surveys should push this record back even further.

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The oldest galaxies JWST found were brighter and more active than expected, with star-formation rates comparable to the one-star-per-year rate of the Milky Way today. But they were squeezed into much more compact regions around one one-thousandth the size of our galaxy. And as JWST peered deep into the early universe, it also examined a more recent swath of cosmic history, up to about 750 million years after the big bang. The older galaxies it found there were still quite young and strange: they were about one-thirtieth the size of the Milky Way (much *bigger* than expected) and had star-formation rates that must have been 1,000 times higher than our galaxy’s. Scientists called these relatively older systems ultramassive galaxies and kept scratching their heads: neither set of galaxies could be wholly explained by current models.

In the journal *Physical Review Letters*, Nashwan Sabti of Johns Hopkins University and his colleagues recently proposed an explanation for JWST’s ultramassive galaxies. They used existing data from Hubble to examine hundreds of galaxies in ultraviolet light in the same epoch of the universe as these galaxies, about 450 million to 750 million years after the big bang. Unlike JWST, which observes primarily in infrared, Hubble is sensitive to the UV end of the electromagnetic spectrum, where young massive stars blaze brightest. Hubble’s UV observations allowed the researchers to better gauge the rates of star formation in the mysterious ultramassive galaxies. “So we have the star-formation rate—the change in stellar mass over time—versus the stellar mass itself from JWST,” Sabti says.

> “We showed Hubble doesn’t give you much wiggle room to play around with cosmology. That means the source [of

ultramassive galaxies] is very likely astrophysics.”
—Nashwan Sabti *Johns Hopkins University*

By comparing those two pieces of information, Sabti and his colleagues found that the galaxies could be explained within the confines of our cosmological model of the universe, the Lambda Cold Dark Matter (Lambda-CDM) model. It best replicates the observed patterns and properties of galaxies and other large cosmic structures. No esoteric physics were required. In fact, any such tweaks would put the Hubble observations at odds with JWST; the galaxies were growing exactly as expected in accordance with Lambda-CDM’s predictions. “We showed that Hubble really doesn’t give you much wiggle room to play around with cosmology,” Sabti says. “That means the source [of the ultramassive galaxies] is very likely astrophysics.”

Boylan-Kolchin says the paper makes a “great point” in comparing Hubble and JWST data from this period of the universe. He isn’t completely convinced just yet, however. “I don’t think the case is airtight that it has to be an astrophysical explanation,” he says. “The loophole is that you’re not necessarily observing the same galaxies with JWST and Hubble. Galaxies can be luminous [in infrared] for JWST but invisible for Hubble. If the most massive ones happen to be in that [infrared] regime, then maybe Hubble wouldn’t be seeing them.”

Sabti’s paper is not the only recent work that points toward an astrophysical explanation for JWST’s peculiar galaxies, however. Earlier this year in the *Astrophysical Journal Letters*, Joseph Silk of Johns Hopkins and Sorbonne University in Paris and his colleagues looked at the earliest galaxies seen by JWST, which predate GN-z11. The researchers wrote that there might be a way to grow the galaxies more quickly in the universe if black holes formed earlier than the galaxies, within the first 50 million years after the big bang. That could explain why star-formation rates in the early universe were so high: the black holes could have powered the galaxies earlier than expected and crushed clouds of dust and gas into stars more quickly. The mechanism involves reasonably well-understood astrophysical processes called feedback and outflow.

“There are far more black holes than we expected” in JWST’s observations, Silk says, “and the galaxies they’re in are very compact,” barely 300 light-years across, compared with the Milky Way’s diameter of 100,000 light-years. “This means the feedback is greatly enhanced,” Silk says. “Our basic hypothesis is that the black holes really formed before most of the stars, and their vigorous outflows then created lots of stars. As time went on, this died away and led to the more conventional star formation that we have [today]. We think this is just a very special phenomenon that occurred early on and can explain the mysteries that we’re seeing with JWST.”

Fabio Pacucci of the Center for Astrophysics | Harvard & Smithsonian and his colleagues have studied the role black holes might have played at a later time in galaxies’ evolution. In a galaxy like our own in the modern universe, the mass of stars outweighs the mass of the galaxy’s central supermassive black hole—a feature that is ubiquitous among large galaxies—by a ratio of 1,000 to 1.

Using JWST to examine galaxies from 750 million to 1.5 billion years after the big bang, Pacucci found that some of them in this window may have a black hole whose mass matches their stellar mass—or perhaps even exceeds it. That points to a model of black hole growth in the early universe in which black holes grew from the direct collapse of clouds of dust and gas in the first 100 million years of the cosmos rather than from stars. This proposal is consistent with that of Silk and his colleagues and thus may bolster the astrophysical explanation of the rapid early growth of galaxies.

If that idea is correct, upcoming gravitational-wave observatories—such as the Laser Interferometer Space Antenna (LISA) space observatory, which was recently approved by the European Space Agency and is set for launch in 2035—might find these “heavy seed” black holes. “If these heavy seeds happened, then we would see a lot of mergers” with LISA, Pacucci says. “It’s possible this will ease the problem of excessive mass.”

There are ways to explain JWST’s galaxies without black holes, too. Guochao Sun of Northwestern University and his colleagues have suggested that some galaxies in the universe might have gone through periods of “bursty” star formation. An abundance of supernovae could have temporarily led to a feedback process over 10 million years or so that increased star formation to rates “10 to 100 times” higher than those of more sedate galaxies, Sun says.

That could have caused the brightness of some galaxies in the early universe to “jump up and down very drastically,” leading to a skewed sample of more visible bright galaxies. “You don’t need to form stars at a very high efficiency,” Sun adds. It may be that JWST’s mysteriously bright early galaxies merely represent the upper end of dramatic fluctuations in star formation, with dimmer, more prosaic galaxies being more numerous but, so far, unseen.

Astrophysics, for the time being, reigns supreme. There is much at stake, however. “The fact that cosmology could be at play here means it’s really worth following it up until it’s excluded,” Boylan-Kolchin says. Black holes and star formation are promising explanations, but scientists will be watching for fresh JWST results to see which, if any, of the new models hold firm.

Jonathan O'Callaghan is an award-winning freelance journalist covering astronomy, astrophysics, commercial spaceflight and space exploration. Follow him on X @Astro_Jonny

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Animals

- ## Cute Little Tardigrades Are Basically Indestructible, and Scientists Just Figured Out One Reason Why
  Tardigrades are microscopic animals that can survive a host of conditions that are too extreme to ever occur on Earth—and scientists want to learn their secrets
- ## This Tiny Fish Makes an Ear-Blasting Screech for Love
  A rice-grain-size fish screams louder than a jackhammer—and we have a lot to learn from its minuscule brain
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  Social context shapes how fiddler crabs communicate by vibrating the ground underneath their burrows

Cute Little Tardigrades Are Basically Indestructible, and Scientists Just Figured Out One Reason Why

Tardigrades are microscopic animals that can survive a host of conditions that are too extreme to ever occur on Earth—and scientists want to learn their secrets

By Meghan Bartels

This tardigrade, imaged by scanning electron microscope, is less than 0.1 millimeter across. Steve Gschmeissner/Science Photo Library

Tiny tardigrades have three claims to fame: their charmingly pudgy appearance, their delightful common names (water bear and moss piglet), and their stunning resilience in the face of threats such as the vacuum of space and temperatures near absolute zero. “They’re masters of protecting themselves,” says Derrick Kolling, a chemist at Marshall University.

Now Kolling and his colleagues have identified a key mechanism contributing to tardigrades’ toughness: a kind of molecular switch that triggers a hardy dormant state. It’s just one piece of the complex system the minuscule creatures use to survive harsh circumstances, but the researchers hope the new work, published in the journal *PLOS ONE*,will encourage further investigations. “It’s opened up a whole huge repertoire of experiments we can now pursue,” says study co-author Leslie Hicks, a chemist at the University of North Carolina at Chapel Hill.

The research began when, on a whim, Kolling put a tardigrade into a machine that detects “free radicals,” or atoms and molecules that contain unpaired electrons. An animal’s normal metabolic processes, as well as environmental stressors such as smoke and other pollutants, can create free radicals inside cells, so he thought it was likely that tardigrades would also produce such molecules.

When they accumulate, free radicals—most notably, reactive forms of oxygen—snatch electrons from their surroundings to achieve stability in a process known as oxidation. This reaction can damage cells and compounds within the body. But in small quantities, free radicals can also act as signaling molecules, Hicks says, and her laboratory studies show that they affect a cell’s behavior when they glom on to and pop off of a variety of proteins.

When Kolling told Hicks about seeing free radicals in a tardigrade, she wondered whether these molecules could have anything to do with the animal’s hardiness. The team devised several experiments to temporarily expose water bears to stress-inducing, free-radical-producing conditions, such as high levels of salt, sugar and hydrogen peroxide. Under these forms of stress, tardigrades curl up into a temporary, protective state of dormancy called a tun. The researchers monitored the conditions in which the tardigrades hunkered down and found that free radicals did seem to induce the tun state, although the mechanism was not yet clear.

Hicks studies signaling interactions between free radicals and the amino acid cysteine, and she decided to test whether that molecule could play a part in tun formation. So she and her colleagues introduced the tardigrades to different kinds of molecules known to block cysteine oxidation. Under stressful conditions, with cysteine unavailable to the free radicals being produced, the tardigrades couldn’t form tuns—pointing to cysteine oxidation as a required mechanism.

Kazuharu Arakawa, a biologist who studies tardigrades at Keio University in Japan, says the new work aligns with previous research; an earlier study showed the role of oxidation in a midge known for withstanding total desiccation (the process of drying out). The similarities suggest the mechanism may be a common trigger for tuns and other forms of hardy dormancy, a phenomenon that scientists call cryptobiosis.

But water bears still hold many mysteries. When they enter the tun state, they temporarily shut down their metabolism—a feat that even cysteine oxidation can’t explain, says Hans Ramløv, a comparative animal physiologist at Roskilde University in Denmark. “There is no single study to date that explains it,” he says. “In my opinion, we are far, far from understanding that.”

Kolling and Hicks agree that there’s much more research to be done to understand how free radicals work in tardigrades. The resilient tun state isn’t the only tactic water bears use to survive environmental stress, and the team plans to scrutinize other strategies. The researchers also aim to study various species of tardigrades (they examined only *Hypsibius exemplaris*), and they expect to find that cysteine oxidation is widely used among the animals.

Hicks hopes that in the long run the work can inform investigations of aging and space travel, which both involve free-radical damage to vital cellular machinery such as DNA and proteins.

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.

This Tiny Fish Makes an Ear-Blasting Screech for Love

A rice-grain-size fish screams louder than a jackhammer—and we have a lot to learn from its minuscule brain

By Elizabeth Anne Brown

Danionella cerebrum is transparent from birth—and incredibly loud.
Dave McNabb/Bolton Library and Museum

In the streams of south-central Myanmar lives a creature that could be easily mistaken for a sentient grain of rice—a grain of rice, that is, with a lot to say and a voice like a jackhammer.

At just 12 millimeters long, the transparent fish *Danionella cerebrum* is among the smallest vertebrates alive, but it may be the world’s loudest animal by weight. Measured underwater and at close range, male *D. cerebrum*’s calls reach an astonishing 140 decibels. That’s as loud as a firecracker, says Verity Cook, a researcher at Charité–Berlin University of Medicine who studies brain activity during acoustic communication. To human ears above water, the fish’s call sounds like a short chirp or a buzzy whine, and it can last more than a minute.

But why does such a tiny fish scream so loudly? Sometimes, it seems, “it’s a love song,” says University of Lisbon marine biologist Clara Amorim, a co-author of a recent study on *D. cerebrum* in the *Journal of the Acoustical Society of America*. Amorim, the study’s lead author Raquel Vasconcelos and their colleagues compared the number of eggs laid by populations of the fish in different tanks.* And it was the chattiest groups—not necessarily the largest—that seemed to lay the most eggs.

It could be that *D. cerebrum’*s screechy serenade encodes information about a male’s fitness, Amorim says. She notes that belting so loudly for a minute straight requires an impressive investment of energy and that females might prefer mates with vocal endurance. In some vocalizing fish species, a male’s ballad can even speed up the maturation of a female’s eggs and promote spawning.

Cook recently discovered that male *D. cerebrum* make their spectacular sounds by rapidly contracting muscles that force a minuscule piece of cartilage to beat like a drum against their swim bladder, an air-filled organ some fish use to control their buoyancy.

Whatever *D. cerebrum* is telling females with its loud calls, it also has a lot to tell scientists about how the brain works, Cook says. The diminutive fish have emerged as a promising model animal for neuroscience: they remain transparent their entire lives, and the top of their skull never closes, resulting in something like a cranial sunroof. This means that, with the help of genetic editing and fluorescent proteins, scientists can watch individual neurons literally light up as they become active, Cook explains. She says *D. cerebrum*’s gabbiness provides a chance for researchers to chart the neural pathways involved in vertebrates’ production and processing of sound.

D. cerebrum has the smallest brain of any living vertebrate—scarcely bigger than a poppy seed. But Cook warns that it shouldn’t be underestimated. “Even tiny fish with little brains have complex, interesting behaviors,” she says. And, it seems, love lives.

**Editor's Note (8/13/24): This sentence was edited after posting to clarify that Raquel Vasconcelos was lead author of the study.*

Elizabeth Anne Brown is a freelance science journalist based in Copenhagen, Denmark. Her work has appeared in *National Geographic*, the *New York Times*, the *Washington Post*, and many other outlets. Read more at elizabeth-anne-brown.com, and follow her on X (formerly Twitter) @eabrown18

Fiddler Crabs Unleash Special Vibrations to Attract Mates—And Deter Foes

Social context shapes how fiddler crabs communicate by vibrating the ground underneath their burrows

By Kiley Price

Fiddler crab near its burrow.
Minju Kim

When male fiddler crabs try to attract a mate, they emit a series of vibrations and pulses by drumming on the ground—essentially a crustacean love song. It turns out that these crabs can produce fight songs as well, drumming a different tune to threaten a foe, researchers report in *Animal Behaviour*.

All sound waves begin with vibration. Human ears are built to detect vibrations or pressure waves traveling through air and water, which our brains perceive as voices or sounds. But many other animals "hear" sound through solid mediums—including the ground. Fiddler crabs primarily use sensory organs in their legs to detect the vibrations of sand particles.

To track the crab's vibration-based soundtracks, researchers placed highly sensitive accelerometers in mudflats next to the crustaceans' burrows on South Korea’s Yeongjong Island. Next, they introduced decoy female crabs made of polymer clay near the burrows.

When courting, male crabs waved their large claw, then played a slow, long series of vibrations to lure these fake females into their burrows. Other times the crabs instead acted hostile to their clay counterparts and drummed out a shorter spurt of quick pulses to accompany defensive behavior. “I was surprised because I didn’t expect that they could make such complicated and sophisticated rhythms,” says study co-author Taewon Kim, a marine biologist at Inha University in South Korea.

This discovery illuminates the world of crustacean communication —and factors that could disrupt it, says Damian Elias, an animal behavior researcher at the University of California, Berkeley. For example, helicopters regularly flying over the study site created vibrations so strong that researchers were unable to record the fiddler crabs’ drumming and had to pause their experiment. Other human activities such as construction are known to disturb species that depend on ground vibrations, although scientists are still exploring the long-term impacts of these disruptions.

“It’s only recently that we really started to appreciate just how many animals communicate acoustically, particularly ones that don’t communicate using airborne vibrations in the way that humans detect them,” Elias says. “We need to think about how animals detect the world if we really want to understand them.”

Kiley Price is a science journalist with a particular focus on the environment, wildlife, ocean health and climate change.

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Arts

- **Contributors to Scientific American's May 2024 Issue**
  Writers, artists, photographers and researchers share the stories behind the stories
- **Poem: 'Lucy'**
  Science in meter and verse

Contributors to *Scientific American*’s May 2024 Issue

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

By Allison Parshall

Kevin Cooley.
Bridget Batch

Stephen Pyne
Life in the Pyrocene

The summer after his high school graduation, Stephen Pyne filled an empty spot on the Grand Canyon’s North Rim fire crew. The opportunity came through “complete serendipity,” he says, and he went on to serve a total of 15 summers on the crew, 12 as the boss. On a fire crew, “you quickly find that fire organizes your life,” he says, just as it organizes all life on Earth.

For this issue, Pyne, an environmental historian, tells a story of the so-called Pyrocene, a term he coined in 2015 in “an attempt to summarize everything I’ve learned” about fire’s intimate relationship with humanity. He has written nearly 30 books on the subject but has struggled throughout his career to find an academic home for his fire-focused work, which didn’t fit cleanly into one department. The subject “was never taught, certainly not at the places where I went to school.” For Pyne’s part, though, he sees fire as an aspect of biology—“a creation of the living world and dependent on the living world.”

Kevin Cooley
Life in the Pyrocene

In the 1960s Kevin Cooley’s mother lost her Los Angeles home in a wildfire. “She talked about ‘before the fire’ and ‘after the fire,’” recalls Cooley (*above*). In that way, fire has always been present in his life—plus, he was “a little bit of a pyromaniac” as a kid. Now a photographer based in L.A., he has made fire one of his central subjects. He began by shooting wildfires, and then, in 2013, he was inspired by the Vatican enclave’s smoke signals to create his own blazes in controlled environments. His work can involve explosions, flares, drones, laser beams and copious amounts of smoke.

Cooley is a “big fan” of Stephen Pyne’s books about fire’s relationship to humanity. So when *Scientific American* asked Cooley whether he would be interested in creating work for Pyne’s feature on the Pyrocene, he thought, “Are you kidding me? Is there anything I’d be more interested in?” For the project, Cooley worked with a fire-breather for the first time, a military veteran named Kavan O’Toole. The experience made him want to incorporate people with this uncommon skill into future projects. “I was like, wow, this is a whole different conversation. I’m going to work with [fire-breathers] some more.”

Joanne Silberner
A Healthy Dose of Quiet

Until recently, Joanne Silberner lived near a highway in Seattle. “When we bought the house, [the highway] wasn’t that loud,” she says. But as its surface deteriorated, it became “loud enough that we couldn’t have a conversation in the backyard.” So Silberner, a multimedia journalist covering medicine and health policy, moved across Puget Sound to Bainbridge Island, where it’s quiet enough to hear the coyotes and the harbor seals calling at night. “It’s made such a difference in my quality of life,” she says. “I didn’t realize how anxious the sound was making me.”

In her article, Silberner covers the deleterious and understudied effects noise can have on our health. Despite clear evidence of the harms of excessive noise—which are borne primarily by disadvantaged communities—noise pollution is barely regulated, leaving people to “suffer without any kind of government intervention,” she says.

Throughout her career, Silberner has been guided by a quote from journalist Amy Goodman: “Go where the silence is and say something.” For this story, Silberner found the directive particularly apt: “There’s not much public awareness of the health effects of noise.”

