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Features

Grizzly Bears Will Finally Return to Washington State. Humans Aren’t Sure How to Greet Them

After decades of debate, grizzlies will be reintroduced to the North Cascades

By Benjamin Cassidy

Brooke Bartleson

Scott Schuyler knew it was going to be a tense evening in Newhalem, where a few dozen scientists, officials and residents had gathered at the community center to talk about living among apex predators. This remote village adjacent to North Cascades National Park is a tiny company town owned and operated by Seattle City Light—a utility that long ago built a succession of dams on the neighboring Skagit River to generate power for Washington State’s largest city.

Schuyler, an Upper Skagit Indian Tribe Elder and policy representative, had already spent years fighting the utility company for impeding salmon runs on his tribe’s ancestral land. He’d witnessed the dams imperil all five Pacific species of the fish found in the river; the tribe's chum salmon fishery had disappeared entirely. That November night another spiritual relative of the Upper Skagit—one who'd been missing for a long time—was on his mind.

For millennia grizzly bears roamed this vast stretch of wilderness in north-central Washington. Fur trappers and hunters killed thousands of them during the 19th century, essentially eliminating them from the landscape. The last official observation of a grizzly in this ecosystem was in 1996. But in the fall of 2023 federal agencies had released a plan to reintroduce grizzly bears to the U.S. portion of the North Cascades Ecosystem—a mountainous region roughly the size of Vermont, located within a couple hours' drive from coastal cities, including Seattle and Bellingham. It's part of a broader recovery effort across the American West that was finally getting traction here after decades of bureaucratic starts and stops.

The U.S. Fish and Wildlife Service and National Park Service had presented three scenarios. Two of them would aim to create an initial group of 25 bears over a five- to 10-year span. These bears would arrive by helicopter and trucks from other regions in the U.S. and British Columbia, with the long-term goal of generating a population of 200 grizzlies in the North Cascades within 60 to 100 years. One course of action would treat them as a threatened species under the Endangered Species Act; another, which the agencies listed as their preferred alternative, would less conventionally designate them as a “nonessential experimental population” under a little-known rule in the act. This would allow authorities greater latitude to catch or kill bears to stop conflicts between the animals and humans. Crucially, it would also allow landowners in some areas to obtain a permit to kill a grizzly under specific circumstances. (A third “no action” alternative would involve no bear movement at all.)

In Alaska’s Lake Clark region, a grizzly bear searches for salmon in a river. Grizzlies haven’t been spotted in Washington’s North Cascades since 1996.
Brooke Bartleson

In a handful of comment sessions held around the region and virtually, the public was now weighing in on how these various plans would affect the environment and the residents’ lives. At another meeting two days earlier in a valley east of the North Cascades, scores of ranchers and other locals had vehemently opposed any plans to reintroduce the bears. Backed by a local congressional representative, they saw such an action as a threat to their livestock and to the community at large. Some speakers blew past their two-minute limits; one man gripped a pitchfork with a cutout of a bear claw that read “NO.”

As Newhalem's first speaker, Schuyler began in a conciliatory tone. "We respect everybody's right to their opinions," he said, before sharing that the history of his tribe had been intertwined with the history of the grizzly bear for 10,000 years. "I hope it's not a surprise to folks," he said, "that we're going to support restoration." Many speakers agreed, making comments along the lines of one from Brenda Cunningham, a retired biologist: "I'm willing to camp with care in these places because I feel we need to share the wilderness with all the species in the ecosystem," she said. "The notion that we need to have completely safe experiences in the wildest areas of this incredible country seems very selfish to me."

But fear of the grizzlies was palpable. Of the six designated recovery zones in the U.S., this one is closest to a major city—the Seattle metropolitan area is home to more than four million people. And the rural communities near the proposed release areas could, according to the plan, experience "adverse" effects such as "depredation of livestock or agriculture." A local farm-bureau president said none of the organization's members supported reintroduction. A campground owner explained that tourists already fret about encountering black bears and suggested that recreationalists might be dissuaded from visiting the North Cascades if they thought grizzlies were around.

As the months-long process played out, debate over human-bear conflict revealed a surprising range of views about what it means to belong to an ecosystem. It also invited a fundamental question: What, exactly, were the grizzlies supposed to bring back?

For thousands of years people who lived in the North Cascades coexisted with grizzly bears. They revered the massive creatures for their hunting skill; according to Upper Skagit lore, the bears could imbue humans with their hunting prowess. The Stetattle Valley, which is part of Upper Skagit ancestral land, draws its name from the Lushootseed word for "grizzly bear."

In the 19th century Upper Skagit bands resisted white settlers' attempts to drive them onto distant reservations. But their four-legged neighbors gradually disappeared as grizzlies became targets for hunters and fur trappers. Between 1820 and 1860 Hudson's Bay Company reported that nearly 4,000 grizzly hides were shipped from trading posts in the area.

Some people fear a grizzly bear reintroduction in Washington could harm salmon populations—but dams are a much bigger threat to the fish.
Brooke Bartleson

Throughout the central and western U.S., hunting and habitat loss caused by new settlements destroyed a population that once stretched from Mexico to the Arctic. Even as the grizzly bear came to symbolize the power of the wilderness, that power, for some, still manifested as a risk to be "managed," and *Ursus arctos horribilis* largely vanished from the landscape. In 1975 grizzlies were listed as threatened in the lower 48 states under the Endangered Species Act. By then, an estimated population of 50,000 bears in the contiguous U.S. prior to 1800 had plummeted to fewer than 1,000.

In the early 1980s a government effort was started to recover the animals in habitat zones across Montana, Idaho, Wyoming and Washington. That initiative eventually included the North Cascades Ecosystem. In the Cabinet-Yaak Ecosystem, which runs across northwestern Montana and northern Idaho, the federal agencies started translocating grizzlies from Canada, where populations were healthy. For the first time in the U.S., people were moving grizzlies for a recovery effort.

Wayne Kasworm, a wildlife biologist with the U.S. Fish and Wildlife Service's Grizzly Bear Recovery Program, can still remember the skepticism from locals when the feds explained they were going to capture bears from the British Columbia backcountry and release them around the Cabinet Mountains, where there were, at most, 15 grizzlies at the time. In part to pacify those pushing back, the program began as an experiment: From 1990 to 1994 they'd capture four young females using foot snares, culvert traps and dart guns and truck them across the border and set them free in remote areas. Then they would see if the bears produced any cubs.

It would take a while to render a verdict. Among North American mammals, only musk oxen reproduce less than grizzlies over the course of a lifetime. Finally, in the early 2000s, DNA analyses from hair-snagging snares helped to prove that one of the bears had produced a number of offspring. Land managers are now seeing the third generation of descendants from that bear, whom they named Irene. Today the ecosystem has probably somewhere between 60 and 65 grizzlies after introducing 26 translocated bears. "Overall, it's gone better than expected," Kasworm says of the recovery program. The government plans to add a bear or two to the Cabinet-Yaak every year for the foreseeable future.

The Cabinet-Yaak recovery has served, in many respects, as a template for the North Cascades, Kasworm says. One major difference between them, however, is that the Cabinet-Yaak augmentation region had a small grizzly population when the program began. "Starting from either no bears or very few bears," Kasworm says, "is possibly a lot tougher than starting with some bears to get a population going."

To establish an initial population of 25 grizzlies in the North Cascades, the reintroduction plan calls for the capture of three to seven bears a year for up to a decade from the wilds of British Columbia; the Greater Yellowstone Ecosystem; and the Northern Continental Divide Ecosystem, which includes Glacier National Park, in northwest Montana. Crews would deploy culvert traps or, where feasible, shoot tranquilizers from helicopters to capture the bears. (In some instances, they may also use snares.)