Amanda Montañez
Graphic Science

Amanda Montañez has always preferred creating observational art based on the world around her over drawing solely from her imagination. As a studio art major in college, “I always loved figure drawing the most,” she says. After working in the art world for a few years, Montañez decided to go to graduate school for medical illustration. During her master’s research project, which communicated to pregnant people how to navigate midwifery care, she “was just kind of struck by how important data visualization is,” especially in helping people understand their health-care options. That ultimately led Montañez to *Scientific American*, where she’s been a graphics editor over the past nine years.

In this issue’s Graphic Science column, Montañez charts how family sizes are shrinking across the world. The story “hit fairly close to home,” she says. Montañez grew up with her grandparents—who lived on the other side of her family’s duplex—as “built-in babysitters.” Now with a young child of her own, she finds herself without family nearby to help with day care. In coming decades, she says, “a lot more people are going to be where I am.”

Allison Parshall is an associate news editor at *Scientific American* who often covers biology, health, technology and physics. She edits the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, Parshall contributes to *Scientific American*'s podcast *Science Quickly*. Her work includes a three-part miniseries on music-making artificial intelligence. Her work has also appeared in *Quanta Magazine* and Inverse. Parshall graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

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Poem: ‘Lucy’

Science in meter and verse

By Lucille Lang Day

Masha Foya

Edited by Dava Sobel

A petite fossilized being of the species
Australopithecus afarensis, she lived
in Ethiopia about three million years ago,
walked upright, three and a half feet tall,
and had a pubic arch similar to that
of a modern woman, but a very small brain.

She was named for the Beatles song
“Lucy in the Sky with Diamonds,”
which was played loudly, over and over
again, in the camp of the anthropologists
who found her in the Awash Valley
of the Afar Triangle at the foot of a gully.

On supporting science journalism

Another Lucy, a chimpanzee born
in 1964, learned American Sign Language.
Using 140 signs, she was interviewed
by the *New York Times* and invited
the reporter into her tree. He declined.
She could have offered to make him tea.

As an adult, she became destructive
when displeased, so her adoptive parents
sent her for rehabilitation in the jungle
of Gambia, but she was depressed there,
often signing “hurt.” She rejected male
chimpanzees, preferring a human mate.

A space mission to the Trojan asteroids
orbiting the sun with Jupiter is also called
Lucy, after the fossil lady from Africa
whose existence shook up the hominin tree.
Lucy the spacecraft will probe mysteries
of organic chemistry and planet formation.

And what about Lucy, the woman raised
on *I Love Lucy*, who often hears her name
called at dog parks? She is waiting to learn
how hominins morphed into humans, why
chimps and monkeys don’t talk, and how
worlds bloomed in the field of space.

Lucille Lang Day is the award-winning author or editor of 20 books, including most recently the collection *Birds of San Pancho and Other Poems of Place* (Blue Light Press, 2020) and the anthology *Poetry and Science: Writing Our Way to Discovery* (Scarlet Tanager Books, 2021). She is also founder and publisher of Scarlet Tanager Books.

Biotech

- ## ‘Smart Gloves’ Teach Piano Playing through Touch
  A high-tech pair of gloves can help make learning instruments and other hands-on activities easier

‘Smart Gloves’ Teach Piano Playing through Touch

A high-tech pair of gloves can help make learning instruments and other hands-on activities easier

By Riis Williams

Thomas Fuchs

Made of thin cotton and stitched together in only 20 minutes, an experimental pair of gloves isn’t particularly fashionable or useful for keeping anyone’s hands warm. Instead the accessory uses tactile sensors woven into its fabric to serve an entirely different purpose: teaching piano and other hands-on skills.

For a study in *Nature Communications*, Massachusetts Institute of Technology graduate student Yiyue Luo and her colleagues created these “smart gloves” using haptic technology, which incorporates physical sensations such as vibrations or force to help with tactile activities. Researchers used the gloves to record one pianist’s hand movements while playing a song. They then relayed those movements to a student through fingertip vibrations, helping the learner build muscle memory and perform the piece with greater precision. “Hand-based movements like piano playing are normally really subjective and difficult to record and transfer,” Luo says. “But with these gloves we are actually able to track one person’s touch experience and share it with another person to improve their tactile learning process.”

Using a computerized embroidery machine, the team embedded small wires linked to a pressure-sensing material in the gloves to detect hand motions. When a piano teacher wearing the gloves repeatedly performed a tune, a machine-learning algorithm processed their movement on the keys and translated it into instructional vibrations. Students wearing their own gloves then attempted to play the same tune, with the fingertip vibrations guiding them through proper movements. (The vibration intensity increased to correct fingering or rhythm mistakes.) By the trials’ end, students who had practiced with the gloves could play more accurately than those who had not. “This type of learning is sort of like when you’re first starting to ride a bike,” says Rice University mechanical engineer Marcia O’Malley, who was not involved in the study. “You use the training wheels to get the sensation of properly riding the bike. Eventually you take them off and start to ride independently.”

The team also tested the gloves’ ability to aid people playing online games with a mouse and keyboard, recording motions from experienced players to guide novices. People who gamed with the gloves' guidance scored better on average than those who did not.

Playing piano or video games is often just for fun, but O'Malley adds that with an improved algorithm, coded to identify and capture finer hand movements, the new glove technology could someday help to teach crucial practices such as surgeries. Instructional haptics "remove a step in the learning process that auditory and visual learning can't," she says. "When vibration is actually felt directly at the point of action, we can act and learn quicker—and with that, there's so much potential."

Riis Williams is a New York City–based science journalist who specializes in climate, health and wildlife reporting. She formerly served as *Scientific American's* news intern.

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Book Reviews

- **How Plant Intelligence Can Soothe Climate Anxiety**
  In a new book, the wisdom of plants is a balm for our changing planet
- **The Dark Side of Nostalgia for Wild, Untouched Places**
  A novel about the tensions between nature and modernity, animal social networks, and more books out now

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How Plant Intelligence Can Soothe Climate Anxiety

In a new book, the wisdom of plants is a balm for our changing planet

By David George Haskell

Chanelle Nibbelink

NONFICTION

The Light Eaters: How the Unseen World of Plant Intelligence Offers a New Understanding of Life on Earth
by Zoë Schlanger.
Harper, 2024 ($29.99)

For a species entirely dependent on plants for food and a livable planet, we give plants curiously little respect. Museums and nature documentaries usually relegate them to the background, mere scenery for the action of animal evolution. This is an ancient bias. Less than 1 percent of European Paleolithic cave paintings feature plants. If you're a plant disdainer, *The Light Eaters*, a stunning book on recent discoveries in plant biology by journalist Zoë Schlanger, will transform how you see not only plants but the nature of all life. And if you are already convinced that plants are fascinating and important, it will deepen your appreciation.

Plant "intelligence" is a controversial idea among biologists. Shoddy but widely reported experiments in the 1970s claimed to show humanlike behaviors in plants, such as enjoying Beethoven and responding to polygraph tests. Scorn for this New Age froth meant that, until relatively recently, studies of animal-like qualities in plants were taboo among respectable plant scientists. Now scientific discoveries have reignited debate. Through Schlanger's careful reporting, we come to understand multiple perspectives rather than being bullied into one camp or another. Schlanger believes plant biology is a "case study" of a scientific revolution in progress. Conflict among competing ideas is, she shows, a necessary part of paradigm change.

Curiosity drives Schlanger's narrative. Do plants sense a wound? We feel her excitement and hesitation as she uses tweezers to pinch a cress leaf. The plant has been genetically modified so that its cells glow when electrical charges pass through them. She is too hesitant with the tweezers at first, then presses hard. The leaf immediately lights up, “veins blazing like a neon sign.” A wave of electrical activity moves through the cress at a millimeter per second until the entire plant is suffused with information about the damaged leaf. The parallels to human pain are visually obvious. Technology paves the way to empathy. As a gardener and cook, I yank and slice plants many times every day. Through Schlanger’s vivid writing, I now understand these plants as living beings that respond to danger on the scale of seconds. I am, as Schlanger writes of her own changed perspective, “regaining material intimacy with the natural world.”

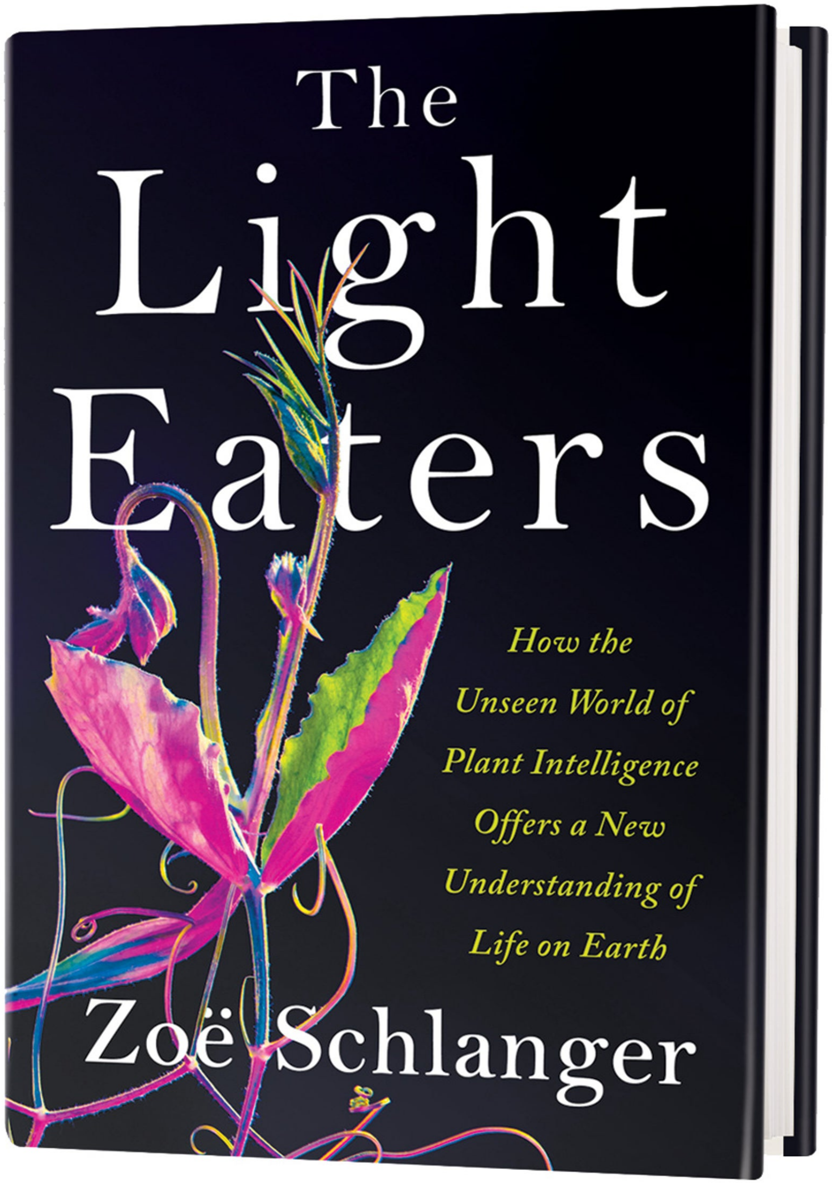
Should I feel guilty or stop gardening? Hardly. We’re animals, so we must eat light indirectly by chomping on plants or on animals that once ate plants. Waves of electrical activity in plant veins are not the same as nerve impulses flowing from animal pain receptors. Biologically and ethically, slicing cabbages differs from cutting animal flesh. Yet an anesthetic can quiet a cabbage’s electrical signals just as it does an animal’s nerves.

The question of plant consciousness looms in the background of these intriguing findings. Wisely, Schlanger points out that we know little about the neural basis of consciousness in animals, let alone in nerveless plants. But her visits to field sites and labs leave no doubt that, conscious or not, plants sense their surroundings and make sophisticated decisions. Leaves pick up the sounds of chewing caterpillars and mount appropriate chemical defenses. Flowers sweeten their nectar when they sense pollinators flying by. Flowers and bees sense one another through ever shifting electrical fields. Plants seem to use memory to adjust their growth and even minute-by-minute presentation of pollen.

The scientific study of plants has advanced to the point where we could drop the quotation marks from plant “intelligence” without fear of veering toward pseudoscience. We must also, though, acknowledge plants' wondrous otherness. Plants sense, remember and make decisions throughout their bodies, in contrast to our primarily brain-centered intelligence.

A personal journey motivates the book and gives it ethical heft. After six years of writing about climate change, Schlanger felt that a "crawling sense of dread threatened to eclipse me." To counter this darkness, she sought stories that "felt wonderful and alive," a quest that led her to plants. Sustained at home by the "satisfying plant drama" of clambering vines and unfurling leaves, she also found pleasure and solace in the latest botanical scientific discoveries. Reading about her pursuit of plant wonder, I felt a growing sense of admiration for plants and kinship with their lives.

This shifted perspective is at the core of the paradigm change that Schlanger explores. Understanding plants' intelligence reframes our everyday experience of eating plants or seeing them growing out of a crack in the sidewalk. In an age when we often feel alienated from a living world in crisis, it is good to be reminded that other species have agency and acumen. Plants have thrived on Earth for half a billion years. They embody not only intelligence but wisdom about how to flourish in the face of change.



David George Haskell is a biologist and award-winning author. His latest book is *Sounds Wild and Broken* (Penguin Books, 2022).

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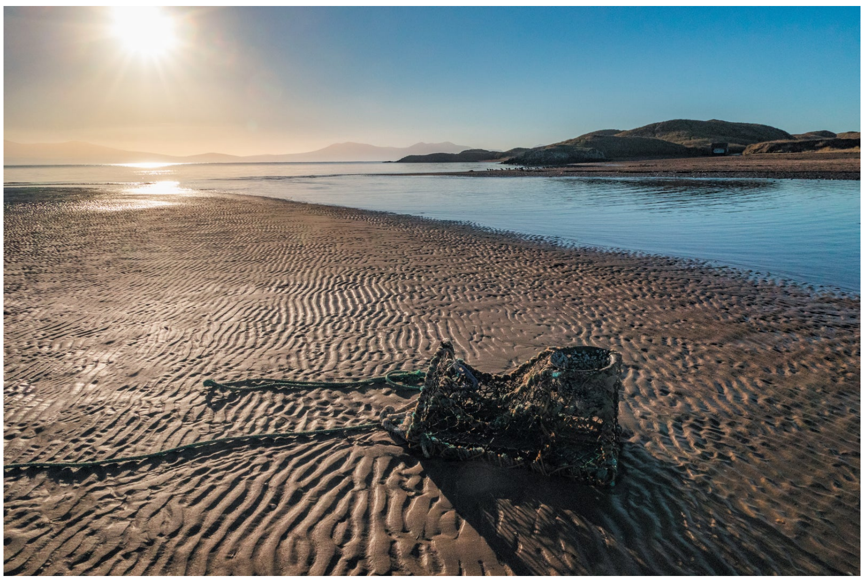
The Dark Side of Nostalgia for Wild, Untouched Places

A novel about the tensions between nature and modernity, animal social networks, and more books out now

By Robin Marie MacArthur



People influence even the wildest places.
Bob-McCraight/Getty Images

FICTION

Whale Fall: A Novel

by Elizabeth O'Connor.
Pantheon, 2024 ($27)

It’s September 1938, and a dead whale washes up on the beach of a remote island off the coast of Wales. So begins this haunting narrative about our waning connection with the land, the isolation and entrapment of rural places (especially for women), human nostalgia, and how it feels to live in a time and place on the cusp of radical change.

Manod, 18 years old, lives in Rose Cottage with her father, her sister and the shadow of her dead mother. She spends her days embroidering stories of humans and whales, gathering seabird eggs from among the rocks with her sister, and dreaming of how and when she will leave this small fishing community behind (as all its young people do).

Not long after the whale washes up on shore (an omen and sign of some kind, according to the islanders), a boat arrives carrying two ethnographers from the mainland. They come in search of the “old ways” with the hope of capturing premodern relations with the natural world, and they spend their days recording folk songs and tales, cataloging Manod’s embroideries and photographing the islanders. For them, Manod and the residents represent everything they want: a raw and wild embeddedness and authenticity. For Manod, they represent everything she wants: an education, modernism, life beyond the island.

Exploring this gap in her debut novel, Elizabeth O’Connor brilliantly exposes the faults in nostalgia and renders ethnography’s troubling history of fabricated documentation, extractionist relationships and links with fascism. Yet she also tenderly portrays what the ethnographers came in search of: lives deeply interlaced with nature, a burgeoning landscape with an abundance of species (birds, animals, moss, lichen, sheep, sea creatures), and a way of life in which the human and nonhuman are still inextricably entwined via livelihood, story and myth.

These minimalist pages shimmer with haunting legends and songs in which a fairy finds her seal skin and disappearsinto the sea, a woman is swallowed by a sea snake and becomes a winter storm, skeletons become gray doves, and daughters become whales. I found myself both yearning for Manod's escape from the island and hoping she might never leave. What a testament to the capaciousness, generosity and emotional range of true art.

IN BRIEF

Halcyon
by Elliot Ackerman.
Knopf, 2023 ($28)

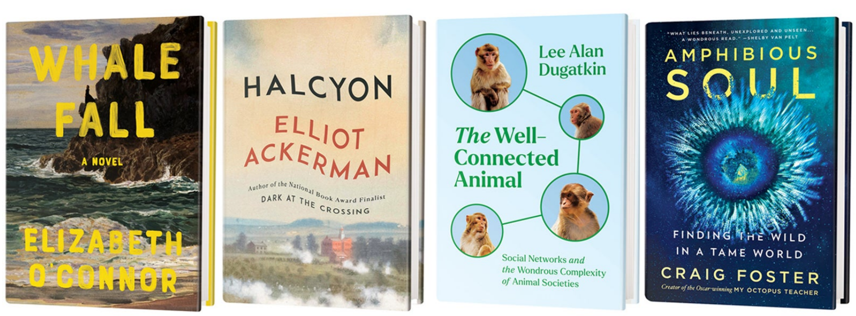
Former Marine Elliot Ackerman layers re-created political history and regenerative science to illuminate the value of compromise and reconciliation. In an alternative history where Bill Clinton resigned and Al Gore had Osama bin Laden killed months after 9/11, historian Martin Neumann laments the plague of political polarization and the "role of compromise in the sustainment of American life." Neumann also contends with the contradictory attitudes of his landlord, the first successful case of genetic resurrection, a new science developed after the mapping of the human genome. Ackerman skillfully provokes philosophical debate on the necessity of death for people, among other ideas. —*Lorraine Savage*

The Well-Connected Animal: Social Networks and the Wondrous Complexity of Animal Societies
by Lee Alan Dugatkin.
University of Chicago Press, 2024 ($29)

In the past 20 years social network analysis has revolutionized our understanding of animal societies. By studying the flow of information within animal groups, animal behaviorists have shown that sophisticated social networks "permeate the natural world." Historian of science Lee Alan Dugatkin reveals the network dynamics behind giraffes' nurseries and vampire bats' reciprocal blood sharing, as well as the dedication necessary to collect these data. Although it may require researchers to paint numbers on honeybees, social networking theory confirms that complex social dynamics are not just for humans. —*Dana Dunham*

Amphibious Soul: Finding the Wild in a Tame World
by Craig Foster.
HarperOne, 2024 ($29.99)

Documentarian Craig Foster won an Academy Award in 2021 for My Octopus Teacher, in which he filmed himself forging a bond with a common octopus. Here he tackles a wilier, more elusive subject—himself. Not even a screenwriter could top Foster's thrilling lived experiences, such as diving into a literal crocodile's den and swimming with sharks. But written text isn't his forte, and jarring subsections and clichéd prose show he's out of his depth (he recounts softly telling the ocean, "Teach me about you ... I want to learn"). Perhaps unintentionally, the memoir evades the question: Does nature exist for us or for itself? —*Maddie Bender*



Robin Marie MacArthur is author of *Half Wild* and *Heart Spring Mountain*. She lives on her family farm in Vermont and teaches writing at Vermont College of Fine Arts.