If a trapped bear met the criteria for being a founder—between two and five years old, with no cubs or history of conflict with humans—they'd transport it by air and truck to remote public land in the North Cascades, tracking the animal via a GPS collar. Other trapped bears would be let go.

A mature female grizzly stands tall to investigate an approaching bear. This behavior is a sign of curiosity, but people sometimes misinterpret it as aggression.
Brooke Bartleson

Mortalities during grizzly captures and translocations are rare; between 1980 and 2009 less than 3 percent of known grizzly deaths in the lower 48 states could be traced to scientific research or conservation, according to the U.S. Fish and Wildlife Service. The bigger uncertainty is what will happen once they've arrived in the North Cascades. A study of 110 grizzly bear translocations in Alberta, Canada, found that these efforts failed 70 percent of the time. In the failure cases, bears were killed both legally and illegally; engaged in repeated conflicts; or wandered back toward their original capture area.

Dana Johnson, policy director with the national nonprofit Wilderness Watch, worries about both the mechanics of translocation—an estimated 144 helicopter landings to release, handle and recollar the grizzlies could disturb surrounding mammals and birds—and the potential disorientation of the founders themselves. "They have established home ranges. They have established social structures. They know where their favorite food sources are," says Johnson, who clarified she does support reintroduction. "These are animals that have communities."

Kasworm, acknowledging the challenges of translocation, estimates it would require moving about 36 bears to build the initial population of 25 in the North Cascades. "Not all of those animals that you move are going to stay where you intended them to be," he says. "And not all of them are going to live." In the Cabinet-Yaak Ecosystem, bear losses have been caused predominantly by humans. In 2009 an elk hunter who said he was acting out of self-defense killed a bear that turned out to be Irene.

The night after Schuyler advocated for the reintroduction program in Newhalem, Shawn Yanity and Kevin Lenon made their way to the front of a packed auditorium inside a high school in Darrington—a logging town 35 miles away. These two tribal leaders had shown up to similarly weigh in on the environmental impact statement of the federal plans, but they had a significantly different message.

"The bear is definitely a big part of our culture here in Indian country, as all the animals are," said Yanity, a former chair of the Stillaguamish Tribe of Indians. "But as time has moved on, things have changed." Specifically, he worried the bears would endanger some of their food and economic resources. "We face declining salmon," he said. (Research in the government's plan shows that the bears aren't expected to endanger the fish population.) Lenon, a member of the Sauk-Suiattle Indian Tribal Council, echoed Yanity's concern about the salmon and said his people would hunt the bears if they were reintroduced. He then stated a belief seemingly shared by many in the room: "These people," he said, referring to the federal officials in attendance, "don't give two cents about any of your human lives. Because I've told them already, you're going get people killed in the North Cascades."

One by one, people raised concerns about their community's safety. Some cited what has happened in Montana, where conservation efforts raised the grizzly population in the Greater Yellowstone Ecosystem from 136 bears in 1975 to 965 bears in 2022. The area in and around Glacier National Park now counts the largest grizzly population in the lower 48 states. The bears have extended their range between these ecosystems, migrating into plains and valleys and encountering more humans along the way. Montana, Idaho and Wyoming have all recently petitioned the federal government to delist the bears from the Endangered Species Act because of the rising number of bears.

Data on conflicts haven't quite caught up to the bears' increasing sprawl. In Yellowstone National Park, though, the National Park Service reports just 44 visitors injured by grizzlies since 1979, or one for every 2.7 million visits. Grizzlies have killed seven visitors since the park was established in 1872—two more than have been struck and killed by lightning during that time. Generally speaking, U.S. Forest Service regional wildlife ecologist Andrea Lyons says, "you're more likely to die driving to the trailhead than you are from a grizzly bear encounter."

The Internet loves the meme, "If not friend, why friend-shaped?" We took the question seriously and asked an expert.

The North Cascades National Park Complex—which drew nearly one million visitors in 2023—isn't Yellowstone busy (4.5 million visitors in 2023) or as popular as Mount Rainier or the Olympic Peninsula, the sites of Washington's two other national parks. Visitors can find true solitude in the alpine expanses where the peaks' snowcaps trickle down to aquamarine lakes and rivers. The region is also the largest of the grizzly bear recovery zones, covering 9,800 square miles. Modeling efforts have found the landscape could easily support about 280 bears. In other words: there's plenty of room for them.

Still, officials don't deny there would be conflicts in the North Cascades. Studies have found that attractants such as orchards, beehives, and cattle and sheep calving areas are associated with encounters between humans and grizzlies. Rates of reported conflicts tend to be highest during grizzlies' extremely hungry phase, called hyperphagia, that occurs before hibernation. As part of the reintroduction plan, agencies would provide more education about bear spray and storage of human food, pet food and garbage.

> "Grizzlies were lost because people killed them. It wasn't some rogue disease or habitat loss."
> —Jason Ransom *National Park Service*

In Washington, the public might have more options for handling encounters. Traditionally, as a threatened species under the Endangered Species Act, bears could be captured or killed only during defense of life, research or conflict situations by federal, state or tribal authorities. Because grizzly bears have disappeared entirely from the North Cascades—unlike in other recovery zones

—officials could use the “nonessential experimental population” designation to allow for additional “take” activities for limiting conflicts. According to the environmental impact statement, this would include permits for landowners to kill a grizzly if it is presenting an ongoing threat to humans, animals or property and if “it is not reasonably possible” to quell the bear via nonlethal means.

Some reintroduction advocates have concerns about allowing greater liberties for taking grizzlies, and they worry that a broader definition of who is allowed to kill a bear, and under what circumstances, might lead to unnecessary bear deaths. Others, such as Jason Ransom, a senior wildlife biologist with the National Park Service, view it as a necessary step to push through a program that has fallen victim to changing administrations and volatile politics for many years. As a scientist who’s long worked on bear recovery, Ransom says it’s not strictly a matter of biology or ecology that underlies his support.

Last September, Ransom trekked to Fisher Creek Basin, the site of the last known killing of a grizzly bear in the North Cascades. There’s something about being in a wild ecosystem “that resonates differently with our well-being as a culture,” he says. “When you have big pieces missing, [our well-being] is degraded.” The grizzlies, he explains, “were lost because people killed them. It wasn’t some rogue disease. It wasn’t habitat loss.”

The last verified sighting at North Cascades National Park came in 1991. (Hikers have filed many false reports of grizzlies since then. Most sightings are probably of black bears, which are comparable in size to interior grizzlies and can have similar blonde, brown and cinnamon coats. But they lack the grizzly’s signature shoulder hump.) Unlike other parts of the country where grizzly bears vanished with habitat loss, however, officials have managed the North Cascades as a grizzly bear recovery area since 1997. Thousands of plant and fungi species could serve as potential food sources; despite their carnivorous reputation, the bears are omnivores who largely dine on vegetation. Huckleberries, a grizzly favorite, abound in the region.

With this diet come ecological benefits. Bear scat would disperse seeds across the landscape. Their massive claws would turn up and aerate soil when they dig for roots and rodents. If humans leave them alone—and they very much want to be left alone—they would become a fixture of the landscape amid a biodiversity crisis. A study published in *Biological Conservation* projects that warmer, wetter weather would create more vegetation for grizzlies to eat. Other species may die off, but grizzlies "are going to be winners in the climate change game," says Ransom, a co-author of the study.

Ransom calls grizzlies a keystone species, in the sense that they have an outsize effect on their natural environments relative to their population size—not in the sense, as some use the term, that an ecosystem will fall apart without them. The North Cascades region has shown it can adapt, and "I hope and expect that the ecosystem will remember them," he says.