Cognition

- **Why Writing by Hand Is Better for Memory and Learning**
  Engaging the fine motor system to produce letters by hand has positive effects on learning and memory

Why Writing by Hand Is Better for Memory and Learning

Engaging the fine motor system to produce letters by hand has positive effects on learning and memory

By Charlotte Hu

Studies continue to show pluses to writing by hand.
Image Source/Getty Images

Handwriting notes in class might seem like an anachronism as smartphones and other digital technology subsume every aspect of learning across schools and universities. But a steady stream of research continues to suggest that taking notes the traditional way —with pen and paper or even stylus and tablet—is still the best way to learn, especially for young children. And now scientists are finally zeroing in on why.

A recent study in *Frontiers in Psychology* monitored brain activity in students taking notes and found that those writing by hand had higher levels of electrical activity across a wide range of interconnected brain regions responsible for movement, vision, sensory processing and memory. The findings add to a growing body of evidence that has many experts speaking up about the importance of teaching children to handwrite words and draw pictures.

Differences in Brain Activity

The new research, by Audrey van der Meer and Ruud van der Weel at the Norwegian University of Science and Technology (NTNU), builds on a foundational 2014 study. That work suggested that people taking notes by computer were typing without thinking, says van der Meer, a professor of neuropsychology at NTNU. “It’s very tempting to type down everything that the lecturer is saying,” she says. “It kind of goes in through your ears and comes out through your fingertips, but you don’t process the incoming information.” But when taking notes by hand, it’s often impossible to write everything down; students have to actively pay attention to the incoming information and process it—prioritize it, consolidate it and try to relate it to things they’ve learned before. This conscious action of building onto existing knowledge can make it easier to stay engaged and grasp new concepts.

To understand specific brain activity differences during the two note-taking approaches, the NTNU researchers tweaked the 2014 study’s basic setup. They sewed electrodes into a hairnet with 256 sensors that recorded the brain activity of 36 students as they wrote or typed 15 words from the game Pictionary that were displayed on a screen.

When students wrote the words by hand, the sensors picked up widespread connectivity across many brain regions. Typing, however, led to minimal activity, if any, in the same areas. Handwriting activated connection patterns spanning visual regions, regions that receive and process sensory information and the motor cortex. The latter handles body movement and sensorimotor integration, which helps the brain use environmental inputs to inform a person's next action.

"When you are typing, the same simple movement of your fingers is involved in producing every letter, whereas when you're writing by hand, you immediately feel that the bodily feeling of producing A is entirely different from producing a B," van der Meer says. She notes that children who have learned to read and write by tapping on a digital tablet "often have difficulty distinguishing letters that look a lot like each other or that are mirror images of each other, like the b and the d."

Reinforcing Memory and Learning Pathways

Sophia Vinci-Booher, an assistant professor of educational neuroscience at Vanderbilt University who was not involved in the new study, says its findings are exciting and consistent with past research. "You can see that in tasks that really lock the motor and sensory systems together, such as in handwriting, there's this really clear tie between this motor action being accomplished and the visual and conceptual recognition being created," she says. "As you're drawing a letter or writing a word, you're taking this perceptual understanding of something and using your motor system to create it." That creation is then fed back into the visual system, where it's processed again—strengthening the connection between an action and the images or words associated with it. It’s similar to imagining something and then creating it: when you materialize something from your imagination (by writing it, drawing it or building it), this reinforces the imagined concept and helps it stick in your memory.

The phenomenon of boosting memory by producing something tangible has been well studied. Previous research has found that when people are asked to write, draw or act out a word that they’re reading, they have to focus more on what they’re doing with the received information. Transferring verbal information to a different form, such as a written format, also involves activating motor programs in the brain to create a specific sequence of hand motions, explains Yadurshana Sivashankar, a cognitive neuroscience graduate student at the University of Waterloo in Ontario who studies movement and memory. But handwriting requires *more* of the brain’s motor programs than typing. “When you’re writing the word ‘the,’ the actual movements of the hand relate to the structures of the word to some extent,” says Sivashankar, who was not involved in the new study.

For example, participants in a 2021 study by Sivashankar memorized a list of action verbs more accurately if they performed the corresponding action than if they performed an unrelated action or none at all. “Drawing information and enacting information is helpful because you have to think about information and you have to produce something that’s meaningful,” she says. And by transforming the information, you pave and deepen these interconnections across the brain’s vast neural networks, making it “much easier to access that information.”

The Importance of Handwriting Lessons for Kids

Across many contexts, studies have shown that kids appear to learn better when they’re asked to produce letters or other visual items using their fingers and hands in a coordinated way—one that can't be replicated by clicking a mouse or tapping buttons on a screen or keyboard. Vinci-Booher's research has also found that the action of handwriting appears to engage different brain regions at different levels than other standard learning experiences, such as reading or observing. Her work has also shown that handwriting improves letter recognition in preschool children, and the effects of learning through writing "last longer than other learning experiences that might engage attention at a similar level," Vinci-Booher says. Additionally, she thinks it's possible that engaging the motor system is how children learn how to break "mirror invariance" (registering mirror images as identical) and begin to decipher things such as the difference between the lowercase b and p.

Vinci-Booher says the new study opens up bigger questions about the way we learn, such as how brain region connections change over time and when these connections are most important in learning. She and other experts say, however, that the new findings don't mean technology is a disadvantage in the classroom. Laptops, smartphones and other such devices can be more efficient for writing essays or conducting research and can offer more equitable access to educational resources. Problems occur when people rely on technology *too much*, Sivashankar says. People are increasingly delegating thought processes to digital devices, an act called "cognitive offloading"—using smartphones to remember tasks, taking a photo instead of memorizing information or depending on a GPS to navigate. "It's helpful, but we think the constant offloading means it's less work for the brain," Sivashankar says. "If we're not actively using these areas, then they are going to deteriorate over time, whether it's memory or motor skills."

Van der Meer says some officials in Norway are inching toward implementing completely digital schools. She claims first grade teachers there have told her their incoming students barely know how to hold a pencil now—which suggests they weren't coloring pictures or assembling puzzles in nursery school. Van der Meer says they’re missing out on opportunities that can help stimulate their growing brains.

“I think there’s a very strong case for engaging children in drawing and handwriting activities, especially in preschool and kindergarten when they’re first learning about letters,” Vinci-Booher says. “There’s something about engaging the fine motor system and production activities that really impacts learning.”

A version of this article entitled “Hands-on” was adapted for inclusion in the May 2024 issue of Scientific American.

Charlotte Hu is a science and technology journalist based in Brooklyn, N.Y. She's interested in stories at the intersection of science and society. Her work has appeared in *Popular Science*, GenomeWeb, Business Insider and *Discover* magazine.

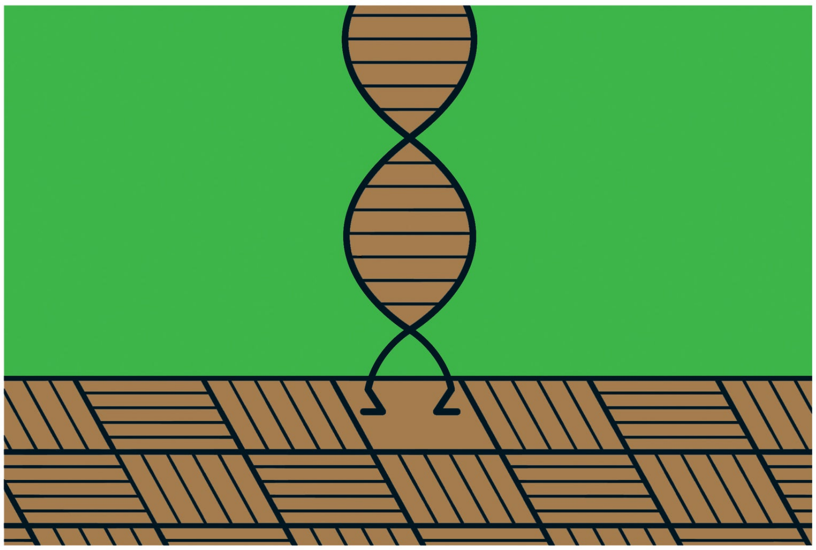
Computing

- **A 'Computer' Built from DNA Can Find Patterns in Photographs**
  Artificial DNA sorts images like a neural network does

A ‘Computer’ Built from DNA Can Find Patterns in Photographs

Artificial DNA sorts images like a neural network does

By Allison Parshall



Thomas Fuchs

Brains are the quintessential decision-makers, gathering and weighing information before choosing a path forward. But in the natural world, many simpler systems accomplish similar tasks. Cells use networks of chemical signals to determine when to reproduce or die. Even water could be said to “decide” whether it will freeze into a snowflake or a hailstone, given the transformation’s exceedingly complex physics, says Erik Winfree, a molecular computing researcher at the California Institute of Technology.

Winfree has long been intrigued by the physical world’s hidden information-processing abilities. For a recent study in *Nature*, he and his collaborators designed a group of artificial DNA strands that, together, can recognize patterns and categorize information.

The system bears key similarities to the “neural network” algorithms that underpin many artificial-intelligence models.

To build computerlike circuits with biological machinery, researchers often turn to self-assembling DNA molecules. These customized strands (or “tiles”) of DNA, when combined in a test tube and cooled, assemble into predictably shaped mosaics that can convey information.

The scientists wanted to know whether that type of setup could recognize patterns—such as by sorting grayscale photographs into categories. To represent images in a test tube, the scientists created a code in which each image pixel corresponded to a particular “shape” of DNA tile. The lighter a pixel, the more of its corresponding DNA tile would be present in the solution.

When cooled, the tiles snapped together like a self-assembling jigsaw puzzle into one of three possible shapes, depending on the balance of DNA tile shapes in the mixture. Each shape represented a category, explains co-author Constantine Glen Evans, a molecular computing researcher now at Maynooth University in Ireland.

The system was built to sort 18 photos into three arbitrary categories, but it could also classify images it had never seen before, such as distorted versions of the same pictures. Like a neural network, it recognized general similarities in images “rather than looking for an exact match,” says co-author Arvind Murugan, a physicist at the University of Chicago.

The research is intended not to be an alternative to neural networks themselves but instead to reveal the computational abilities “that matter already has,” Murugan says. The scientists hope to find similar computational abilities within other systems in nature; such abilities “could be hidden in all kinds of things that we don’t notice,” Murugan says.

“It’s just intrinsically interesting,” says biomolecular engineer Rebecca Schulman of Johns Hopkins University, who was not involved in the new research. The fact that information can be stored implicitly through the interactions of large groups of molecules, similarly to how it’s stored in large groups of neurons in a neural network, “is something that I have never seen before,” she says.

The findings are like a first, fleeting glimpse at an “exotic” deep-sea ecosystem, Schulman adds. “It’s maybe a calling to go back and look harder.”

Allison Parshall is an associate news editor at *Scientific American* who often covers biology, health, technology and physics. She edits the magazine's Contributors column and weekly online Science Quizzes. As a multimedia journalist, Parshall contributes to *Scientific American*'s podcast *Science Quickly*. Her work includes a three-part miniseries on music-making artificial intelligence. Her work has also appeared in *Quanta Magazine* and Inverse. Parshall graduated from New York University's Arthur L. Carter Journalism Institute with a master's degree in science, health and environmental reporting. She has a bachelor's degree in psychology from Georgetown University. Follow Parshall on X (formerly Twitter) @parshallison

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Culture

- **Fossil and Living Birds Reveal the Dazzling Biology of Feathers**
  Reducing noise improves health, JWST’s galaxies change astronomy, and there’s new hope for people with prostate cancer
- **Readers Respond to the January 2024 Issue**
  Letters to the editors for the January 2024 issue of Scientific American

The Dazzling New Science of Feathers

Reducing noise improves health, JWST’s galaxies change astronomy, and there’s new hope for people with prostate cancer

By Laura Helmuth

Scientific American, May 2024

Have you ever picked up a feather and felt how smooth, sleek, firm or fluffy it is? (The Migratory Bird Treaty Act prohibits possession of most bird feathers, but if you find a feather and stick it in your cap or pack, nobody here at *Scientific American* will turn you in.) Feathers are marvels of evolutionary engineering that have been studied for centuries, but in the past few years, as paleontologist Michael B. Habib details, scientists have made some big discoveries about their evolution, structure and function. We hope the story will help you appreciate the specializations of hummingbirds, hawks, penguins, owls, and more.

The “strong force” that pulls together protons, neutrons and atomic nuclei is, as its name suggests, the strongest force we know of in the universe. It’s also the least understood. But recently physicists have made real progress in measuring the strong force. Among other things, they’ve discovered that it becomes constant at a certain distance between particles. Stanley J. Brodsky, Alexandre Deur and Craig D. Roberts recount how their independent lines of research merged to uncover new properties of the force that binds together most of the matter in the universe.

Children want to be fair, and they acquire a sense of justice at a very young age: they quickly learn that hurting other people is wrong and that sharing is right. But this developing sense of morality can conflict with their developing sense of belonging. Children readily pick up on us-versus-them group identities based on factors such as race and gender. Psychologist Melanie Killen describes what she and her colleagues have learned about morality and prejudice in children. Based on their research, they created a training program that successfully teaches kids to be more inclusive and empathetic.

We are living in the age of fire—the Pyrocene, a term coined by environmental historian Stephen Pyne. As he writes, humans tamed fire and changed the world. He breaks our relationship with fire into three waves and chronicles how fire has changed human bodies and civilization and is now changing all life on the planet. Enjoy the dramatic, fire-breathing photo-essay by Kevin Cooley that accompanies the article.

Prostate cancer is one of the most common types of malignancies, but thanks to advances in detection, evaluation and treatment, it has become increasingly manageable. Marc B. Garnick, a leading expert on prostate cancer, explains how the disease starts and grows. He also provides an overview of the methods that can now be used to monitor and stop it, adding years to patients' lives.

Some of the first images captured by the James Webb Space Telescope a few years ago were shocking: they revealed overgrown galaxies in the early universe—galaxies that, according to cosmological theory, shouldn't have existed. As science writer Jonathan O'Callaghan shows, astronomers are coming up with new theories to explain these unexpected galaxies and improve our understanding of their formation.

One of the things I appreciate most about walks in nature (the kinds of walks where you might find a feather and where the loudest sound is a screaming cicada) is how peaceful they are. If you've ever tensed up in irritation at leaf blowers, shouty bars, obnoxious car horns, or other noise pollution, health correspondent Joanne Silberner's story may feel like vindication. A growing body of research documents how and why noise can cause a range of health problems and how you can reduce your exposure to improve your health. And our Science of Health columnist Lydia Denworth explores the importance of nature and well-being. May you be surrounded by pleasant and welcome sounds as you delve into this month's issue.

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

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Readers Respond to the January 2024 Issue

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

By Aaron Shattuck

Scientific American, January 2024

VIEW FROM THE VOID

“Cosmic Nothing,” by Michael D. Lemonick, describes large empty areas of the universe called voids. It includes a quote from astronomer Gregory Scott Aldering concerning a void in the constellation Boötes: “If the Milky Way had been in the centerof the Boötes void, we wouldn’t have known there were other galaxies [in the universe] until the 1960s.” What technology came into play at that time that would have allowed us to see and identify galaxies for the first time?

RICK FRANEY *BELLINGHAM, WASH.*

On supporting science journalism

In the same manner as the scenario with the Milky Way and the Boötes void, I would imagine that if our present universe were in a huge void with a radius of more than 14 billion light-years, we would not know of other universes outside it. What are the possibilities of that?

HIROYUKI UCHIDA *TOKYO*

LEMONICK REPLIES: *Regarding Franey's question: Aldering may well have been referring to electronic detectors that replaced photographic plates used for recording the light gatheredby our biggest telescopes. These detectors were invented in the late 1960s, although they weren't used in earnest in astronomy until a few years afterward.*

To answer Uchida: It's interesting to speculate about what things would look like if our entire universe were inside a gigantic void, but we know of no way such a void could be created. The voids I discuss in the article were formed mostly by the effects of dark matter and dark energy in an expanding universe. Something else would be necessary to create a void more than 28 billion light-years across.

SUPPLEMENTAL DAMAGE

As a physician who embraces critical thinking, I appreciated "The Rise and Fall of Vitamin D," by Christie Aschwanden. The article focused on how worries about widespread vitamin D deficiencies are overblown. There are also dangers of vitamin D excess, which can cause hypervitaminosis D. This condition involves acute toxicity caused by high levels of calcium in the blood and can include confusion, vomiting and muscle weakness.

Vitamin D is fat-soluble, and as Aschwanden points out, it is stored in body fat and the liver. Chronic consumption of “megadoses” can lead to chronic intoxication, which may lead to kidney stones, bone demineralization and ectopic calcification. People can avoid toxicity when they get vitamin D from biosynthesis through exposure to sunlight.

There are many who think more and more consumption of vitamins must be beneficial. Taking megadoses of water-soluble vitamins and minerals just produces expensive urine and something to brag about at cocktail parties.

RALPH M. JONES *CHILLIWACK, BRITISH COLUMBIA*

WILD TILE

In “The Missing Piece,” Craig S. Kaplan describes the discovery of the first aperiodic monotile, a shape that can cover an infinite surface without repeating a pattern. It seems to me an inelegant loophole that mathematicians permit that tile (“the hat”) or the subsequently found shape called the turtle to be considered a monotile. Both must be reflected, which, in my mind, makes each two different tiles! The family of shapes called spectres repeat without flipping and were given arbitrary wavy edges to avoid reflections. But in physical reality, tiles generally have a definite front and back and can’t be just flipped, so there is no need for such edges in real life.

KEN WOOD *NEWPORT, WALES*

The pentagonal metatiles in the “Metatiles” and “Substitution (Metatiles)” diagrams are made up of slightly different shapes! I also notice that in the “Metatiles” illustration, the pentagonal metatile and the parallelogram-shaped metatile have the exact same underlying pair of hat tiles, which looks rather suspicious.

PHILIP KRAUSHAR *VIA E-MAIL*

At the beginning of the article there’s an illustration showing that regular pentagons don’t tile. I wonder, though, if the black kites in that illustration could be considered a second tile element and if the pentagons and kites together would be capable of an infinite tiling. If so, would that tiling be nonperiodic or aperiodic?

PETER FARSON *EUGENE, ORE.*

KAPLAN REPLIES: *In response to Wood: Reflecting a shape indeed makes it behave quite differently in the real world (think of shoes, for example). We can see as far back as Euclid’s time, however, that a shape and its reflection are regarded as “the same” in geometry. To me, that legitimizes the hat as a true aperiodic monotile, although spectres are still interesting for their ability to avoid reflections.*

Kraushar has done great detective work! At every level in our substitution process, the metatiles all flex slightly (except the equilateral triangle, of course). For that reason, we describe the rules as “nonrigid.” But they still work in that the analogousmetatiles at each generation combine to form supertiles using the same rules. The “Substitution (Metatiles)” diagram shows the theoretical limit of this flexing process: idealized shapes that truly are rigid. Needless to say, this was too much to explain in my article.As scientists are fond of saying, “see the paper for full details.”

To answer Farson: It's definitely possible to create tilings with regular pentagons and 36-degree rhombuses (the black shapes in that diagram). German artist Albrecht Dürer even studied such tilings in the early 16th century. They're quite beautiful, but they don't form an aperiodic set: you can construct periodic tilings from these two shapes.

AGING AND BMI

"Stepping Off the BMI Scale" [The Science of Health], Lydia Denworth's column on body mass index, did not mention changes in height as we age. At 83, I have lost about nine centimeters (3.5 inches) from scoliosis and kyphosis. My weight has not changed, but my BMI has gone up as my height has gone down. This is yet another reason to discount the BMI's medical importance.

LAWRENCE GETTLEMAN *VIA E-MAIL*

ERRATA

"Quick Hits," by Lori Youmshajekian [Advances], should have described niobium as a rare transition metal, not a rare-earth metal, in the entry about China.

"Not Your Father's DNA," by Sneha Khedkar, should have said that mitochondria power almost every type of human cell, not almost every human cell.

"The Era of Monster Telescopes," by Phil Plait [The Universe; March], should have said that the area of a telescope's mirror is proportional to the square of its radius, not that a telescope mirror's area is the square of its diameter.

In "Last Stand," by Alexis Marie Adams [April], the map of the Yaak River watershed incorrectly described Unit 72 as a 300-acre parcel. As noted in the main text, this area is 192 acres.

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

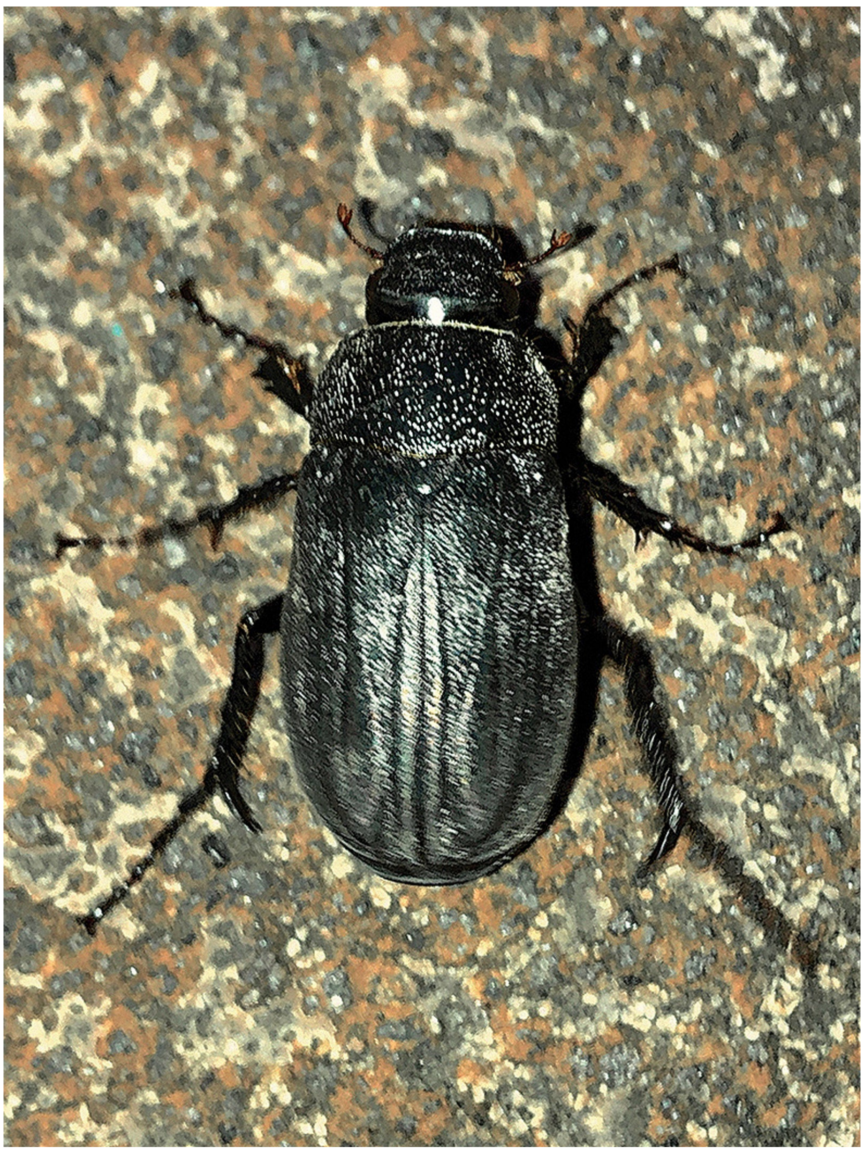
Genetics

- **Unraveling the Secrets of This Weird Beetle’s 48-Hour Clock**
  New research examines the molecular machinery behind a beetle’s strange biological cycle

Unraveling the Secrets of This Weird Beetle’s 48-Hour Clock

New research examines the molecular machinery behind a beetle’s strange biological cycle

By Andrew Chapman



Black chafer beetle.
KKPCW (CC BY-SA 4.0)

Nearly all animals follow 24-hour activity cycles based on their genetically built-in circadian clocks. But one beetle species operates in 48-hour time chunks instead—apparently driven by a strict schedule for sex. A study in *Current Biology* shows that a particular gene somehow activates with a two-day pattern to contribute to this cycle.

Both male and female black chafer beetles hide underground during the day and emerge every second night to search for food and a mate. Once aboveground, the females climb plant stalks while secreting sexy-smelling pheromone trails to lead males to them.

Walter Leal, a chemical ecologist at the University of California, Davis, had long wondered whether males of this species sense the females' pheromones on a 48-hour cycle as well. In the new study, he and his colleagues used a recently released "transcriptome"—a catalog of these insects' RNA—to finally dig into this schedule's genetic basis. They identified genes likely to produce odor receptors—and found that only one made a receptor fitting the female's pheromone. Their experiments confirmed that disrupting this gene's activity halted males' attraction.

Next the team monitored how much of this receptor the male beetles produced over time, to determine when they'd be best at tracking the pheromone. Receptor production spiked at night every 48 hours around the time female pheromone production peaked, then hit a low the next night. "We found a 48-hour [receptor-producing] cycle, which is synchronized with the females," Leal says. "It's a beautiful story." The findings show the 48-hour cycle is present in both sexes and engrained on the molecular level.

Biological rhythms typically rely on environmental cues such as day and night; there are no known 48-hour cues in nature. Future work will untangle what drives this cycle in black chafer beetles and how the genes regulate their timing. Jennifer Hurley, a biologist at Rensselaer Polytechnic Institute, says research is revealing how environmental signals can affect biological rhythms. With studies like this, she says, "the field is recognizing that the number of rhythms in biology is enormous."

Andrew Chapman is a Truckee, Calif.–based freelance science writer who covers life sciences and the environment.

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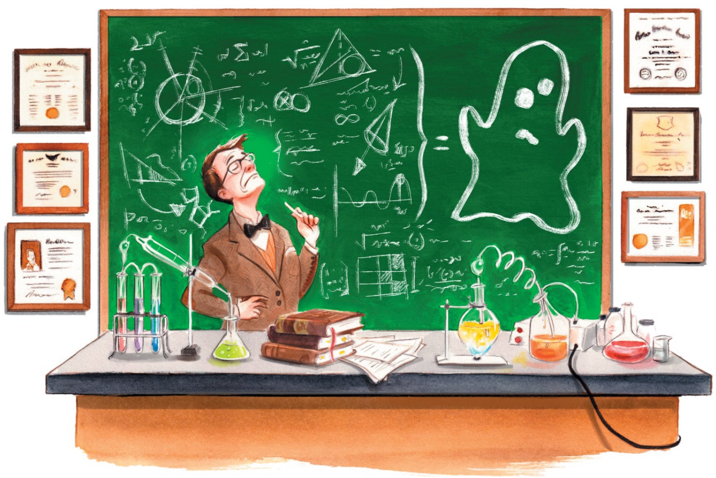
History

- ## In Matters of Scientific Debate, Follow the Houdini Rule
  Scientific expertise is typically limited and specific. When evaluating scientific claims, look to the relevant experts
- ## May 2024: Science History from 50, 100 and 150 Years Ago
  Pavlov’s dogs; Mercury’s dark side

In Matters of Scientific Debate, Follow the Houdini Rule

Scientific expertise is typically limited and specific. When evaluating scientific claims, look to the relevant experts

By Naomi Oreskes



Scott Brundage

In the late 19th and early 20th centuries, leading scientists around the world believed that paranormal activity might be detected and demonstrated by scientific methods. The history of their attempts tells us something important about the limits and specificity of scientific expertise.

The Society for Psychical Research was founded in the U.K. in 1882 to investigate possible paranormal activity, including mesmerism, thought transference, apparitions and even haunted houses. Prominent members included economist Henry Sidgwick, physicist Oliver Lodge (a pioneer in the study of electromagnetism), and writer Arthur Conan Doyle. These men sought to study the subject in a scientific manner, “without prejudice or prepossession of any kind.” Other well-known scientists who attended séances included Harvard University psychologist and philosopher William James (one of the founders of a philosophical school known as pragmatism) and British biologist Alfred Russel Wallace (who, along with Charles Darwin, developed the theory of evolution by natural selection).

Mainstream media reported on these efforts, often uncritically. “Soul Has Weight, Physician Thinks,” declared a *New York Times* headline on March 11, 1907. With four medical colleagues as witnesses, “reputable physician” Duncan MacDougall of Massachusetts had placed the body of a dying man on a specially designed bed, with built-in scales, next to an empty but otherwise identical bed. At the moment of the man’s death, the scales reportedly shifted, indicating a weight loss on his side of approximately one ounce. Five other cases showed losses between an ounce and half an ounce. In the case of one large, “phlegmatic” man, the weight loss was delayed a minute; MacDougall concluded that the deceased’s sluggish nature led his soul to depart without alacrity. (Wikipedia suggests this experiment is the source of the popular notion that the human soul weighs 21 grams.)

The *Times* similarly reported the work of Charles Henry, a mathematics professor at the Sorbonne in France. “Soul Can Be Measured, Mathematician Holds,” a headline announced on September 20, 1925. The evidence here consisted of radiating “biological vibration,” which occurred when death disrupted life’s delicate equilibrium. This observation marked "the first time science has ever admitted that tangible proof of the soul's existence may be found," the article asserted, insisting that the professor was not a "psychic or a dreamer" but a scientist who had harnessed "all the information available about colored auras and recollections of previous existences that so far have been almost exclusively exploited by cranks."

These accounts remind us that the views of a scientist are not necessarily equivalent to "science." MacDougall and Henry might have believed they had proved the soul's existence, but most of their contemporaries did not. One obvious problem was that these experiments assumed the existence of the thing they were trying to prove—essentially a circular argument.

The history of psychical research also shows why we should take novel scientific claims with a grain of salt, especially those that would fulfill one of our dearest wishes, such as communicating with lost loved ones or enjoying eternal life. What seems plausible today—even at Harvard and the Sorbonne—may appear preposterous down the road.

Perhaps the most important lesson, though—especially in our current environment saturated with misinformation and disinformation—concerns the specificity of scientific expertise: scientists are specialists, and their training rarely prepares them to evaluate claims beyond their particular areas of focus.

What expertise, exactly, would be needed to evaluate claims of the supernatural or paranormal? Another tale from the annals of psychic inquiry helps to answer that question. It is the story of Boston medium Mina Crandon, popularly known as "Margery."

In 1922 *Scientific American* announced the establishment of a prize committee to investigate psychic claims, promising $5,000 to anyone who could demonstrate the reality of paranormal or supernatural activity. Margery had been put forward as a candidate. Her evaluation committee included Harvard psychologist and member of the Royal Society William McDougall; Massachusetts Institute of Technology physicist Daniel F. Comstock (who later helped to develop the Technicolor process for making color movies); and world-renowned magician and escape artist Harry Houdini. Although the historical facts are somewhat disputed, it seems that the committee was leaning toward awarding Margery the prize until Houdini identified her techniques as the tricks they were. It was a magician—not a physicist or a mathematician—who had the expertise to recognize the supposed medium's sleight of hand.

Nowadays all kinds of people make scientific claims, often with little or no expertise in the matter at hand. Some are scientists driving outside their lane. American physicist and inventor William Shockley, who shared the 1956 Nobel Prize in Physics for creating the transistor, used his stature to promote racism and eugenics.

Physicist John F. Clauser, a 2022 Nobel Laureate who was honored for his contributions to quantum information science, is a self-declared climate change "denier" who has been taking to podiums around the world to argue against the scientific consensus that the planet is undergoing dangerous warming. Various celebrities have falsely claimed that vaccines cause autism, and politician Robert F. Kennedy, Jr., is spreading misinformation about vaccines as part of a presidential campaign.

So the next time you are wondering whom to trust about a scientific matter, ask yourself this: Who has the necessary expertise to assess this situation? Put simply: Who is the Houdini in this case?

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

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

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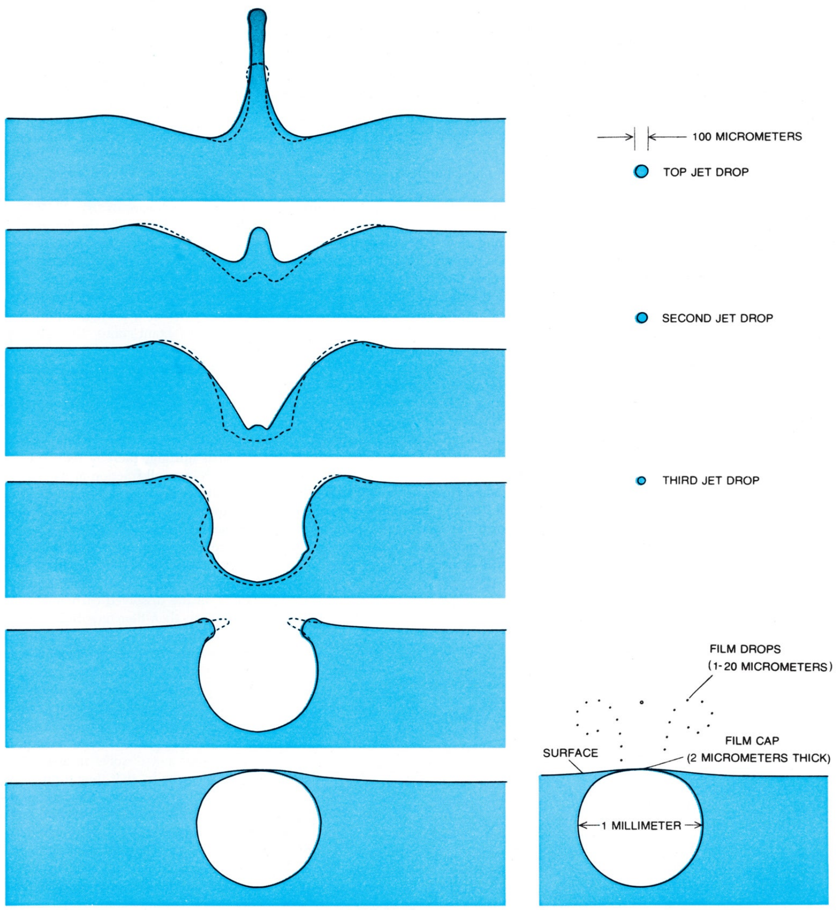
May 2024: Science History from 50, 100 and 150 Years Ago

Pavlov's dogs; Mercury's dark side

By Mark Fischetti



1974, Bursting Bubbles: "Some 3 or 4 percent of the sea surface is covered with bubbles at any moment. They provide the chief mechanism for injecting into the atmosphere substances in the top micrometer of the ocean [such as sodium and potassium ions, proteins and plankton]. The drawings show (*from bottom to top*) how a collapsing bubble projects a high-velocity jet of liquid into the air." *Scientific American*, Vol. 230, No. 5; May 1974

1974

Mercury's dark side

“On March 29, Mariner 10 transmitted revelatory information about Mercury. The spacecraft’s pictures showed that Mercury strongly resembles the Earth’s moon in that its surface is much cratered, little eroded and has large, smooth areas, or ‘seas.’ Moreover, data on the infrared radiation from the planet’s dark side and illuminated side indicate that its surface is much like the moon’s: low in density and therefore probably rich in silicon and poor in iron. The overall mass of Mercury, however, indicates that the density is 5.5 grams per cubic centimeter, compared with 3.3 grams for the moon. Its core must therefore consist of heavy material, probably rich in iron and poor in silicon. Thus Mercury, unlike the moon and like the Earth, is a highly differentiated body.”

1924

Hydrogen Bomb, Perhaps

“The atomic weight of hydrogen is not exactly 1.0 but by careful measurement is found to be 1.0077. In this slight discrepancy an immense store of possible energy is indicated, which someday, when we have learned how, may become accessible for good or ill. When hydrogen is packed into helium, [a small portion disappears]. The 1.0077 becomes 1.0. Although the disappearing fraction is small, the result would put all our other sources of energy to shame. The packing of atoms into atoms is a violent kind of phenomenon.

And the undoing of atoms into non-circulating ether is the most violent of all."