On March 21, after reviewing nearly 13,000 public comments, the U.S. Fish and Wildlife Service and the National Park Service took a big step toward approval: They issued a final environmental impact statement that reiterated their preference to reintroduce grizzly bears to the North Cascades as a nonessential experimental population. An official "record of decision" was published in April, though there is not yet a set timeline for when bear translocations may begin. (A similar process is now underway for the Bitterroot Ecosystem, a designated grizzly recovery zone in Idaho and Montana; a decision is expected by 2026.)

Two subadult grizzly bears wrestle in Alaska’s Katmai region.
Brooke Bartleson

Regardless of what moves the U.S. government makes, grizzlies will likely be arriving in the North Cascades. Since the passage of a tribal council resolution in 2014, the Okanagan Nation Alliance—an organization that supports a coalition of First Nations—has been working to recover grizzly bears in Canada. This year the group is planning to augment a population of about six bears on the Canadian side of the North Cascades, according to biologist Cailyn Glasser, a resource manager for the Okanagan Nation Alliance.

The bears “don’t care about borders,” Glasser says. As the region’s grizzly population grows, she thinks it’s only a matter of time before the bears venture south to the U.S. (Glasser says she's in regular contact with U.S. officials to coordinate their efforts.) The bears are "going to go back and forth, and the reality is that the best habitat in that ecosystem is right along the border."

To Schuyler, the Upper Skagit Indian Tribe Elder, grizzlies and people can always coexist: "It's just never a choice between us or them." Schuyler traveled to Washington, D.C., in March to impart this belief to representatives of a government that historically tried to force his people from their land. The parallel wasn't lost on him. "We're advocating for ourselves," he says, "not just the grizzly bear."

Benjamin Cassidy is an award-winning journalist based in the Pacific Northwest.

Lifting the Veil on Near-Death Experiences

What the neuroscience of near-death experiences tells us about human consciousness

By Rachel Nuwer

Galen Dara Smith

For decades François D'Adesky, a retired diplomat and civil servant who now lives in Brussels, spoke to no one about his near-death experience (NDE). It happened at the age of 13, when he was hospitalized for acute appendicitis. D'Adesky vividly recalls seeing his body on the operating table and then passing through a tunnel, where he met strange beings who radiated luminosity and goodness. "Your time has not come," an older being, who d'Adesky intuited was God, told him. "You have not undertaken your Earth mission."

Then D'Adesky perceived traveling "at breakneck speed through time and space, back to the beginning of the creation of the world," he says. He eventually arrived at a gardenlike paradise where spiritual beings—one of whom was his deceased grandmother, another a childhood friend who had died at the age of five—

communicated telepathically with him. D’Adesky’s grandmother took him by the hand and led him back into the clinic, where he woke up in his body in excruciating pain.

D’Adesky spent his adult life striving to discover what his special mission was. Eventually he came to see it as the role he played in “making the world a better place,” he says. That included helping, as an official with the United Nations, to get a key resolution passed at the 2011 U.N. Climate Change Conference. It wasn’t until a few years later, though, when NDEs were entering the public discourse more often, that he started sharing the story of his pivotal experience beyond his immediate family. “I had been afraid for my reputation,” he says.

Near-death experiences have been reported across time and cultures. An astounding 5 to 10 percent of the general population is estimated to have memories of an NDE, including somewhere between 10 and 23 percent of cardiac arrest survivors. A growing number of scholars now accept NDEs as a unique mental state that can offer novel insights into the nature of consciousness. “Now, clearly, we don’t question anymore the reality of near-death experiences,” says Charlotte Martial, a neuroscientist at the University of Liège in Belgium. “People who report an experience really did experience something.”

Those who undergo an NDE also return with “this noetic quality from the experience, which very often changes their life,” adds neuroscientist Christof Koch of the Allen Institute in Seattle, who writes about NDEs and other states of consciousness in his 2024 book, *Then I Am Myself the World*. “They know what they’ve seen.”

A handful of researchers, mostly emergency room doctors, began collecting qualitative data about NDEs after the 1975 publication of psychiatrist and physician Raymond A. Moody’s book *Life after Life*, which detailed patients’ accounts of near-death experiences. Since then, only a few research teams have attempted to empirically investigate the neurobiology of NDEs. But their findings are already challenging long-held beliefs about the dying brain, including that consciousness ceases almost immediately after the heart stops beating. This discovery has important implications for current resuscitation practices, which are based on outdated beliefs about what happens to the brain during cardiac arrest, says neuroscientist Jimo Borjigin of the University of Michigan Medical School. “If we understand the mechanisms of death, then this could lead to new ways of saving lives.”

Like psychedelic drugs and other means of altering consciousness, NDEs could also serve as probes for revealing fundamental truths about the mind and brain. Such states are perturbations to the system of consciousness, “and when you perturb a system, you understand better how it works,” says Christopher Timmermann, a postdoctoral fellow at the Center for Psychedelic Research at Imperial College London. “If we want to understand the nature of experience, we have to take into account what’s happening at the margins of nonordinary states.”

Moreover, there are important existential implications, although exactly what those might be continues to be debated in the scientific literature and at conferences, including at a 2023 meeting held by the New York Academy of Sciences. It explored consciousness through the lens of death, psychedelics and mysticism. “These transcendent experiences are found in the major world religions and traditions,” says Anthony Bossis, a clinical assistant professor of psychiatry at the New York University Grossman School of Medicine, who helped to organize the conference. “Might they have some greater purpose for helping humanity cultivate understanding and awareness of consciousness?” he asks. The weightiness of such questions makes careful study of NDEs and their rigorous interpretation all the more critical, Martial says: “It’s important to disentangle empirical findings versus belief.”

On an overcast February afternoon, Martial was meeting with the 20 members of her neuroscience laboratory when her phone began to ring. She had asked to be alerted if someone arrived at the Liège university hospital on the verge of death.

Martial bolted toward the elevator, and within about two minutes she made it into the hospital lobby, its crisscrossing escalators and geometric motifs reminiscent of an M. C. Escher drawing. In the resuscitation room, Aurore Ancion, an emergency physician and doctoral candidate in medical sciences, was already waiting. Laid out on one of the room’s two beds was a bearded man in his mid-70s, his hospital gown open to expose his belly and chest.

Despite being in the middle of an episode of atrial fibrillation, the man was alert and cracking jokes. He giggled nervously as Ancion, working around two other emergency doctors, placed a cap over his head for an electroencephalogram (or EEG, to measure electrical signals in the brain) and adhered two oxygen readers to his forehead. Martial, standing in the back, peered through tortoiseshell glasses at a laptop, where two spiky lines in red and blue began scrolling across the screen—precise measurements, to the trained eye, of the patient’s brain activity.

The doctors eventually had to anesthetize the man and shock his heart back into a normal rhythm. Martial and her colleagues hope the data from his and other patients' visits to the resuscitation room and from follow-up interviews will provide the most detailed picture to date of what transpires in the human brain during close encounters with death.

Many people who had an NDE describe one or more of a specific set of characteristics. They may recall separating from their body and viewing it in real time from above. They may pass through tunnels and see light, encounter deceased relatives or compassionate entities, and have a sense of vastness and deep insight. People may undergo a life review and morally evaluate the choices they have made, including by experiencing the joy or pain their actions caused others. "What's intriguing is that when people die, they don't evaluate themselves based on their own standards of morals," says Sam Parnia, director of critical care and resuscitation research at the N.Y.U. Langone medical center. "They evaluate themselves based on a universal standard."

Although most people describe their NDE in glowing terms, a minority recount visits to hell-like regions, encounters with demonic beings or terrifying voids. In a 2019 study, Martial and her colleagues found that among 123 people who reported an NDE, 14 percent classified it as negative—a proportion Martial says she's "sure" is an underestimate because of how disturbing these memories can be.