Pavlov's Dogs

"The basis of nervous activity is formed by so-called reflexes and instincts. For example, food stimulates the food reflex, which in animals consists of certain movements and secretions. But if some indifferent agent is presented many times with the feeding, it begins to stimulate the food reaction. Thus, if we produce some distinct musical sound and always at the same time feed a dog, after a while this sound, used alone, will produce the same food reaction as the food itself. In this way, some reflexes are acquired. The inborn reflexes we call unconditioned, and the acquired reflexes we call conditioned. —I. P. Pawlow of Petrograd [Ivan Petrovich Pavlov of St. Petersburg, Russia]"

1874

Mountains Hidden by Desert

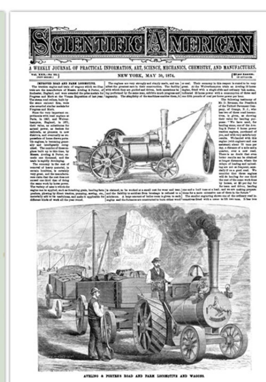
"Among the geological deductions of the Wheeler expedition are the following: All that portion of the U.S. west of the plains is characterized by corrugation, that is, the geological formations once horizontal have been bent and broken and thrown into ridges so as to produce a mountainous country. The ridges vary greatly but agree in general northerly trend. In the lower parts of this great mountain system, the slow but indefatigable agencies of rain and stream have accumulated so great an amount of detritus that the valleys are clogged and the mountains are nearly or quite buried. In this way have been produced the great desert plains of Utah, Arizona and Southern California, from the surface of which a few half-sunken peaks jut forth."

When the Skunk Bites

“While it is apparently difficult to add anything to the odium which is already attached to the common skunk, Rev. Horace C. Hovey brings forward proof that the animal is as dangerous as it is disagreeable. In a paper, he considers that a new disease has been discovered, to which he gives the name *rabies mephitica*, transmitted by the bite of the skunk. Mr. Hovey gives a large number of instances of people and animals dying from this cause in fearful convulsions. In view of the great number of skunks in portions of the country, it would appear that a more extended investigation into this disease is of much importance.”

Killer Mollusk

“The Jardin d’Acclimatation of Paris was recently presented with a medusan polypus, a rare species of mollusk, which was placed in a tank of water with similar organisms. To the surprise of the curators, it was found that after twenty-four hours the creature had killed every other occupant of the vessel. Analysis of the water proved that the liquid was water no longer, but vinegar. The polypus, it appeared, has the property of changing water into a strong acetic solution. The animal, it is said, produces alcohol, which it transforms into vinegar.”



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

- **How Our Thoughts Shape the Way Spoken Words Evolve**
  What makes a word survive or go extinct?

How Our Thoughts Shape the Way Spoken Words Evolve

What makes a word survive or go extinct?

By Anvita Patwardhan

Thomas Fuchs

Charles Darwin found inspiration for his theory of evolution in birds' beaks, giant tortoise shells—and language. "The survival or preservation of certain favored words in the struggle for existence is natural selection," he wrote in *The Descent of Man* in 1871.

Language gradually shifts over time. Much research examines how social and environmental factors influence language change, but very little grapples with the forces of human cognitive selection that fix certain words into the lexicon. For an extensive new study, published in the *Proceedings of the National Academy of Sciences USA*, scientists investigated just that.

In an experiment much like a game of telephone, thousands of participants read English-language stories and rewrote them to be read by other participants, who then rewrote them for others. Only certain words from the first stories survived in the final versions. Researchers analyzed the word types speakers consistently favored, theorizing that such preferences drive language change over time. The scientists also separately analyzed two large collections of English historical texts from the past two centuries, containing more than 40 billion words—again seeing only certain types survive.

The results converged to show three properties that give words an “evolutionary advantage” by helping them stick in the brain: First, words typically acquired at an early age (such as “hand,” “uncle” or “today”) are stabler. Next, concrete words linger better than abstract ones: “dog” persists longer than “animal,” which persists longer than “organism.” Lastly, emotionally exciting words—whether negative or positive—tend to endure.

Early language-evolution models assumed that language becomes increasingly complex over time. But Indiana University Bloomington cognitive scientist and study co-author Fritz Breithaupt says the new study supports a more recent theory that language ultimately gets more efficient and easier to understand. Still, as the study notes, “the English language is not baby talk.” Breithaupt explains: “Yes, we shift toward simple language, but then we also grab complex language that we need.” New words that address the intricacies of modern life may somewhat balance out this shift.

The proposed trend toward “simpler” language is controversial. Columbia University linguist John McWhorter more or less agrees with the study’s results about evolutionary advantages within language. He questions, however, implications regarding the overall efficiency of English—a language he says contains things like “needlessly complex” grammatical vestiges. “There are about five ways to indicate the future in English,” he says. “I pity anybody who doesn’t grow up with it natively” and wants to learn it.

Study lead author Ying Li, a psychologist at the Chinese Academy of Sciences and a non-native English speaker, notes that English had even more perplexing grammar in the past. McWhorter, Li supposes, “would complain more if he traveled back 800 years ago.”

Anvita Patwardhan is a freelance science and health reporter. She is based in the San Francisco Bay Area.

Mathematics

- **The Strangely Serious Implications of Math's 'Ham Sandwich Theorem'**
  A simple solution to gerrymandering crumbles when confronted with math's "ham sandwich theorem"

The Strangely Serious Implications of Math’s ‘Ham Sandwich Theorem’

A simple solution to gerrymandering crumbles when confronted with math’s “ham sandwich theorem”

By Jack Murtagh


Thomas Fuchs

Consider lunch. Perhaps a nice ham sandwich. A knife should neatly halve the ham and two bread slices. But what if you slip? Oops—the ham now rests folded under a flipped plate; one slice of bread is on the floor, and the other is stuck to the ceiling. Here’s some solace: geometry ensures that a single straight cut, perhaps with a room-size machete, can still perfectly bisect all three pieces of your tumbled lunch, leaving exactly half of the ham and half of each slice of bread on either side of the cut. That’s because math’s “ham sandwich theorem” promises that for any three (potentially asymmetrical) objects in any orientation, there is always some straight cut that can simultaneously bisect them all. This fact has some bizarre implications, as well as some sobering ones, as it relates to gerrymandering in politics.

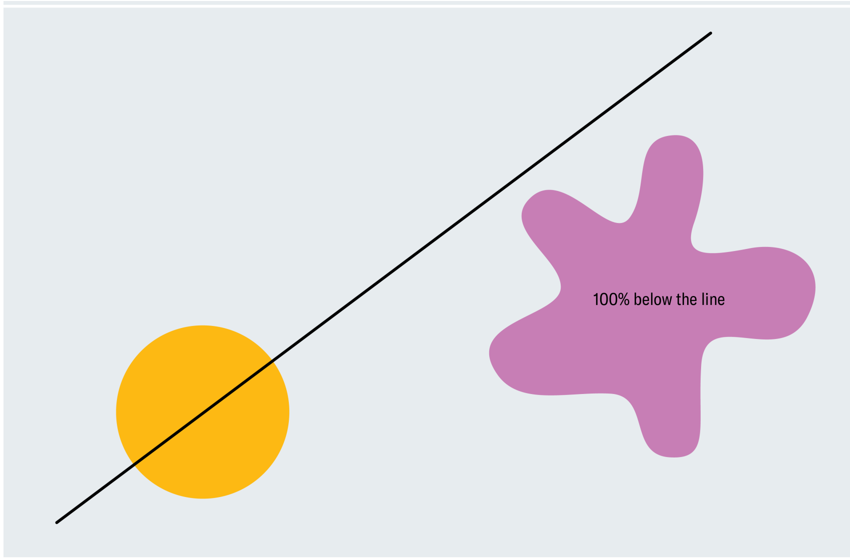
The theorem can be generalized to other dimensions. A more mathematical phrasing is that n objects in n-dimensional space can be simultaneously bisected by an (n – 1)-dimensional cut. That ham sandwich is a bit of a mouthful, but we’ll make it more digestible. On a two-dimensional piece of paper, you can draw whatever two shapes you want, and there will always be a (one-dimensional) straight line that cuts both perfectly in half. To guarantee an equal cut for three objects, we need to graduate to three dimensions and cut with a two-dimensional plane: think of that room-ravaging machete as a thin piece of paper you slip between the two halves of the room. In three dimensions, the machete has three degrees of freedom: you can move it back and forth across the room, stop and rotate it to different angles, and then rock the machete from side to side (the way you might angle a knife to cut carrots obliquely instead of straight).

If you can imagine a four-dimensional ham sandwich, as mathematicians like to do, then you can picture how you might bisect a fourth ingredient with a three-dimensional cut.

To get a sense of how to prove the ham sandwich theorem, consider a simplified version: two 2-D shapes, one a circle and the other a blob. Any line that passes through the center of a circle bisects it (asymmetrical shapes don't necessarily have a true center; we're using a circle to make things easier for now). How do we know that some line also bisects the blob? Pick a line through the center of the circle that doesn't intersect the blob at all. As depicted in the first panel of the graphic in the next column, 100 percent of the blob lies below our line. Now slowly rotate the line around the center of the circle like a windmill wheel. Eventually it breaches the blob, cuts through more and more of it, and then passes below it so that 0 percent of the blob lies below the line. From this process we can deduce that there must be a moment at which 50 percent of the blob lies below the line. We're gradually but continuously moving from 100 to 0 percent, so we must pass every amount in between, meaning at some point we are at exactly 50 percent (calculus fans might recognize this as the intermediate value theorem).

This argument proves that there is some line that simultaneously bisects our shapes (although it doesn't tell us where that line is). It relies on the convenient fact that every line through the center of a circle bisects it, so we can freely rotate our line and focus on the blob without worrying about neglecting the circle. Two asymmetrical shapes require a subtler version of our windmill technique, and the extension to three dimensions involves more sophisticated arguments.

Interestingly, the theorem holds true for our sandwich even if the ham and bread are broken into multiple pieces. Use a cookie cutter to punch out ham snowmen, then cube your bread and bake it into croutons; a perfectly equal cut will always exist (individual snowmen and croutons won't necessarily be halved, but the total amount of ham and bread will be).



Amanda Montañez

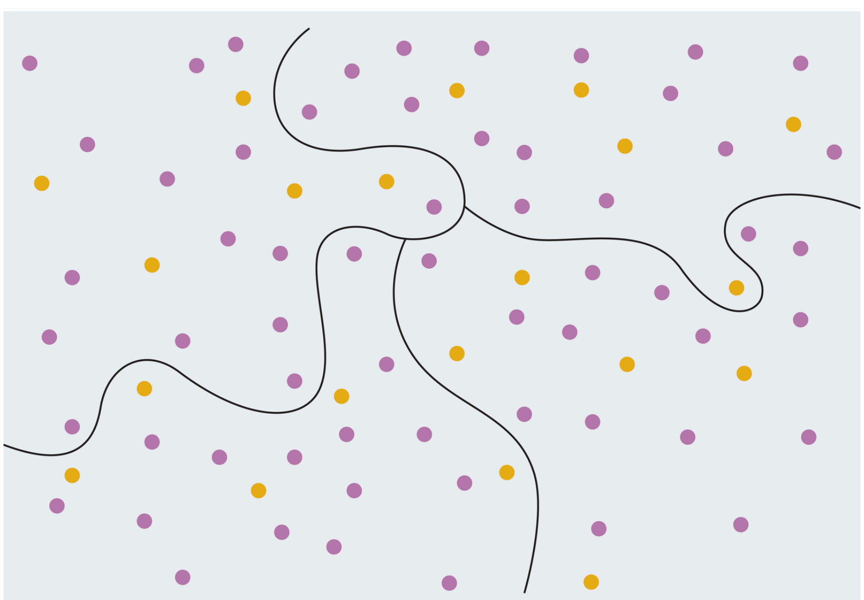
Taking this idea to its extreme, we can make a similar claim about points. Draw scattered red and green dots on a piece of paper, and there will always be a straight line with exactly half the red dots and half the green dots on either side of it. This version requires a small technicality: points that lie exactly on the dividing line can be counted on either side or not counted at all (for example, if you have an odd number of reds, then you could never split them evenly without this caveat).

Contemplate the bizarre implications here. You can draw a line across the U.S. so that exactly half of the nation's skunks and half of its Twix bars lie above the line. Although skunks and Twix bars are not actually single points, they might as well be when compared with the vast canvas of the American landmass. Kicking things up a dimension, you can draw a circle on Earth (slicing through a globe leaves a circular cross section) that contains half of the world's rocks, half of its paper and half of its scissors, or any other zany categories you wish.

The ham sandwich theorem carries far less whimsical consequences for the perennial problem of gerrymandering. In the U.S., state governments divide their states into electoral districts, and each district elects a member to the U.S. House of

Representatives. Gerrymandering is the practice of carving out these district boundaries deliberately for political gain.

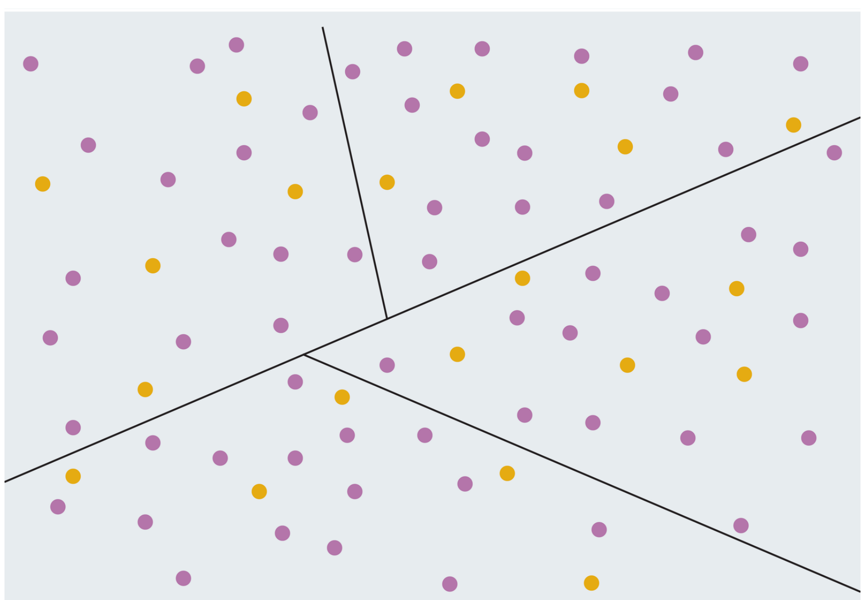
As a simplified example, imagine a state with a population of 80 people; 75 percent of them (60 people) favor the Purple Party, and 25 percent (20 people) prefer the Yellow Party. The state will be divided into four districts of 20 people each. It seems fair that three of those districts (75 percent) should be Purple and the fourth should be Yellow so that the state's representation in Congress accords with the preferences of the population. A crafty cartographer, however, could squiggle district boundaries in such a way that each district contains 15 Purple-leaning voters and five people who vote Yellow. In this way, every district would be majority Purple, and 100 percent of the state's representation would come from the Purple Party rather than 75 percent. In fact, with enough voters, any percentage edge that one party has over another (say, 50.01 percent Purple versus 49.99 percent Yellow) can be exploited to help that party win every district; just make it so that 50.01 percent of every district supports it.



Amanda Montañez

Of course, those districts look highly artificial. A seemingly obvious way to curtail gerrymandering would be to place restrictions on the shapes of the districts and disallow the tentacled monstrosities that we often see on American electoral maps. Indeed, many states impose such rules. Although it might seem like mandating “normal” district shapes would go a long way toward ameliorating the problem, clever researchers have applied a certain geometric theorem to show how that’s a bunch of baloney.

Let’s revisit our example: a total of 80 voters consisting of 60 Purple Party supporters and 20 Yellow Party supporters. The ham sandwich theorem tells us that no matter how they’re distributed, we can draw a straight line with exactly half of the Purple voters and half of the Yellow voters on either side (30 Purple and 10 Yellow on both sides). Now treat the two areas you’ve created as new ham sandwiches, splitting each in half with its own straight line so that every resulting region contains 15 Purples and five Yellows. Purple now has the same gerrymandered advantage as before (it wins every district), but the resulting regions are all simple shapes with straight-line boundaries!



Amanda Montañez

Repeated ham-sandwich subdivision will always produce relatively simple districts (in math-speak, they’re convex polygons except where they potentially share a boundary with an existing state border). This means that basic regulations on the shapes of congressional districts probably can’t preclude the worst instances of gerrymandering. Although math and politics may seem like distant fields, an idle geometric diversion has taught us that the most natural-sounding solution to gerrymandering doesn’t cut the mustard.

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

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Mental Health

- ## Walks in Green Parks Mean Stronger Immune Systems and Better Mental Health
  Contact with nature improves physical and mental health, but greenery is not easily reached by all
- ## The Internet's 'Dog Mom' Talks the Science of the Human-Dog Bond
  Jen Golbeck, “dog mom” to a group of golden retrievers called the Golden Ratio on social media, talks about the science of the bond between humans and their dogs and all the ways that the canines benefit people

Walks in Green Parks Mean Stronger Immune Systems and Better Mental Health

Contact with nature improves physical and mental health, but greenery is not easily reached by all

By Lydia Denworth

Jay Bendt

Like so many people, I took refuge in the outdoors during the worst of the COVID pandemic, going on socially distanced walks and sitting on the deck in all kinds of weather. Being outside reduced the chance of infection, but it also helped in other ways. “I think everybody got that nature seemed to be the solution for a lot of the stress issues that people were dealing with,” says Jay Maddock, an experimental psychologist and director of the Center for Health & Nature at Texas A&M University. Scientists got it, too. Research into the health benefits of nature has “exploded” since then, Maddock says.

More time in the green is associated with lower blood pressure, strengthened immune systems, lower risk of cardiovascular disease and improved sleep. A recent study found it might slow the shortening of the telomeres that cap our chromosomes, a sign of biological aging. And there is convincing evidence that time in nature reduces depressive symptoms, alleviates stress and improves cognitive function.

A 2019 study of more than 19,000 people in the U.K. found that those who reported spending at least 120 minutes in nature (such as parks, woodlands or beaches) every week had better health or higher well-being than those who spent less time. It didn't matter whether people reached the total time in many small increments or one long block. Researchers are also investigating beneficial health effects of "blue space" (water) and "brown space" (deserts).

The research is also highlighting health inequality created by disparities in access to green space—something else the pandemic shone a spotlight on. Jennifer D. Roberts, a health equity scholar at the University of Maryland, says the lowest-income communities are "less likely to have trees; they're less likely to have parks of ample acreage and high quality." According to one recent study, neighborhoods that were once redlined (a now outlawed practice that deemed certain areas "hazardous" for investment) have less green space today than areas with similar demographics that were not redlined.