Somewhat surprisingly, religious people don't seem to be more inclined toward NDEs. There is, however, preliminary evidence of another group being more likely to have NDEs: those who are prone to REM sleep intrusion, a condition that occurs when rapid eye movement (REM) sleep intrudes into wakefulness and blends elements of dreaming and waking. During the seconds or minutes it lasts for, people may have an out-of-body experience, sense that someone or something is in the room with them, or want to move but find that they can’t. In 2019 Daniel Kondziella, a neurologist at the Copenhagen University Hospital network’s Rigshospitalet, and his colleagues recruited a sample of 1,034 adults from the general population in 35 countries. Ten percent of the study participants had experienced an NDE, and of those, 47 percent also reported REM sleep intrusion—a statistically significant association. Among the people who had not had NDEs, just 14 percent reported REM sleep intrusion.

Still, little is known about the neurobiology of NDEs. Open questions include whether they are driven by a single, core mechanism or are a more variable response to “understanding somehow that death is near,” as Timmermann says. A few researchers, including Martial, are peering into the brains of people who are approaching or undergoing death, in the hope of understanding what is going on.

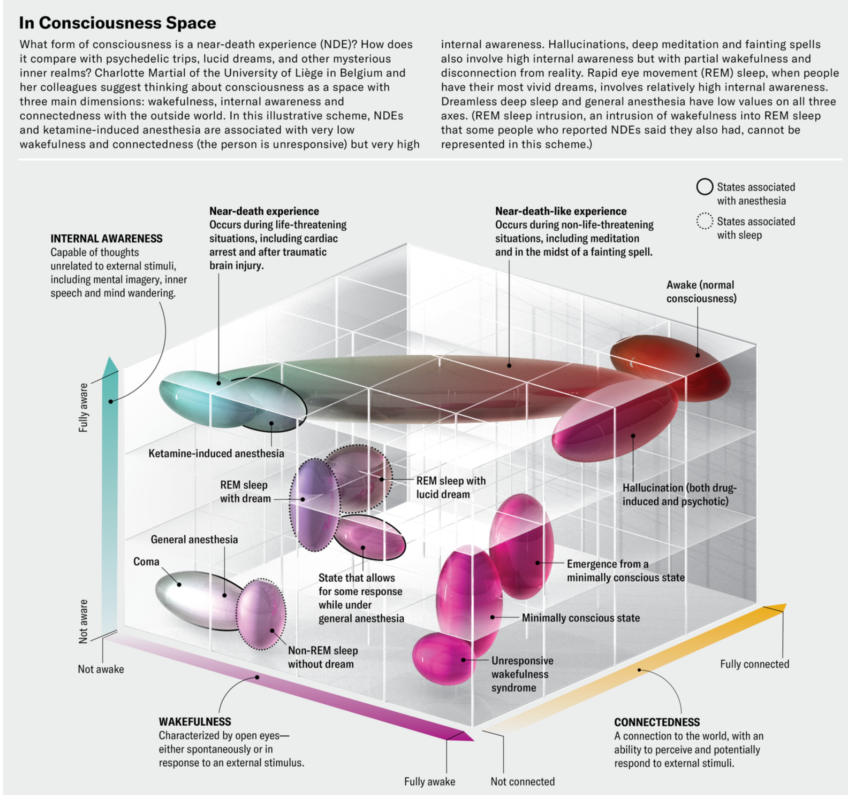
In 2023 Borjigin and her colleagues published what they suspect could be a signature of NDEs in the dying brain. The researchers analyzed EEG data from four comatose patients before and after their ventilators were removed. As their brains became deprived of oxygen, two of the dying patients exhibited a paradoxical surge of gamma activity, a type of high-frequency brain wave linked to the formation of memory and the integration of information.

Borjigin had seen the same upwelling of activity in previous studies of the brains of healthy rats during induced cardiac arrest. In the rodents, the surge occurred across the entire brain. In humans, though, it was confined primarily to the junction of the brain’s temporal, parietal and occipital lobes, a region involved in multiple features of consciousness, including visual, auditory and motion processing. Past research has also associated the region with out-of-body sensations, as well as with altruism and empathy. Although these are all regular components of NDEs, Borjigin says, it’s impossible to know whether the two patients actually experienced an NDE because they did not live to tell about it. But "I could almost guess what they might have experienced," she says.

A 2023 study led by Parnia and detailed in his 2024 book, *Lucid Dying*, provides further evidence of brain activity after patients' hearts have stopped. Parnia and his colleagues worked with 25 hospitals in the U.S., the U.K. and Bulgaria to review EEG and brain-oxygen data from 567 people who experienced an in-hospital cardiac arrest. Medical staff managed to collect interpretable EEG data from 53 of these patients. Most showed an electrical flatline during the crisis, but in around 40 percent of those cases, neurological activity consistent with that of conscious brains transiently reemerged—in some instances up to an hour into CPR.

A different subset of 53 patients from the study survived. Doctors collected EEG and brain-oxygen levels for too few of these people to draw a correlation between any potential memory they had of the event and their brain activity. The authors were able to interview 28 of the survivors, and six had a "recalled experience of death," as Parnia refers to NDEs.

Parnia and his colleagues also sought to test conscious and unconscious awareness, including reports of out-of-body experiences, by projecting a series of 10 random images on a tablet placed near patients' heads and by playing a repeated recording of the names of three fruits—apple, pear, banana—to them through headphones every minute for five minutes while they were unconscious. None of the survivors could remember the images that had been projected. One person who had a recalled experience of death correctly named the fruits in order, although this could have been by chance, Parnia says.



Violet Isabelle Frances for Bryan Christie Design; Source: “Near-Death Experience as a Probe to Explore (Disconnected) Consciousness,” by Charlotte Martial et al., in *Trends in Cognitive Sciences*, Vol. 24; March 2020 (*reference*)

According to Parnia, this study presents “a coherent, mechanistic explanation” for how and why people have recalled experiences of death. When someone starts dying, Parnia says, the brain becomes dysfunctional. Some actions are immediately lost, such as brain stem reflexes, but others that are normally suppressed to optimize performance for ordinary life suddenly become disinhibited because the brain’s natural braking systems are no longer working. As a result, “your entire consciousness comes to the fore,” Parnia says. The purpose of this change, he suggests, is to prepare the person “for a new reality”—the transition from life to death, a condition in which, Parnia believes, consciousness endures.

Other scientists flatly disagree. “When you have an NDE, you must have a functioning brain to store the memory, and you have to survive with an intact brain so you can retrieve that memory and tell about it,” Kondziella says. “You can’t do that without a functioning brain, so all those arguments that NDEs prove that there’s consciousness outside the brain are simply nonsense.”

Kondziella, Martial, and others instead theorize that NDEs might be part of a last-ditch survival tactic. Species across the animal kingdom “play dead”—a behavior technically called thanatosis—when they perceive a mortal threat, typically from an attacking predator. If fight-or-flight fails, the instinct to feign death kicks in as an attempt to forestall the danger. The animal becomes immobilized and unresponsive to external stimuli—but with continued awareness so that, given a chance, it can escape. “Personally, I believe the evolutionary aspect really is the key to understanding what NDEs are and how they came about,” Kondziella says. “There is a perfectly valid biological explanation.”

Martial and others have also criticized the methodological rigor of Parnia’s study. One concern, Martial says, is that the team based its findings on visual readings of patients’ EEGs rather than on “a proper statistical analysis.” Parnia says he and his colleagues applied the standard method for reading EEGs that “every physician in the world” uses in clinical practice. Those who are criticizing the study, he adds, are “just ignoring it because [they] don’t like it.”