Access to parks and other greenery is linked to health disparities that can't be explained by factors such as race, ethnicity and socioeconomic status alone, says epidemiologist Marcia P. Jimenez of the Boston University School of Public Health. "There are higher-level determinants of health, which are our access to food, our exposure to air pollution, noise, green space and the socioeconomic status of our neighborhood." More access to green space tends to give a bigger relative health boost to disadvantaged groups than to more privileged ones, research is starting to show. "If we were to increase greenness among these vulnerable populations, we could essentially tackle health inequalities. This is where to begin," Jimenez says.

To get a more precise measure of local greenery for some studies, scientists use Google Street View data and something called the normalized difference vegetation index, which uses satellite imagery to quantify plant density and health in an area of land. A company called Nature-Quant based in Bend, Ore., recently used machine learning to develop NatureScore, which combines multiple datasets on parks, tree canopies, and air, noise and light pollution to develop a score between 0 and 100 as a proxy for greenness for every address in the U.S. (a heavily urban environment would generally score below 30 and a forest above 70).

In a 2024 study, Maddock and his colleagues were the first to use NatureScore to analyze health outcomes, specifically for mental health. They looked at outpatient mental health service utilization, mostly for depression, anxiety or stress, across 1,169 zip codes in Texas. After adjusting for demographic and socioeconomic factors, they found that rates of mental health service use were about 50 percent lower in neighborhoods with NatureScores higher than 60. In 2022 Jimenez and her colleagues published a paper in *JAMA Open Network* using data from the long-running Nurses' Health Study II to show that living in areas with more green space was associated with higher scores for overall cognition and for psychomotor speed and attention. This difference could be partly explained by fewer depressive symptoms.

There are several possible explanations for these findings. One theory holds that nature provides a respite from the mental fatigue of modern life and the built environment, thereby restoring attentional resources. A 2024 experiment that had nearly 100 participants offers support for the idea: the researchers found that a 40-minute walk in nature enhanced people's ability to coordinate higher-level cognitive functions—such as problem-solving and multitasking—more than a 40-minute walk in an urban environment did.

A second theory suggests that time spent in nature activates the parasympathetic nervous system, which reduces the body's stress responses. Studies show reductions in cortisol levels—part of those responses—after exposure to greenery. In addition, green space affects health indirectly because time outdoors encourages physical activity and offers chances for social connection, both of which improve mental and physical well-being.

Studies such as Jimenez's and Maddock's are aimed at policymakers more than individuals, but they remind us all of the importance of seeking out greenery wherever we live. I recently downloaded the NatureDose app, another Nature-Quant product, which allows me to track time outside the way I count steps. And we should all try to heed the advice that Jimenez gives to her students: "I see how stressed they are, especially during exams," she says. "I tell them, 'Go out for a walk.'"

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

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

The Internet's 'Dog Mom' Talks about the Science of the Human-Dog Bond

Jen Golbeck, "dog mom" to a group of golden retrievers called the Golden Ratio on social media, talks about the science of the bond between humans and their dogs and all the ways that the canines benefit people

By Andrea Thompson

Shideh Ghandeharizadeh

If you spend much time in the dog-loving corners of the Internet, you've probably heard of Jen Golbeck—or at least seen her dogs.

As a computer scientist at the University of Maryland who studies social media, Golbeck wanted to create a space on these platforms that felt like a respite from the widespread anger she'd witnessed across the political spectrum after the 2016 U.S. presidential election. Every day going on eight years now, she and her husband have shared photographs and videos of the "Golden Ratio"—their punny name for their pack of golden retrievers—with the world. The dogs dance in anticipation of their food bowls, swim in the ocean behind their Florida Keys home and wrestle one another.

Golbeck hoped this window into her dog-full world would be soothing for others.

Golbeck’s many dogs (the current roster includes Venkman, Feta, Guacamole, Remoulade, Chief Brody and Gorgonzola) have enriched her life, joining her on runs and comforting her in stressful times. They have also shown her love, especially after they have gotten older or when they have been ill. These experiences, along with her academic background in information studies, made her want to delve into the science of the human-dog bond, which she does in her book *The Purest Bond: Understanding the Human-Canine Connection* (Atria, 2023), written with science writer Stacey Colino. *Scientific American* spoke with Golbeck about the book and her relationships with her own dogs.


Jen Golbeck

[*An edited transcript of the interview follows*.]

One of my favorite moments in the book is when you describe yourself as coping with tough days by lying on the floor and being enveloped "in a cloud of golden retrievers." It sounds like heaven. How did you come to realize the power of the bonds between you and your pups?

We open the book with middle school me. I was bullied. Everything in life sucked. I was also really depressed—kind of borderline suicidal. I was having a really hard time, and my parents could tell that something was wrong. But they didn't put me in therapy. They bought me a golden retriever puppy—his name was Major—which turned out to be totally the right move. (I did end up in therapy later, which was great. Don't skip therapy.) I call him "my suicide-prevention dog"—that's what he lives on as in my heart. He was everything I needed at that point: He was nonjudgmental and wanted to be with me. He was the only entity in the universe I didn't feel awkward around. I could confide in him. He gave me this place to get away from all those other problems and feel like I was important and I mattered and I was worthy.

I loved dogs before that, but he was the first one who kind of opened my eyes to the real power that that relationship can have, that it can be quite transformative. Fast-forward a bunch of time: my husband and I rescue special-needs golden retrievers; currently we have several of them. We take in seniors, hospice cases and ones with complicated medical needs. It's so rewarding. We get to watch them transform from these very sick, broken dogs into happy, joyful dogs who appreciate this warm, gentle life.

The book delves into the science of how we relate to our dogs. Can you talk about some of the physiological effects dogs can have on us?

If you look at any part of your [health]—physical, mental, psychological or social—your dogs are going to make all of that better. The science is really strong there.

There's a great study that we cite in the book that talks about how if you have a heart attack, you are less likely to die within a year after it if you own a dog than if you don't have a dog. And you can be like, "Well, yeah, if you have a dog, you're going to walk more, right?" But even if you control for the amount of walking, people who have dogs still live longer. So this was a real question: If physical activity isn't the cause, why is it that our physical health is improved by having dogs?

If you look across all these different studies, one of the themes that emerges is something that we already knew from psychology: If you have a robust system of social support—you've got a supportive family, and you've got a big social network of friends and people who care about you—your health markers tend to be better. That social support is critical for your physical health, not just your psychological health.

It turns out that dogs are able to serve as those social-support systems in our lives as well as people can in some ways. A few studies get deep down into the statistics of it, and they find that the physical benefits of having a dog are greater for people who have smaller social networks. So, for instance, older adults who maybe have lost their spouse, their social circle is smaller, they’re dealing with loneliness—they see these dramatic increases in benefits from having dogs.

Do you have any favorite bits of research you came across when writing the book?

When I was in middle school, I had a science teacher who told us that dogs didn’t really love us back—that if they licked us, it was because we were salty. And I remember being so mad, but I was 12, so I had no capacity to argue back. Now I have written a book to avenge that memory.

The science is so clear that dogs love us back. We know from psychology about these things called attachment bonds and that the ones we form with our primary caregiver early on can go on to influence our relationships for the rest of our life. One of the ways researchers have studied attachment bonds is by putting babies in fMRI [functional magnetic resonance imaging] machines, which show the parts of your brain that have increased blood flow when you’re thinking about different things. When the researchers let the babies see their moms, a certain part of their brain lights up that doesn’t light up for family friends or people they don’t know as well. So we know that that part of the brain is responsible for the attachment bond. That’s where it manifests neurologically.

Researchers have done this study with dogs. They trained dogs to lie really still in an fMRI machine—which is kind of amazing by itself—and then they had the dog’s human come up so they could see and smell the person. And the same part of the dogs’ brains lit up when they saw their human as happened in babies when they saw their mother. So what we know is that on a neurological level, dogs have that same kind of love response when they see us as babies have when they see their mom.

That’s not the only study that shows this real biological evidence that our dogs love us back. We can measure it in hormone levels—for example, when we pet and interact with our dog, we get this surge of oxytocin. But the dogs get that surge, too, when we pet them or gaze into their eyes. I just love how it’s this classic science of love and connection that shows up perfectly with dogs.

Are there any misconceptions people may have about dogs and how we relate to them that you particularly want to dispel?

When I tell people I have six golden retrievers, often I’ll get asked, like, “Which one is the alpha?” If I’m feeling kind, I will say I am. And if I’m not feeling kind, I’ll give them the lecture, which is that the science of a hierarchy among dogs has been very thoroughly debunked. There were studies originally that were like, “Oh, there’s the alpha; there’s a beta; there’s kind of aggression in there to keep each other in line.” But it was these contrived studies of dogs in these captive, unloving environments where they were being studied in not a gentle way. The side effect of that environment was that they ended up establishing this hierarchy to survive these kinds of torturous situations.

Dogs are very social creatures. They live in families. If you think of a human family, is there an alpha there? I mean, maybe there’s somebody who’s a little more in charge, and there are different personalities, but you’re all coexisting together. And that’s what dogs want, too. If you try to adopt this kind of aggressive “I am the alpha; you will do as I say; pin them down” thing, dogs are smart, and they’ll respond to that. But they want to have respectful, gentle, caring relationships.

Is there anything you want people who are thinking about getting a dog to take away from the book?

Colino and I talked about making a PowerPoint to go with the book for people who are trying to convince their family members to get a dog. If you are thinking about getting the dog, and you need evidence, that's exactly what this book is.

Our main audience is probably people who already have dogs. I don't think there's anything in the book that's going to be earth-shattering for them; what you're going to find is recognition of a lot of your own experience with dogs and all this rigorous science that backs it up. I hope it gives you new insights into the things that you feel, and you'll find out some new things about just how deep that relationship goes.

One of the takeaways I've heard a lot of people mention is "I just felt so validated"—because sometimes people treat us like we're a little crazy for loving dogs as much as we do. This book is going to give you all the scientific evidence that you're not crazy. You're not making it up. All of this is real and profound.

IF YOU NEED HELP

*If you or someone you know is struggling or having thoughts of suicide, help is available. Call or text the **988 Suicide & Crisis Lifeline at 988** or use the online **Lifeline Chat**.*

Andrea Thompson is an associate editor covering the environment, energy and earth sciences. She has been covering these issues for 16 years. Prior to joining *Scientific American*, she was a senior writer covering climate science at *Climate Central* and a reporter and editor at *Live Science*, where she primarily covered earth science and the environment. She has moderated panels, including as part of the United Nations Sustainable Development Media Zone, and appeared in radio and television interviews on major networks. She holds a graduate degree in science, health and environmental reporting from New York University, as well as a B.S. and an M.S. in atmospheric chemistry from the Georgia Institute of Technology. Follow Thompson on Bluesky @andreatweather.bsky.social

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Neuroscience

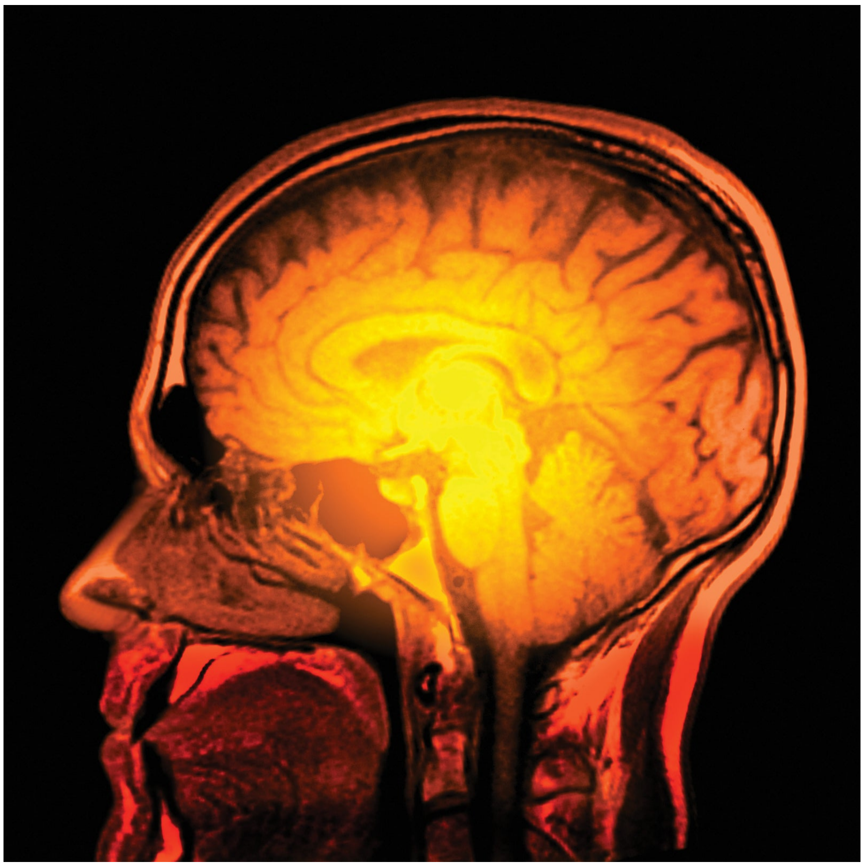
- ## Scientists Discover Extensive Brain-Wave Patterns

  Certain brain layers specialize in particular waves—which might aid understanding of neuropsychiatric disorders

Scientists Discover Extensive Brain-Wave Patterns

Certain brain layers specialize in particular waves—which might aid understanding of neuropsychiatric disorders

By Simon Makin



Alfred Pasieka/Science Source

The brain's cortex, which handles higher cognitive functions in mammals, is split into six distinct physical layers marked by varying cell types, sizes and connections—and new research suggests these layers specialize in generating different brain waves, too. Outer layers seem to process sensory input, whereas deeper layers control what the brain does with the resulting information.

The new study, published in *Nature Neuroscience*, shows that rapid gamma waves often originate in outer layers, whereas slower alpha and beta waves arise in the deeper ones. This holds true across 14 cortical regions and four species, including humans. “When you see [a pattern] that ubiquitous and robust, you know it’s doing something very important,” says Massachusetts Institute of Technology neuroscientist Earl Miller, one of the study’s senior authors. The findings may have implications for understanding—and even treating—neuropsychiatric conditions.

Through multiple experiments, the researchers found the same pattern in each of 14 cortical regions in five macaques. They also saw it in brain-wave recordings from humans and other primates, and they found that mouse brain waves followed the same gradient (though with a broader frequency range).

Cortical brain layers, at less than a millimeter thick, are challenging to record from individually—so the study authors used probes containing multiple electrodes to measure all layers at once. An algorithm helped them pinpoint which layers those readings came from, and they confirmed these origins with an anatomical study.

“It’s really good that people are recording from different layers of the cortex,” says Helen Barbas, a primate neurobiologist at Boston University. “The fact they have a lot of information on this will give the impetus to others to follow.” She’s also curious what happens in cortical regions that are not as clearly divided into layers as those tested.

The researchers' previous work suggested that high-frequency brain waves encode sensory information and that lower frequencies represent control signals. "We believe it's literally the balance between your brain processing incoming sensory information and its control over that information," Miller says. If this distinction is right, imbalances between these brain waves could be involved in neuropsychiatric disorders. For instance, if higher frequencies dominate (meaning the brain is processing sensory information excessively), this could cause attention problems or sensory overload. Too little high-frequency activity could be involved in psychosis because it would reduce information from the outside world, increasing the brain's reliance on internally generated signals.

The new study suggests which layers these mismatches might originate in. Brains of people who have schizophrenia are known for reduced high-frequency gamma waves, for example. Co-lead author Andre Bastos of Vanderbilt University and his colleagues plan to check whether specific cells in shallower layers, which are likely involved in generating these waves, are dysfunctional in those with schizophrenia.

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

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Planetary Science

When We Find Earth 2.0, What's Next?

We're looking for another Earth. But how likely is it that we'll find a duplicate of home?

By Phil Plait

An illustration of an Earth-size exoplanet.
Aaron Alien/Alamy Stock Photo

When I write or give public talks about exoplanets—alien worlds orbiting other stars—the most common question I'm asked is, "When will we find another Earth?"

It's a good question. As we're learning, space is filled with a great many wildly differing worlds, and it's natural to wonder whether there's an Earth 2.0 out there or whether they're all truly, well, alien.

Our galaxy, the Milky Way, harbors hundreds of billions of stars. A recent census of local stars shows that planets occur at least as often as stars, so there could be trillions of planets in our galaxy alone. Of course, realistically, that doesn't mean every star has a planet; rather some don’t have any, and others have teeming solar systems.

Exoplanets come in a dizzying variety of types, some incredibly bizarre: planets as big as Jupiter but skimming so close to their host stars’ surfaces that the scorching heat strips away their atmosphere, turning them into mega comets; worlds bigger than Earth but smaller than Neptune, which are the most common kind of exoplanet seen despite our solar system’s lack of one; and planets where it might rain molten iron. Oddballs abound.

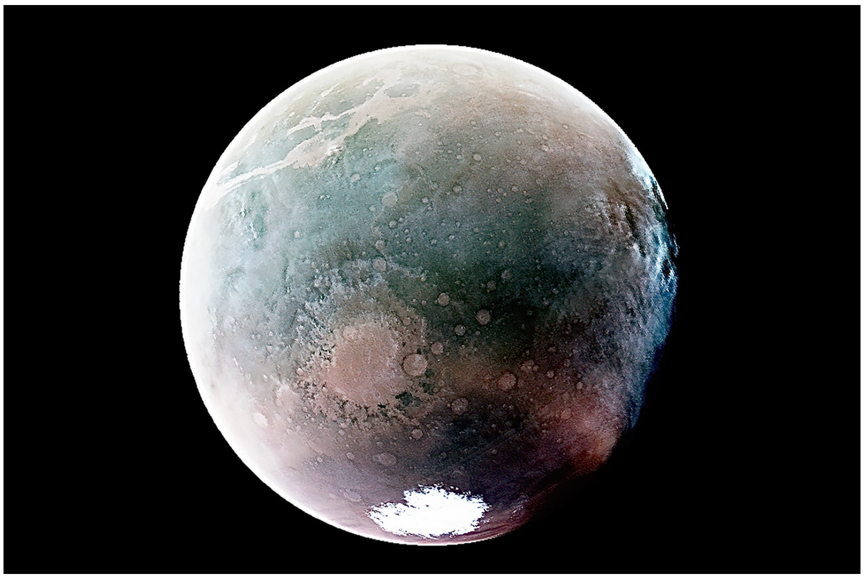
And, yes, the list includes many Earth-size worlds. Of the 5,500 or so exoplanets found to date, about 100 are close in size to our home planet. But there’s more to Earth than just its size.

If you’re looking for an exact replica—say, with Earth’s size, mass and composition, as well as breathable air and drinkable water—those odds look pretty long. Planetary formation involves a lot of random variables that affect how a planet forms and evolves over time. Even small changes can lead to dramatically differentplanetary evolution, and many of these variables interact. For example, a planet a little bit warmer than Earth—perhaps orbiting a hotter star or closer to a cooler star—could wind up with a runaway greenhouse effect that boils its oceans and eventually heats its desiccated surface to the melting point of lead. There but for the grace of Venus go we.