In their latest study, Martial and her colleagues plan to use the most rigorous approach to date to collect both subjective and objective data from around 100 patients, including EEG and brain-oxygen readings, plus information from several rounds of interviews and surveys with survivors in the group. The University of Liège team is also trying to more thoroughly evaluate claims about out-of-body experiences. Around 79 percent of people who have an NDE report leaving their body, and some wake up knowing facts about their environment that they seemingly should not know. “I’m not saying it’s not true, but here we want to objectively test it,” Martial says.

To this end, she and her colleagues have decorated the hospital resuscitation room with unexpected objects and images, some of which are hidden in places that could be viewed only from the vantage point of someone near the ceiling. While a patient is in the resuscitation room, including while they are conscious, the team plays an audio clip of various words and animal sounds once every minute. They will test for recollections of any images or sounds in follow-ups with surviving participants, and they will also use video recordings to compare people's memories with reality.

An easier approach to studying NDEs is via safe proxies such as hypnosis, induced fainting and psychedelic drugs. None of these methods produce true NDEs, but the states they trigger may have some overlap with the dying brain. In 2018 Timmermann, Martial and their colleagues published a study comparing NDEs with the effects of *N,N*-dimethyltryptamine (DMT), a mind-altering component of ayahuasca, a South American plant-derived psychedelic brew. Trace amounts of DMT also occur endogenously in humans. "There's speculation that that's somehow underlying NDEs, but the data are very elementary," Timmermann says.

In the study, 13 volunteers received intravenous DMT in a lab setting and rated their experience on a scale commonly used to measure NDEs, as developed by psychiatrist Bruce Greyson in 1983. The researchers compared the DMT group's scores and subjective accounts with other people's taken from an NDE database that Martial and her colleagues have been compiling since 2016. (The database includes around 2,000 accounts, accepted from anyone who contacts the Liège team claiming to have had an NDE and then fills out a lengthy questionnaire.)

They found "striking overlap" between the DMT and NDE groups, Martial says, with people in both describing a sense of entering into an unearthly realm, separating from their body, encountering mystical beings and seeing a bright light. People in both groups also reported feelings of peace, unity and joy. There was just one significant difference: those in the NDE group more frequently experienced reaching a border demarcating a point of no return.

Roland Griffiths, a psychiatrist at Johns Hopkins University who pioneered studies of psilocybin and who died last October, reported similar findings with his colleagues in 2022. The authors compared 3,192 people who had undergone an NDE, a psychedelic drug trip or a nondrug-induced mystical experience. The team found “remarkably similar” long-term outcomes across subjects in all three groups, including a reduced fear of death and lasting positive effects of insights they had gained.

In another study, published in 2024 in the journal *Neuroscience of Consciousness*, Martial, Timmermann and their colleagues interviewed 31 people who had experienced an NDE and had also tried a psychedelic drug—LSD, psilocybin, ayahuasca, DMT or mescaline—to see what they had to say about the similarities and differences between the events. Participants reported stronger sensory effects during their NDE, including the sensation of being disembodied, but stronger visual imagery during their drug trip. They reported feelings of spirituality, connectedness and deeper meaning across both.

In comparisons of these mystical experiences, “the common ground that’s striking to me is in things like a profound, deep sense of love—that all is love and that consciousness is love,” says Bossis, who studies the effects of psilocybin in people with terminal cancer, focusing on relieving end-of-life distress, enhancing spirituality, and providing a greater sense of meaning and fulfillment in life. “There’s also a sense of transcending time as we know it and a greater acceptance of the mystery of life and death.”

To Guy Vander Linden, a retired government administrator in Brussels, his NDE is still a “gift.” It happened in 1990 after a serious bike accident. He was enveloped by a force of overwhelming love and a deep sense of “spirituality not connected to religion,” he says. He also felt an expansiveness in which “I was everything and nothing.”

Vander Linden left the hospital a different person. His fear of death was extinguished, he says, because he now knew that “to die is something fantastic.” He no longer saw value in material things and got rid of his car and two extra houses. He also felt compelled to share his NDE with others through books and conferences. These changes affected his relationships, including with his wife, whom he has since divorced. “She said I’m crazy,” Vander Linden recalls. “To come back with an experience that others haven’t had—it creates conflict.” Years later he is still able to tap into the love he felt when he was bathed in the clear light of what he’s come to conceive of as universal consciousness.

Regardless of how people interpret NDEs, studying them may expand the boundaries of resuscitation, provide a better understanding of mind and brain, and shine a flicker of light on some of the deepest mysteries of existence.

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

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Revolutionary Genetics Research Shows RNA May Rule Our Genome

Scientists have recently discovered thousands of active RNA molecules that can control the human body

By Philip Ball

James Yang

Thomas Gingeras did not intend to upend basic ideas about how the human body works. In 2012 the geneticist, now at Cold Spring Harbor Laboratory in New York State, was one of a few hundred colleagues who were simply trying to put together a compendium of human DNA functions. Their project was called ENCODE, for the Encyclopedia of DNA Elements. About a decade earlier almost all of the three billion DNA building blocks that make up the human genome had been identified. Gingeras and the other ENCODE scientists were trying to figure out what all that DNA did.

The assumption made by most biologists at that time was that most of it didn't do much. The early genome mappers estimated that perhaps 1 to 2 percent of our DNA consisted of genes as classically defined: stretches of the genome that coded for proteins, the workhorses of the human body that carry oxygen to different organs, build heart muscles and brain cells, and do just about everything else people need to stay alive. Making proteins was thought to be the genome's primary job. Genes do this by putting manufacturing instructions into messenger molecules called mRNAs, which in turn travel to a cell's protein-making machinery. As for the rest of the genome's DNA? The "protein-coding regions," Gingeras says, were supposedly "surrounded by oceans of biologically functionless sequences." In other words, it was mostly junk DNA.

So it came as rather a shock when, in several 2012 papers in *Nature*, he and the rest of the ENCODE team reported that at one time or another, at least 75 percent of the genome gets transcribed into RNAs. The ENCODE work, using techniques that could map RNA activity happening along genome sections, had begun in 2003 and came up with preliminary results in 2007. But not until five years later did the extent of all this transcription become clear. If only 1 to 2 percent of this RNA was encoding proteins, what was the rest for? Some of it, scientists knew, carried out crucial tasks such as turning genes on or off; a lot of the other functions had yet to be pinned down. Still, no one had imagined that three quarters of our DNA turns into RNA, let alone that so much of it could do anything useful.

Some biologists greeted this announcement with skepticism bordering on outrage. The ENCODE team was accused of hyping its findings; some critics argued that most of this RNA was made accidentally because the RNA-making enzyme that travels along the genome is rather indiscriminate about which bits of DNA it reads.

Now it looks like ENCODE was basically right. Dozens of other research groups, scoping out activity along the human genome, also have found that much of our DNA is churning out “noncoding” RNA. It doesn’t encode proteins, as mRNA does, but engages with other molecules to conduct some biochemical task. By 2020 the ENCODE project said it had identified around 37,600 noncoding genes—that is, DNA stretches with instructions for RNA molecules that do not code for proteins. That is almost twice as many as there are protein-coding genes. Other tallies vary widely, from around 18,000 to close to 96,000. There are still doubters, but there are also enthusiastic biologists such as Jeanne Lawrence and Lisa Hall of the University of Massachusetts Chan Medical School. In a 2024 commentary for the journal *Science*, the duo described these findings as part of an “RNA revolution.”

What makes these discoveries revolutionary is what all this noncoding RNA—abbreviated as ncRNA—does. Much of it indeed seems involved in gene regulation: not simply turning them off or on but also fine-tuning their activity. So although some genes hold the blueprint for proteins, ncRNA can control the activity of those genes and thus ultimately determine whether their proteins are made. This is a far cry from the basic narrative of biology that has held sway since the discovery of the DNA double helix some 70 years ago, which was all about DNA leading to proteins. “It appears that we may have fundamentally misunderstood the nature of genetic programming,” wrote molecular biologists Kevin Morris of Queensland University of Technology and John Mattick of the University of New South Wales in Australia in a 2014 article.

Another important discovery is that some ncRNAs appear to play a role in disease, for example, by regulating the cell processes involved in some forms of cancer. So researchers are investigating whether it is possible to develop drugs that target such ncRNAs or, conversely, to use ncRNAs themselves as drugs. If a gene codes for a protein that helps a cancer cell grow, for example, an ncRNA that shuts down the gene might help treat the cancer.

A few noncoding RNAs had been known for many decades, but those seemed to have some role in protein manufacture. For instance, only a few years after Francis Crick, James Watson and several of their colleagues deduced the structure of DNA, researchers found that some RNA, called transfer RNA, grabs onto amino acids that eventually get strung together into proteins.

In the 1990s, however, scientists realized ncRNA could do things quite unrelated to protein construction. These new roles came to light from efforts to understand the process of X-inactivation, wherein one of the two X chromosomes carried by females is silenced, all 1,000 or so of its genes (in humans) being turned off. This process seemed to be controlled by a gene called *XIST*. But attempts to find the corresponding XIST protein consistently failed.

The reason, it turned out, was that the gene did not work through a protein but instead did so by producing a long noncoding (lnc) RNA molecule. Such RNAs are typically longer than about 200 nucleotides, which are the chemical building blocks of DNA and RNA. Using a microscopy technique called fluorescence in situ hybridization, Lawrence and her colleagues showed that this RNA wraps itself around one X chromosome (selected at random in each cell) to induce persistent changes that silence the genes. “This was the first evidence of a lncRNA that does something,” Lawrence says, “and it was totally surprising.”

> If noncoding RNAs power the way a cell processes genetic information, it is possible they can be used in medicine.

XIST isn't that unusual in generating an ncRNA, though. In the early 2000s it became clear that transcription of noncoding DNA sequences is widespread. For example, in 2002 a team at biotech company Affymetrix in Santa Clara, Calif., led by Gingeras, who was working there at the time, reported that much more of human chromosomes 21 and 22 gets transcribed than just the protein-coding regions.

It was only after ENCODE published its results in 2012, however, that ncRNA became impossible to ignore. Part of the antipathy toward those findings, says Peter Stadler, a bioinformatics expert at Leipzig University in Germany, is that they seemed like an unwanted and unneeded complication. "The biological community figured we already knew how the cell works, and so the discovery of [ncRNAs] was more of an annoyance," he says. What's more, it showed that simpler organisms were not always a reliable guide to human biology: there is far less ncRNA in bacteria, studies of which had long shaped thinking about how genes are regulated.

But now there is no turning back the tide: many thousands of human lncRNAs have been reported, and Mattick suspects the real number is greater than 500,000. Yet only a few of these have been shown to have specific functions, and how many of them really do remains an open question. "I personally don't think all of those RNAs have an individual role," Lawrence says. Some, though, may act in groups to regulate other molecules.

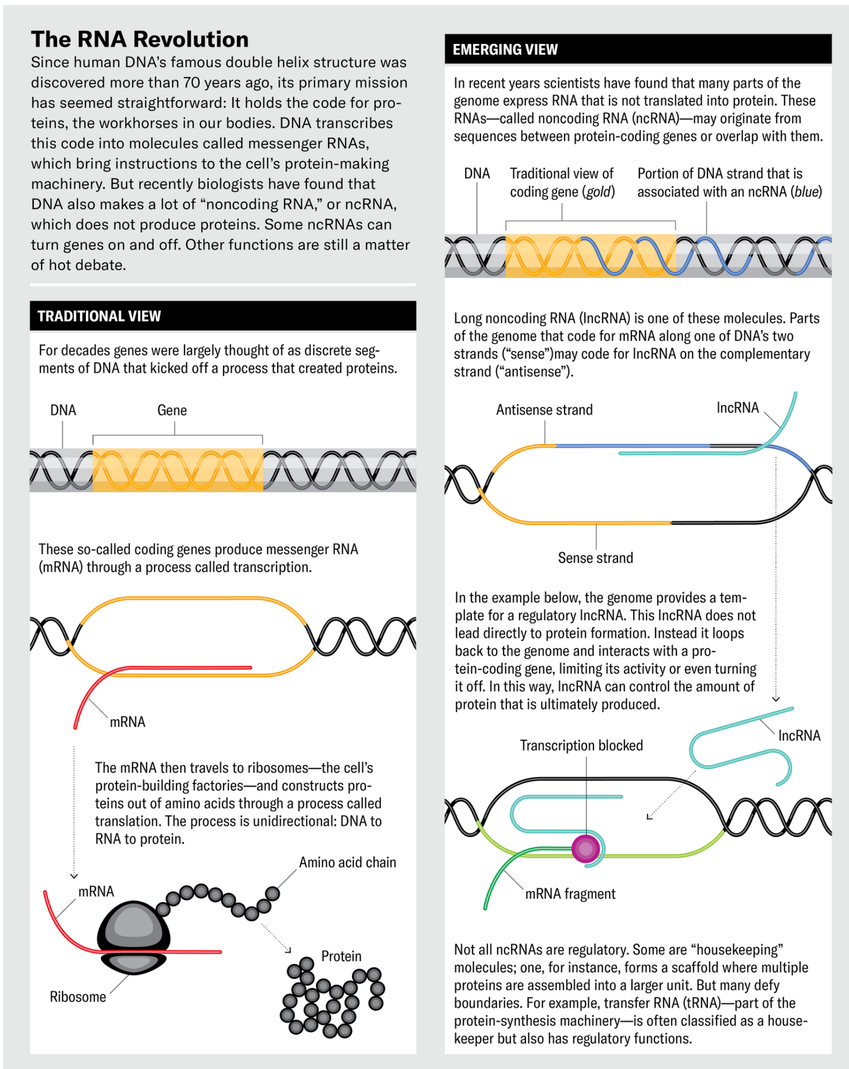
How lncRNAs perform such regulation is also still a matter of debate. One idea is that they help to form so-called condensates: dense fluid blobs containing a range of different regulatory molecules. Condensates are thought to hold all the relevant players in one place long enough for them to do their job collectively. Another idea is that lncRNAs affect the structure of chromatin—the combination of DNA and proteins that makes up chromosome fibers in the cell nucleus. How chromatin is structured determines which of its genes are accessible and can be transcribed; if parts of chromatin are too tightly packed, the enzyme machinery of transcription can't reach it. "Some lncRNAs appear to be involved with chromatin-modifying complexes," says Marcel Dinger, a genomics researcher at the University of Sydney.

> If only 1 to 2 percent of the RNA from our genome was encoding proteins, what was the rest for? Some, scientists knew, carried out crucial tasks such as turning genes on or off.

Lawrence and Hall suspect that lncRNAs could supply scaffolds for organizing other molecules, for example, by holding some of the many hundreds of RNA-binding proteins in functional assemblies. One lncRNA called NEAT1, which is involved in the formation of small compartments in the nucleus called paraspeckles, has been shown capable of binding up to 60 of these proteins. Or such RNA scaffolding could arrange chromatin itself into particular structures and thereby affect gene regulation. Such RNA scaffolding could have regularly repeating modules and thus repetitive sequences—a feature that has long been regarded as a hallmark of junk DNA but lately is appearing to be not so junky after all. This view of lncRNA as scaffolding is supported by a 2024 report of repeat-rich ncRNAs in mouse brain cells that persist for at least two years. The research, by Sara Zocher of the German Center for Neurodegenerative Diseases in Dresden and her co-workers, found these ncRNAs seem to be needed to keep parts of chromatin in a compact and silent state.