As we're experiencing now, even a relatively small change in atmospheric carbon dioxide can have profound effects on the global environment. This factor alone probably won't make Earth uninhabitable, but the changes are happening rapidly enough that they're making things decidedly uncomfortable.

On top of that, Earth hasn't always been Earth-like as we understand it. For two billion years our world lacked what we would consider a breathable atmosphere, and it was only through a catastrophic environmental change that free oxygen became available. It's also possible that our planet went through at least one period of total glaciation, the hypothetical "snowball Earth" era. Although this last idea is controversial, it's clear that for long periods Earth was not the clement home we now know.

Moreover, there's growing consensus in the scientific community around the idea that Mars was once more habitable than its current thin atmosphere and dry surface would imply. Several billion years ago it might have been more like Earth is now than Earth was then. Perhaps even Venus—now a decently convincing version of hell—could have once been habitable.



NASA's MAVEN (Mars Atmosphere and Volatile EvolutioN) mission acquired stunning views of Mars in ultraviolet images taken at points along our neighboring planet's orbit around the Sun.
NASA/LASP/CU Boulder

Even the very notion of habitability is fuzzier than you might think. There are icy moons in the outer solar system that have oceans of water under their frozen surfaces, as well as other conditions potentially conducive for life. Eternal darkness in temperatures just above freezing may not sound like Eden, but it could be paradise for life that evolved there.

All this is to say we don't think we've found a planet orbiting another star that's just like Earth. For one thing, we don't know enough about the atmospheres and chemical compositions of these worlds to say whether they're Earth-like. Of the 100 Earth-size exoplanets mentioned earlier, only three also have roughly Earth's mass and receive about the same amount of light and heat from their host star. Three. That's a tiny fraction, but to be fair, our current discovery methods are better at finding big, hot planets. Small, mild ones like our own are far tougher to spot.

But methods improve all the time, and we may not have to wait too much longer for astronomers to announce they've found an Earth analogue among the stars. When we do, what then?

It's not like we can go there. There's no USS Enterprise we can use to warp over to the nearest Earth 2.0, and without faster-than-light travel, it would be a long trip. Even the fastest spaceship ever launched would take the better part of a millennium to get to the nearest star system, Proxima Centauri (which does actually host an Earth-size planet that might—might—be within our range of acceptability). Better pack a lunch.

So many sci-fi movies tell us we need to evacuate Earth that it's a trope. This idea is far more fi than sci, though; humanity increases its number by more than 70 million people every year. You'd need to launch 2,000 SpaceX Starships every day just to keep up with that increase, even ignoring the less than helpful travel times. Easing population pressure via interstellar immigration is a nonstarter.

Establishing a settlement is a tall order, too. We don’t even really know how to do this in low-Earth orbit, on the moon or on Mars. We’re a long, long way from being able to set up shop on an alien Earth even if we could easily get to one.

When I’m asked about Earth 2.0, the implicit part of the question is whether we can travel to it and live there. Simply put, we can’t. So why look if we can’t go?

Because—to paraphrase a possibly apocryphal answer to a similar question—it’s probably there. We look because we want to know.

Searching for an Earth clone isn’t the point of exoplanetary science—except it really kind of is. Scientifically speaking, we look for other planets because we want to understand how they form, how conditions change their physical properties, and how they differ from or mirror the planets in our own solar system.

But emotionally, we yearn to see another pale blue dot somewhere out in the depths of space, to know that somewhere, sometime, conditions were just so to replicate—or at least resemble—those with which we are so familiar. Certainly, just knowing it’s out there would profoundly change the way we see the universe and our place in it. Such a discovery would also help us understand Earth better.

It may also help us answer the most fundamental question humans have ever had: How did we get here? For millennia this question has inspired speculation, myth, religion and philosophy. With a distant blue-white world hovering in the eyepiece, it becomes science. Knowable. And then we can, perhaps, indulge ourselves further. If we find another habitable world, we can dare to crack open the door for the next Big Question: Are we alone?

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

American.

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

Plants

- **This Flower Refrigerates Itself to Survive Scorching Summers**
  A humble thistle blossom in southern Spain somehow keeps itself up to 18 degrees Fahrenheit cooler than the surrounding air

This Flower Refrigerates Itself to Survive Scorching Summers

A humble thistle blossom in southern Spain somehow keeps itself up to 18 degrees Fahrenheit cooler than the surrounding air

By Elizabeth Anne Brown

The clustered carline thistle blooms despite intense heat.
undefined undefined/Getty Images

Southern Spain's landscape in high summer is perhaps best described as "crunchy." Under the unrelenting sun, grass turns to brown straw, and almost everything green shrivels and dies—except for the clustered carline thistle, a plant with humble yellow flowers and a surprising superpower.

Every August this thistle is one of the only plants to flower in most of Spain's arid Mediterranean habitats, giving it a virtual monopoly on the local bees and other pollinators. But how can the thistle survive, much less bloom, when its neighbors are reduced to twigs and dust?

Spanish National Research Council evolutionary ecologist Carlos M. Herrera was conducting a census of pollinators in the Sierra de Cazorla mountain range when he peered into a thistle blossom, lightly touching the flower, to see how much nectar was inside. To his astonishment, it felt unmistakably cool—even after hours in direct sun. Herrera says he immediately sensed he was “about to make a discovery.”

During scorching Spanish heat waves, Herrera measured the temperature inside thistle flower heads and the ambient air temperature less than an inch away. He found the flower heads were routinely nine degrees Fahrenheit cooler than their surroundings, with the difference approaching 18 degrees F for some flowers on the hottest days. His observations are detailed in the *Scientific Naturalist*.

Sanna Sevanto, a physicist and plant physiologist at Los Alamos National Laboratory who studies how plants respond to environmental stress, says Herrera’s finding is exciting and could confirm a risky plant survival strategy that has, until now, only been theorized.

Sevanto and other scientists have documented apparent self-cooling in tree leaves, but that effect is probably coincidental, she says. To perform photosynthesis, leaves need access to carbon dioxide, which enters through tiny pores called stomata on a leaf’s surface.

When stomata open to let carbon dioxide in, some water escapes, thereby causing evaporative cooling that lowers the leaf's temperature slightly.

But for the Spanish thistles, evaporative cooling could be the goal rather than just a side effect of photosynthesis. Herrera suggests the plant could essentially be sweating: sacrificing precious water, extremely scarce in Spain's arid summers, to prevent its delicate reproductive organs from overheating.

Herrera says that such cooling could occur anywhere that the flower head contains water, including in its liquid nectar. Some flower species have stomata on their petals, which Sevanto says would be an easy route for releasing water. Opening stomata in a drought is a big gamble, though, and she notes that so far "we have not observed a plant that would do it to cool themselves."

As well as checking the thistle's petals for stomata under a microscope, Herrera has more experiments planned for the next sweltering summer. For one, he will manipulate a plant's water supply to try to prove its cooling is really a "sweating" action, and in a second, he will look for novelties in the thistle's root structure that could explain how it is able to take in enough water to invest in cooling.

As heat waves become more frequent and intense with climate change, it's increasingly important to study unusual adaptations that help plants survive heat stress. But ultimately, "whether these plants will have water enough to keep the system working," Herrera says, is "another story."

Elizabeth Anne Brown is a freelance science journalist based in Copenhagen, Denmark. Her work has appeared in *National Geographic*, the *New York Times*, the *Washington Post*, and many other outlets. Read more at elizabeth-anne-brown.com, and follow her on X (formerly Twitter) @eabrown18

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refrigerates-itself-to-survive-scorching-summers

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Policy

- **We Need to Make Cities Less Car-Dependent**
  Reducing the need for car travel is better for health, the environment and public safety
- **To Design Cities Right, We Need to Focus on People**
  Far too often city planning is approached as an engineering problem instead of connecting people with the land

We Need to Make Cities Less Car-Dependent

Reducing the need for car travel is better for health, the environment and public safety

By The Editors

Barry Williams for NY Daily News via Getty Images

In the 1970s a nation confronted a crisis of traffic deaths, many of them deaths of children. Protesters took to the streets to fight an entrenched culture of drivers who considered roads their domain alone. But this wasn't the U.S.—it was the Netherlands. In 1975 the rate of traffic deaths there was 20 percent higher than in the U.S., but by the mid-2000s it had fallen to 60 percent lower than in the U.S. How did this happen?

Thanks to Stop de Kindermoord ("Stop Child Murder"), a Dutch grassroots movement, traffic deaths fell and streets were restored for people, not cars. Today the country is a haven for cyclists and pedestrians, with people of all ages commuting via protected bike lanes and walking with little fear of being run over. It's time the U.S. and other countries followed that example.

The U.S. has the highest number of traffic deaths among wealthy countries, with more than 38,000 deaths per year between 2015 and 2019. The death rate is more than double the average rate in other wealthy countries. Vehicle crashes are among the leading causes of death in the U.S. But it doesn't have to be this way. We can design or redesign streets to make people drive more slowly or to discourage driving altogether. We can invest in better public transit, including subways and buses with dependable, on-time service. And we can change zoning laws to allow denser housing and mixed-use developments, so people can live closer to where they work, attend school or socialize. These are changes that even the largest, most sprawling cities can and should implement.

Making these changes curbs air pollution, which causes millions of excess deaths worldwide every year, and reduces the amount of greenhouse gas we pump into the atmosphere with every drive to the grocery store. Traffic deaths and air pollution are social justice issues, disproportionately harming people of color. In addition, cities that are more car-dependent are often less accessible for the considerable part of the population that can't drive, including children, people with disabilities, people who can't afford a car or insurance, and many older people.

Many U.S. cities have abundant space for parking and wide, multilane "stroads," a mix between a street (where cars move slowly and people can walk safely) and a road (where cars move fast, such as a highway). Stroads are optimized for moving many vehicles through an area at high speed. Yet widening or expanding the number of streets only incentivizes more people to drive, which creates more traffic.

At the same time, cars have gotten bigger and deadlier—SUVs and trucks now represent more than 80 percent of car sales in the U.S. If we want to give more space to pedestrians, cyclists and people using wheelchairs, we need to separate them from high-speed vehicles by building more well-maintained sidewalks, curbs with inclined cuts and protected bike lanes and by implementing traffic-calming measures such as narrower streets, speed bumps and traffic medians.

We should invest in improving public transit to make it an inviting alternative to cars. Buses need reliable schedules and dedicated lanes so they don't get stuck in the traffic we're trying to reduce. And expanding subways and other rail-based transit will help to bring in jobs and development.

Cities such as New York, Chicago and Philadelphia already have fairly good public transit and have increased the number of bike lanes and pedestrian-only areas. Early in the COVID pandemic, these and other cities implemented "open streets," which block off most car traffic at certain times to make space for pedestrians, cyclists, playing children and outdoor diners. We need to ensure they can persist.

Minneapolis, a smaller city, added bike lanes and banned single-family zoning, a major contributor to urban sprawl. Ann Arbor, Mich., banned right turns on red—a dangerous practice that spread during the 1970s fuel crisis as a way to save gas—at 50 downtown intersections. Even in car-centric Tempe, Ariz., developers created a car-free neighborhood. More spread-out cities could focus on denser nodes or neighborhoods that have some public transit and build those out.

Too often efforts to reduce car dependence are met with fierce opposition by people who dismiss them as "socialism" or a "war on cars." But drivers also benefit from many of these changes, which would reduce traffic and make driving safer. Others argue that these changes will harm people with disabilities, yet the opposite may be true—reduced car dependence, if paired with improved, disability-centered infrastructure, could make cities *more* accessible. And emergency vehicles aren't much help to anyone if they're stuck in traffic.

Creating better road designs and public transit will require significant up-front investment, and the effects may not be seen for years. But we could subsidize the cost the way we already subsidize driving. We could eliminate free parking. We could set up congestion pricing in dense city centers, as New York City plans to do, and use the proceeds to fund public transit alternatives. And we can add more bike lanes and open streets, which are cheaper to put in place and provide immediate benefits.

In much of the U.S., it is still illegal to build anything denser than single-family homes, and housing often has minimum parking requirements that take up valuable real estate. If we encourage cities to build duplexes, triplexes and apartment buildings, especially near transit hubs, fewer people will need cars.

The same solutions won't work everywhere, and change won't happen all at once. Each city has its own unique considerations and challenges. And such an ambitious project will require rethinking many of our assumptions about American car culture. But the benefits could make everyone healthier and safer.

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

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To Design Cities Right, We Need to Focus on People

Far too often city planning is approached as an engineering problem instead of connecting people with the land

By Tim Keane


Andriy Onufriyenko/Getty Images

In the mid-1990s I attended a public county meeting in Cornelius, N.C., a town next to Davidson, where I had just been hired as a city planner. Davidson was at odds with the county's proposed thoroughfare plan. The plan reflected the type of misguided investment that communities have been making for decades, furthering sprawl under the guise of development. Davidson municipal officials hired me because they foresaw that a proliferation of subdivisions and shopping centers would irrevocably alter the dynamics of this old, distinctive college town and its countryside.

When I entered the Cornelius Town Hall, a resident was berating the Cornelius planner, demanding to know who had drawn the lines on the thoroughfare plan map. The lines represented future “major” and “minor” roads, and people understood what they signified: highways clogged with cars and surrounded by parking lots, stale buildings, sad berms and endless subdivisions.

I told the resident I had drawn the lines (although I hadn’t). I explained that he and everyone else in the room had come to live in the countryside, and they had made the choice to drive whenever they wanted to do anything. Suddenly, the meeting became productive, focused on what we were creating collectively rather than on what “the government” was inflicting on people.

Attempts in the U.S. to make better neighborhoods, towns and cities are a hapless mess resulting from an obdurate approach. If you’ve attended a planning meeting anywhere, you have probably witnessed the miserable process in action—unrestrainedly selfish fighting about false choices and seemingly inane procedures. Rather than designing places for people, we see cities as a collection of mechanical problems with technical and legal solutions. We distract ourselves with the latest rebranded ideas about places—smart growth, resilient cities, complete streets, just cities, 15-minute cities, happy cities—instead of getting down to the actual work of designing the physical space. These “plans” lack a fundamental vision. And they’re not successful.

Our flawed method of city planning started in 1925, developed for Cincinnati by the Technical Advisory Corporation, founded in 1913 by George Burdett Ford and E. P. Goodrich in New York City. New York adopted the country's first comprehensive zoning ordinance in 1916, an effort Ford led. Not coincidentally, the advent of zoning, and then comprehensive planning, corresponded directly with the Great Migration of six million Black people from the U.S. South to cities in the North, Midwest and West. New city-planning practices were a technical means to discriminate and exclude.

This first comprehensive plan also ushered in another type of dehumanization: city planning by formula. To justify the widening of downtown streets by cutting into sidewalks, engineers used a calculation that reflected the cost to operate an automobile in a congested area—including the cost of a human life, because crashes killed people. Engineers also calculated the value of a sidewalk through a formula based on how many people the elevators in adjoining buildings could deliver at peak times. In the end, Cincinnati's planners recommended widening the streets for cars, which were becoming more common, by shrinking sidewalks. City planning became an engineering equation, one focused on separating people and spreading the city out to the maximum extent possible.

We still use similar techniques, planning cities project by project, "balancing" individual property rights and interests and concentrating on administrative processes. We argue for months or years about each project and are never satisfied. What distinguishes city planning from other pursuits is its effect on the whole community. Moving from project to project is not what should matter most in planning; administrators and lawyers can handle that. Exceptional solutions to our major city-planning problems, such as housing affordability and climate resilience, will never be achieved piecemeal.

Planning should be chiefly a design process, not a legal one. Design-based, community-scaled solutions are paramount because populations now must grow within existing places rather than sprawl, which has ruined too much land, generated too many greenhouse gases and wasted too much of our time as we drive for every simple thing. A city and all its neighborhoods must get better with more people in them.

The degree to which a city becomes more equitable and resilient has to do with its physical attributes. How the city changes determines our ability to deal with housing costs, mobility and climate adaptation.

Making places that are resilient and economically, socially and environmentally sustainable requires a different relationship with the land. Creating the incredible amount and diversity of housing we desperately need is possible only when we learn how to design and build in existing neighborhoods and on existing streets. The best solution to building on the vacant lot down the street will not be found in land-use law and litigation.

The best buildings have an overarching concept that leads the design of the details. If we are to tackle our greatest problems, the same principle—an overarching design concept—must apply to cities as well.

Boise, Idaho, where until recently I was the city planner, is an interesting example. The built urban and suburban parts of this midsize city are in close relation with the desert to the south and foothills to the north. Boise can grow entirely within its existing footprint.

The city enacted a new set of citywide rules based on the physical attributes we seek: a denser city with a great diversity of housing where walking and transit are real options for more people; a city that keeps growing but depletes less of our natural resources such as water and energy. Boise’s discussions and decisions are conceived at the scale of the city and aim to unlock the ingenuity of the entire community.

A version of this approach can exist for every city, no matter the size. I’ve explored these issues in a small town, a small city and a big city: first Davidson, then Charleston, S.C., then Atlanta, then Boise. As Atlanta’s guiding treatise, the *Atlanta City Design*, says: “When we talk about design, we’re not merely describing the logical assembly of people ... and places. We’re talking about intentionally shaping the way we live our lives.” We achieve this goal by understanding how a place’s physical attributes best enable creativity, ingenuity and restoration.

It is significant that the angry man at the county meeting in North Carolina was pointing to a place on the map that people for centuries traversed using the trails of what is known as the Occaneechi Path. This route, which connected communities of Indigenous peoples, was eventually overlaid first by the railroad and then by the interstate, each built atop the disease, violence and death wrought by European settlers, with the builders sowing new devastation and division of their own.

Furthering our most destructive national obsession—the consumption of more land and greater resources, compounded by procedural and administrative waste—will not yield true hope or useful action. Only by committing ourselves to acknowledge, atone, repair and restore as we design cities as physical space will we have any chance to live in meaningful relation with one another, nature and the land.

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

Tim Keane has led city planning departments in Davidson, N.C., Charleston, S.C., Atlanta and, Boise, Idaho, working for numerous mayors. Among his collaborative work is the *Atlanta City*

Design—a design concept for the entire city—which was incorporated into the City of Atlanta Charter in 2017.