These lncRNAs are just one branch of the noncoding RNA family, and biologists keep discovering others that appear to have different functions and different ways of affecting what happens to a cell—and thus the entire human body.

Some of these RNAs are not long at all but surprisingly short. Their story began in the 1980s, when Victor Ambros, working as a postdoctoral researcher in the laboratory of biologist Robert Horvitz at the Massachusetts Institute of Technology, was studying a gene denoted *lin-4* in the worm *Caenorhabditis elegans*. Mutations of *lin-4* caused developmental defects in which "the cells repeated whole developmental programs that they should have transitioned beyond," says Ambros, now at the University of Massachusetts Medical School. It seemed that *lin-4* might be a kind of "master regulator" controlling the timing of different stages of development.



Jen Christiansen; Source: John Mattick, UNSW Sydney (consultant)

"We thought *lin-4* would be a protein-coding gene," Ambros says. To figure out what role this putative protein plays, Ambros and his colleagues cloned the *C. elegans* gene and looked at its product—and found that the effects of the gene may not be mediated by any protein but by the gene's RNA product alone. This molecule looked ridiculously short: just 22 nucleotides long, a mere scrap of a molecule for such big developmental effects.

This was the first known microRNA (miRNA). At first “we thought this might be a peculiar characteristic of *C. elegans*,” Ambros says. But in 2000 Gary Ruvkun, another former postdoc in the Horvitz lab, and his co-workers found that another of these miRNA genes in *C. elegans*, called *let-7*, appears in essentially identical form in many other organisms, including vertebrates, mollusks and insects. This implies that it is a very ancient gene and “must have been around for 600 million to 700 million years” before these diverse lineages went their separate ways, Ambros says. If miRNAs are so ancient, “there had to be others out there.”

Indeed, there are. Today more than 2,000 miRNAs have been identified in the human genome, generally with regulatory roles. One of the main ways miRNAs work is by interfering with the translation of a gene’s mRNA transcript into its corresponding protein. Typically the miRNA comes from a longer molecule, perhaps around 70 nucleotides long, known as pre-miRNA. This molecule is seized by an enzyme called Dicer, which chops it into smaller fragments. These pieces, now miRNAs, move to a class of proteins called Argonautes, components of a protein assembly called the RNA-induced silencing complex (RISC). The miRNAs guide the RISC to an mRNA, and this either stops the mRNA from being translated into a protein or leads to its degradation, which has the same effect. This regulatory action of miRNAs guides processes ranging from the determination of cell “fate” (the specialized cell types they become) to cell death and management of the cell cycle.

Key insights into how such small RNAs can regulate other RNA emerged from studies in *C. elegans* in 1998 by molecular biologists Andrew Fire, Craig Mello and their co-workers, for which Fire and Mello were awarded the 2006 Nobel Prize in Physiology or Medicine. They learned that RISC is guided by slightly different

RNA strands named small interfering (si) RNA. The process ends with the mRNA being snipped in half, a process called RNA interference.

MiRNAs do pose a puzzle, however. A given miRNA typically has a sequence that matches up with lots of mRNAs. How, then, is there any selectivity about which genes they silence? One possibility is that miRNAs work in gangs, with several miRNAs joining forces to regulate a given gene. The different combinations, rather than individual snippets, are what match specific genes and their miRNAs.

Why would miRNA gene regulation work in this complicated way? Ambros suspects it might allow for “evolutionary fluidity”: the many ways in which different miRNAs can work together, and the number of possible targets each of them can have, offer a lot of flexibility in how genes are regulated and thus in what traits might result. That gives an organism many evolutionary options, so that it is more able to adapt to changing circumstances.

One class of small RNAs regulates gene expression by directly interfering with transcription in the cell nucleus, triggering mRNA degradation. These PIWI-interacting (pi) RNAs work in conjunction with a class of proteins called PIWI Argonautes. PiRNAs operate in germline cells (gametes), where they combat “selfish” DNA sequences called transposons or “jumping genes”: sequences that can insert copies of themselves throughout the genome in a disruptive way. Thus, piRNAs are “a part of the genome’s immune system,” says Julius Brennecke of the Institute of Molecular Biotechnology of the Austrian Academy of Sciences. If the piRNA system is artificially shut down, “the gametes’ genomes are completely shredded, and the organism is completely sterile,” he says.

Still other types of ncRNAs, called small nucleolar RNAs, work within cell compartments called nucleoli to help modify the RNA in ribosomes—a cell’s protein-making factories—as well as transfer RNA and mRNA. These are all ways to regulate gene expression. Then there are circular RNAs: mRNA molecules (particularly in neurons) that get stitched into a circular form before they are moved beyond the nucleus into the cytoplasm. It’s not clear how many circular RNAs are important—some might just be transcriptional “noise”—but there is some evidence that at least some of them have regulatory functions.

In addition, there are vault RNAs that help to transport other molecules within and between cells, “small Cajal-body-specific RNAs” that modify other ncRNAs involved in RNA processing, and more. The proliferation of ncRNA varieties lends strength to Mattick’s claim that RNA, not DNA, is “the computational engine of the cell.”

If ncRNAs indeed power the way a cell processes genetic information, it is possible they can be used in medicine. Disease is often the result of a cell doing the wrong thing because it gets the wrong regulatory instructions: cells that lose proper control of their cycle of growth and division can become tumors, for example. Currently medical efforts to target ncRNAs and alter their regulatory effects often use RNA strings called antisense oligonucleotides (ASOs). These strands of nucleic acid have sequences that are complementary to the target RNA, so they will pair up with and disable it. ASOs have been around since the late 1970s. But it has been hard to make them clinically useful because they get degraded quickly in cells and have a tendency to bind to the wrong targets, with potentially drastic consequences.

Some ASOs, however, are being developed to disable lncRNAs that are associated with cancers such as lung cancer and acute myeloid leukemia. Other lncRNAs might act as drugs themselves. One known as MEG3 has been found, preliminarily, to act as a tumor suppressor. Small synthetic molecules, which are easier than ASOs to fine-tune and deliver into the body as pharmaceuticals, are also being explored for binding to lncRNAs or otherwise inhibiting their interactions with proteins. Getting these approaches to work, however, has not been easy. “As far as I am aware, no lncRNA target or therapeutic has entered clinical development,” Gingeras says.

James Yang

Targeting the smaller regulatory RNAs such as miRNAs might prove more clinically amenable. Because miRNAs typically hit many targets, they can do many things at once. For example, miRNAs in families denoted miR-15a and miR-16-1 act as tumor suppressors by targeting several genes that themselves suppress cell death (apoptosis, a defense against cancer) and are being explored for cancer therapies.

Yet a problem with using small RNAs as drugs is that they elicit an immune response. Precisely because the immune system aims to protect against viral RNA, it usually recognizes and attacks any “nonself” RNA. One strategy for protecting therapeutic RNA from immune assault and degradation is to chemically modify its backbone so that it forms a nonnatural “locked” ring structure that the degrading enzymes can’t easily recognize.

Some short ASOs that target RNAs are already approved for clinical use, such as the drugs inotersen to treat amyloidosis and golodirsen for Duchenne muscular dystrophy. Researchers are also exploring antisense RNAs fewer than 21 nucleotides long that target natural regulatory miRNAs because it is only beyond that length that an RNA tends to trigger an immune reaction.

These are early days for RNA-based medicine, precisely because the significance of ncRNA itself in human biology is still relatively new and imperfectly understood. The more we appreciate its pervasive nature, the more we can expect to see RNA being used to control and improve our well-being. Nils Walter of the Center for RNA Biomedicine at the University of Michigan wrote in an article early in 2024 that the burgeoning promise of RNA therapeutics “only makes the need for deciphering ncRNA function more urgent.” Succeeding in this goal, he adds, “would finally fulfill the promise of the Human Genome Project.”