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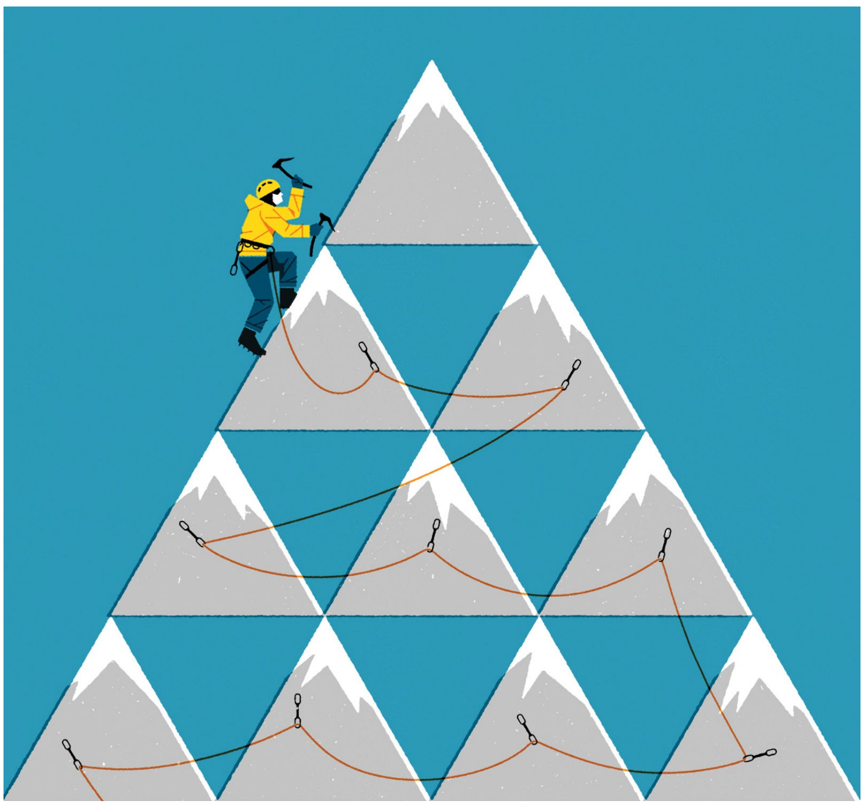
Psychology

- **The Secret to Accomplishing Big Goals Lies in Breaking Them into Flexible, Bite-Size Chunks**
  Subgoals can make all the difference when ambitious targets seem too daunting

The Secret to Accomplishing Big Goals Lies in Breaking Them into Flexible, Bite-Size Chunks

Subgoals can make all the difference when ambitious targets seem too daunting

By Aneesh Rai, Marissa Sharif, Edward Chang, Katy Milkman & Angela Duckworth



Matthew Harrison Clough

The prospect of learning a new language can be daunting, especially for an adult. Spending dozens of hours a year on lessons just to make slow progress on a new skill can seem like too much—particularly for someone who is juggling work and family responsibilities as well. That was certainly how one of us (Milkman) felt about her decades-long ambition to learn Spanish.

That all changed, however, when a popular language-learning app presented a more attractive approach: complete one lesson—just six or seven minutes long—each day to eventually become bilingual. This adds up to about 40 hours of study per year, the equivalent of a full work week, but it is presented as a bite-size daily commitment.

At first glance, breaking down a bigger goal into smaller pieces might seem like a superficial “reframing trick.” In actuality, it is a versatile goal-setting strategy that you can apply to almost any target—whether it’s learning a second language, picking up a new skill at work, starting an exercise regimen or saving for retirement. But how certain are scientists that this trick is effective? Through a large, multimonth field experiment, we were able to confirm the power of this technique—which validates much older research with contemporary scientific standards.

In the 1970s Albert Bandura and other psychologists conducted a series of pioneering studies with small populations of students and community members. Their findings suggested there were benefits to breaking an ambitious target into small “subgoals.” Since that time, surprisingly little research has explored this approach. In particular, there has been a lack of experimental research using large sample sizes, naturalistic settings (that is, where people are going about their daily life) and prespecified analysis plans. Our team conducted a massive new field experiment with state-of-the-art methods to assess whether breaking big goals up really can meaningfully improve outcomes. We published our findings in the

Journal of Applied Psychology, and our results offer several insights for tackling your goals.

For our study, we partnered with Crisis Text Line (CTL), a nonprofit organization that provides free crisis counseling via text message. All CTL volunteers are asked to commit to 200 hours of counseling work within a year of finishing a lengthy training program for crisis counselors. This target is fairly ambitious, given that Americans clock less than 70 hours a year on average with organizations where they formally volunteer. We were curious about whether breaking down this big, 200-hour goal could make it more approachable for people and increase the number of hours they worked.

In our experiment, more than 9,000 CTL volunteers received e-mails every other week for three months. We randomly assigned them to e-mail lists with different descriptions of the 200-hour yearly commitment. One group was encouraged to hit the 200-hour mark by volunteering “some hours every week,” with no detailed goal breakdown. Two other groups were given clear subgoals: we encouraged one to volunteer for four hours per week and the other to volunteer for eight hours every two weeks (both approaches added up to 200 hours a year). Then we tracked how much time each group of trained crisis counselors actually spent volunteering during our three-month study.

Breaking down big goals into more manageable chunks had a meaningful and sustained impact on volunteering. People who were encouraged to focus on a smaller subgoal (volunteering four hours a week or eight hours every two weeks) volunteered 7 to 8 percent more than their peers who were simply asked to hit their big goal with a little work each week. This may sound like a modest increase, but when scaled across CTL’s thousands of volunteers, our intervention translated to thousands of additional counseling hours every month at essentially zero cost to the organization.

We also found suggestive evidence that the more flexible “eight hours every two weeks” framing led to more durable benefits over time. Although volunteering declined across all participants each week during the 12-week experiment, this decline was slower in the “eight hours every two weeks” condition than in the stricter “four hours every week” condition. This finding suggests that making modest goals flexible may encourage more long-term perseverance.

Our study dovetails with research by behavioral scientists Hal Hershfield and Shlomo Benartzi, both at the University of California, Los Angeles, and Steven Shu of Cornell University. Their work shows that people are four times more likely to sign up for a savings program when the required deposit is described as $5 a day rather than (the equivalent) $150 a month. Hershfield and his colleagues theorized that people may find it less painful to make frequent but small payments than they would to give up an equivalent, large lump sum. Similarly, we believe part of why subgoals motivate people is that these objectives make them focus on committing small bits of time or money to their goal in the near future, which is less daunting than making equivalent but larger and longer-term commitments. Taken together, this recent research suggests that whether goals require taking a single action or “keeping your nose to the grindstone,” subgoals may help.

So don’t plan to run 365 miles this year; aim for seven miles a week. And instead of promising to commit 200 hours to a goal in a year, mark four hours a week or eight every two weeks on your calendar. As for Milkman, after 365 practice days, lo and behold, becoming bilingual is at last on the horizon for her.

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

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

Aneesh Rai is an assistant professor of management and organization at the Robert H. Smith School of Business at the University of Maryland.

Marissa Sharif is an assistant professor of marketing at the Wharton School of the University of Pennsylvania.

Edward Chang is an assistant professor of negotiation, organizations and markets at Harvard Business School.

Katy Milkman is a behavioral scientist and James G. Dinan Professor of Operations, Information and Decisions at the Wharton School. She is co-director of the Behavior Change for Good Initiative.

Angela Duckworth is Rosa Lee and Egbert Chang Professor at the University of Pennsylvania and author of *Grit: The Power of Passion and Perseverance* (Scribner, 2016).

Sociology

- ## Everyone Will Have Fewer Relatives in the Future
  Changing demographics mean shrinking families and more older relatives in future decades

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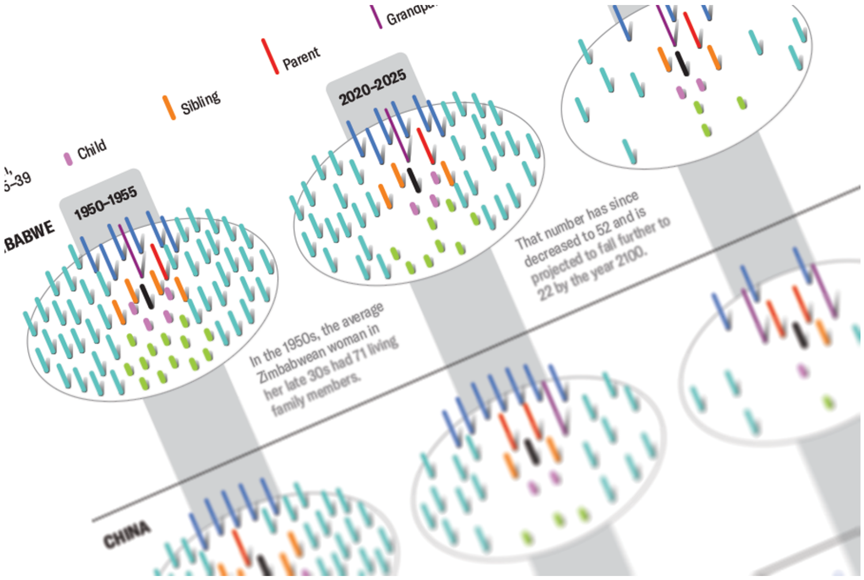
Everyone Will Have Fewer Relatives in the Future

Changing demographics mean shrinking families and more older relatives in future decades

By Lauren J. Young & Amanda Montañez



Amanda Montañez

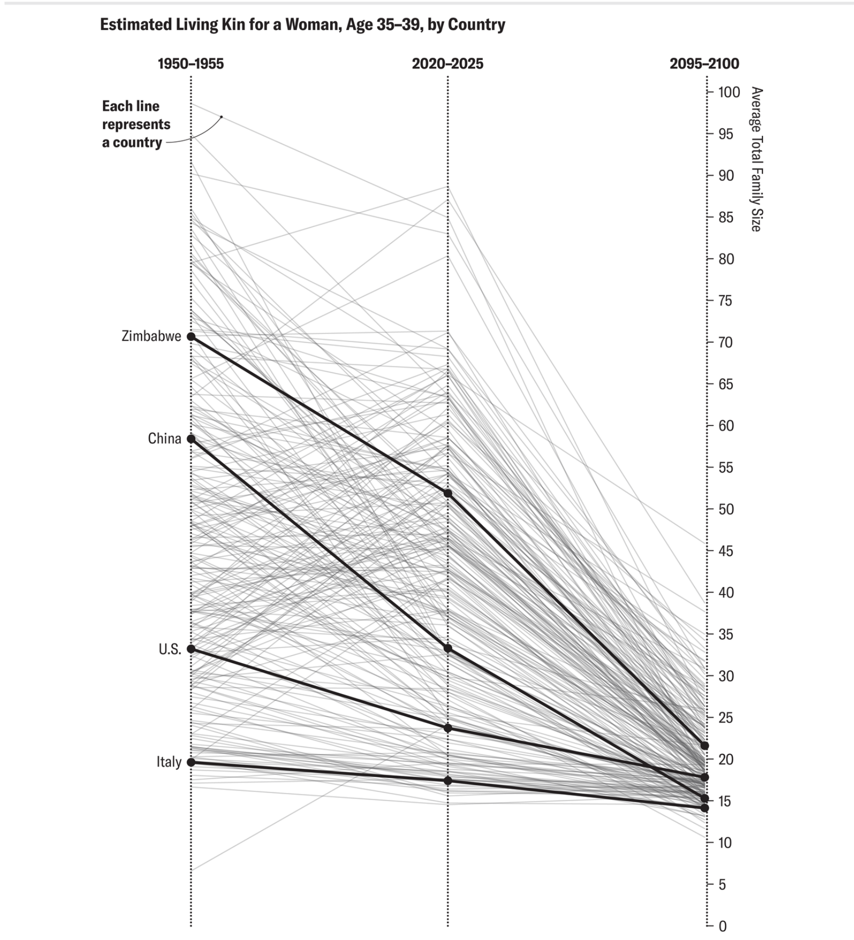
Family structures worldwide are in for a dramatic shift because of a global demographic transition toward lower birth and death rates. In a recent study, researchers estimated that the average 65-year-old woman's family will decline from 41 relatives in 1950 to 25 in 2095—a drop of nearly two fifths. This reduction is even more pronounced in countries that lack strong institutional support systems, such as Zimbabwe, which is projected to see a 71 percent decrease in family size.

This thinning of family networks is already apparent in China, which is dealing with the consequences of reproduction restrictions, such as the "one-child policy" in effect from 1979 to 2015, among other factors. In 1950 the average Chinese newborn had approximately 11 cousins, but by 2095 that number will decrease to one. And all four of that future newborn's grandparents will probably be alive at the time of their birth, skewing the average age of their family older.

These changes in family structure could put unprecedented pressure on caregivers of both children and older adults, says lead study author Diego Alburez-Gutierrez, a social scientist at the Max Planck Institute for Demographic Research in Rostock, Germany. Societies have been built around the expectation that supportive family networks will always exist, he says, “but that is going to change in the near future.”

Families around the World Are Getting Smaller

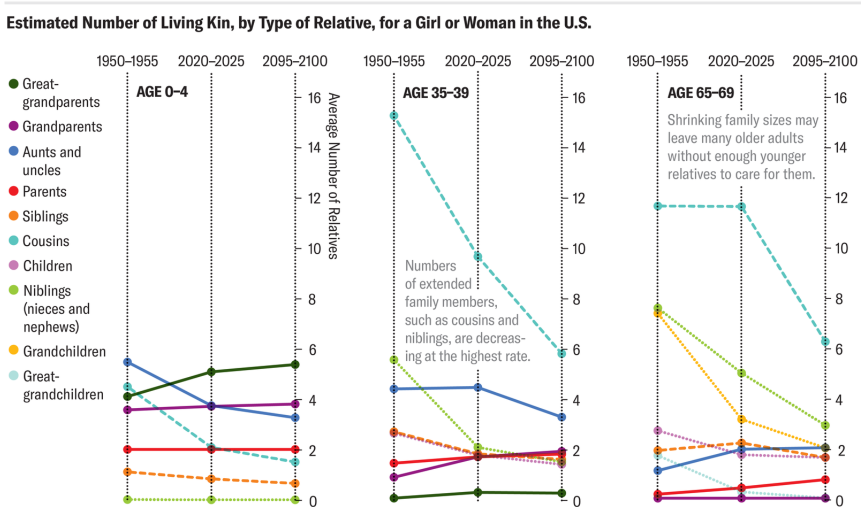
Past and present family sizes reflect substantial variations by country, but a look toward 2100 shows that the overall trend of shrinking networks is virtually universal.



Amanda Montañez; Source: “Projections of Human Kinship for All Countries,” by Diego Alburez-Gutierrez et al., in *Proceedings of the National Academy of Sciences USA*, Vol. 120, No. 52; December 19, 2023 (*data*)

The Size and Composition of a Person’s Family Changes throughout Their Life

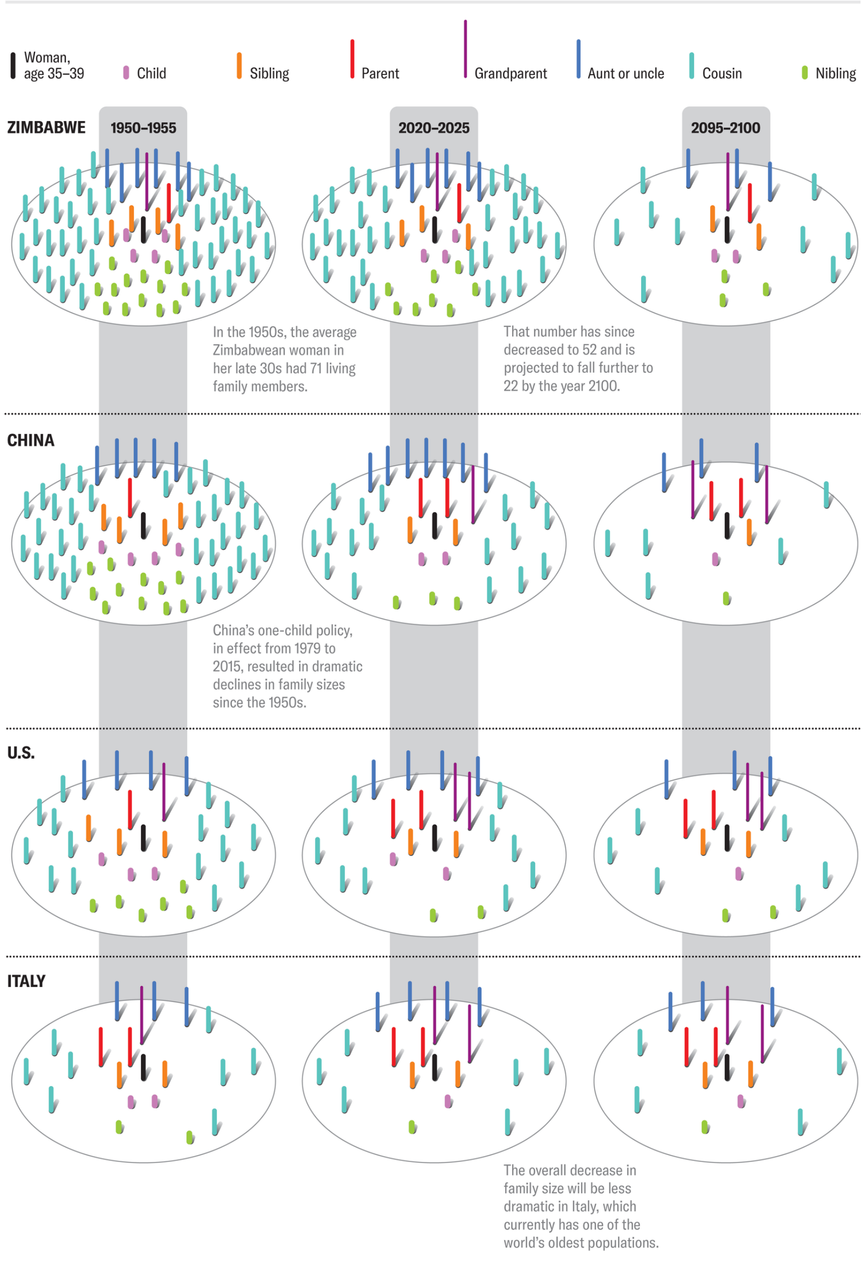
Looking at family composition from the perspective of different age groups reveals the significance of the impending changes for caretaking of both young and old people.



Amanda Montañez; Source: "Projections of Human Kinship for All Countries," by Diego Alburez-Gutierrez et al., in *Proceedings of the National Academy of Sciences USA*, Vol. 120, No. 52; December 19, 2023 (*data*)

What Past, Present and Future Families Look Like, by Country

The following values reflect the perspective of a woman, age 35–39.



Amanda Montañez; Source: “Projections of Human Kinship for All Countries,” by Diego Alburez-Gutierrez et al., in *Proceedings of the National Academy of Sciences USA*, Vol. 120, No. 52; December 19, 2023 (*data*)

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

Amanda Montañez has been a graphics editor at *Scientific American* since 2015. She produces and art directs information graphics for the *Scientific American* website and print magazine. Montañez

has a bachelor's degree in studio art from Smith College and a master's in biomedical communications from the University of Toronto. Before starting in journalism, she worked as a freelance medical illustrator. Follow her on Bluesky @unamandita.bsky.social

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