Despite this potential of noncoding RNA in medicine, the debate continues about how much of it truly matters for our cells. Geneticists Chris Ponting of the University of Edinburgh and Wilfried Haerty of the Earlham Institute in Norwich, England, are among the skeptics. In a 2022 article they argued that most lncRNAs are just “transcriptional noise,” accidentally transcribed from random bits of DNA. “Relatively few human lncRNAs ... contribute centrally to human development, physiology, or behavior,” they wrote.

Brennecke advises caution about current high estimates of the number of noncoding genes. Although he agrees that such genes “have been underappreciated for a long time,” he says we should not leap to assuming that all lncRNAs have functions. Many of them are transcribed only at low levels, which is what one would expect if indeed they were just random noise. Geneticist Adrian Bird of the University of Edinburgh points out that the abundance of the vast majority of ncRNAs seems to be well below one molecule per cell. “It is difficult to see how essential functions can be exerted by an ncRNA if it is absent in most cells,” he says.

But Gingeras counters that this low expression rate might reflect the very tissue-specific roles of ncRNAs. Some, he says, are expressed more in one part of a tissue than in another, suggesting that expression levels in each cell are sensitive to signals coming from surrounding tissues. Lawrence points out that, despite the low expression levels, there are often shared patterns of expression across cells of a particular type, making it harder to argue that the transcription is simply random. And Hall doubts that cells are really so prone to “bad housekeeping” that they will habitually churn out lots of useless RNA. Lawrence and Hall’s suggestion that some lncRNAs have collective effects on chromatin structure would mean that no individual one of them is needed at high expression levels and that their precise sequence doesn’t matter too much.

That lack of specificity in sequence and binding targets, Dinger says, means that a mutation of a nucleotide in an ncRNA typically won’t have the same negative impact on its function as it tends to in a protein-coding DNA sequence. So it would not be surprising to see quite a lot of sequence variation. Dinger argues that it makes more sense to assume that “genetically encoded molecules are potentially functional until shown otherwise, rather than junk unless proven functional.” Some in the ENCODE team now agree that not all of the 75 percent or so of human genome transcription might be functionally significant. But many researchers make the point that surely many more of the noncoding molecules do meaningful things than was suspected before.

Demonstrating functional roles for lncRNAs is often tricky. In part, Gingeras says, this may be because lncRNA might not be the biochemically active molecule in a given process: it might be snipped up into short RNAs that actually do the work. But because long and short RNAs tend to be characterized via different techniques, researchers may end up searching for the wrong thing.

What's more, long RNAs are often cut up into fragments and then spliced back together again in various combinations, the exact order often depending on the condition of the host cell.

At its roots, the controversy over noncoding RNA is partly about what qualifies a molecule as "functional." Should the criterion be based on whether the sequence is maintained between different species? Or whether deleting the molecule from an organism's repertoire leads to some observable change in a trait? Or simply whether it can be shown to be involved in some biochemical process in the cell? If repetitive RNA acts collectively as a chromosome "scaffold" or if miRNAs act in a kind of regulatory swarm, can any individual one of them really be considered to have a "function"?

Gingeras says he is perplexed by ongoing claims that ncRNAs are merely noise or junk, as evidence is mounting that they do many things. "It is puzzling why there is such an effort to persuade colleagues to move from a sense of interest and curiosity in the ncRNA field to a more dubious and critical one," he says.

Perhaps the arguments are so intense because they undercut the way we think our biology works. Ever since the epochal discovery about DNA's double helix and how it encodes information, the bedrock idea of molecular biology has been that there are precisely encoded instructions that program specific molecules for particular tasks. But ncRNAs seem to point to a fuzzier, more collective, logic to life. It is a logic that is harder to discern and harder to understand. But if scientists can learn to live with the fuzziness, this view of life may turn out to be more complete.

Philip Ball is a science writer and former *Nature* editor based in London. His most recent book is *How Life Works* (University of Chicago Press, 2023).

Adolescent Anxiety Is Hard to Treat. New Drug-Free Approaches May Help

Research on the developing brain points to new ways to help young people with anxiety disorders

By BJ Casey & Heidi Meyer

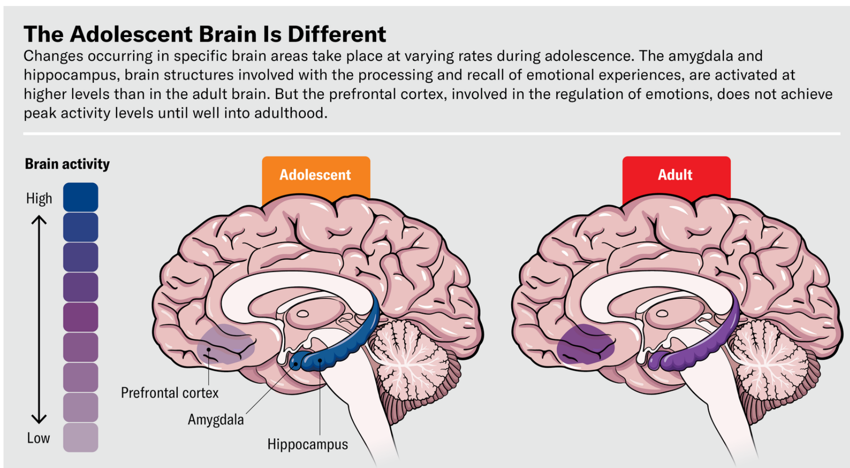
Ellen Weinstein

Adolescence is a remarkable period of development and learning, a time when youths explore and adapt to changes in their social worlds and begin to form a sense of who they are and hope to be. It is a time when they first demonstrate a dramatic adaptability to the unique cognitive, emotional, physical, social and sexual demands placed on them as they transition from dependence on their parents or caregivers to relative independence. It is also, unfortunately, a time when the emergence of most mental health problems peaks.

The most common mental health concerns facing adolescents today are anxiety disorders, and their prevalence has been increasing for the past decade. A survey of tens of thousands of teens showed that this prevalence increased roughly 30 to 40 percent between 2012 and 2018, and based on evidence from teens from Germany, it rose another 70 percent during the first few years of the COVID pandemic. Yet anxiety disorders in young people are largely undertreated.

The only evidence-based behavioral treatments for anxiety are cognitive-behavioral therapies (CBTs). They involve identifying triggers of anxiety and then desensitizing the affected person to them through coping strategies such as positive thought reframing or breathing exercises, along with repeated exposure to the triggers in a safe environment. Although CBT is the most established treatment for adolescent anxiety, not all youths who try it experience relief. Among those who do, many fail to maintain improvements over time. A mere 20 to 50 percent of patients treated for anxiety without medication during adolescence remain in remission six years after initial CBT. The consequences can be long-lasting and severe. Left untreated, anxiety can lead to more serious chronic illnesses such as depression and substance use disorder later in life, greater susceptibility to physical illnesses and, in extreme cases, suicide.

Fortunately, new discoveries about the adolescent brain are showing promising paths forward for the treatment of anxiety. Current research benefits from rapidly advancing imaging technologies that can reveal patterns of neural activity and exciting potential avenues for intervention. These modalities have already provided access to the inner workings of the developing brain in laboratory animals and teens, and scientists hope they will lead to new approaches in clinical practice that take into account the unique changes in the human brain during adolescence. By focusing on the developing brain and the behaviors it generates early on in life, we may be better able to alter anxiety-related memories, identify cues and situations that help to reduce symptoms, and mitigate the adverse effects of anxiety for young people before they become a more chronic affliction in adulthood.



Ni-ka Ford

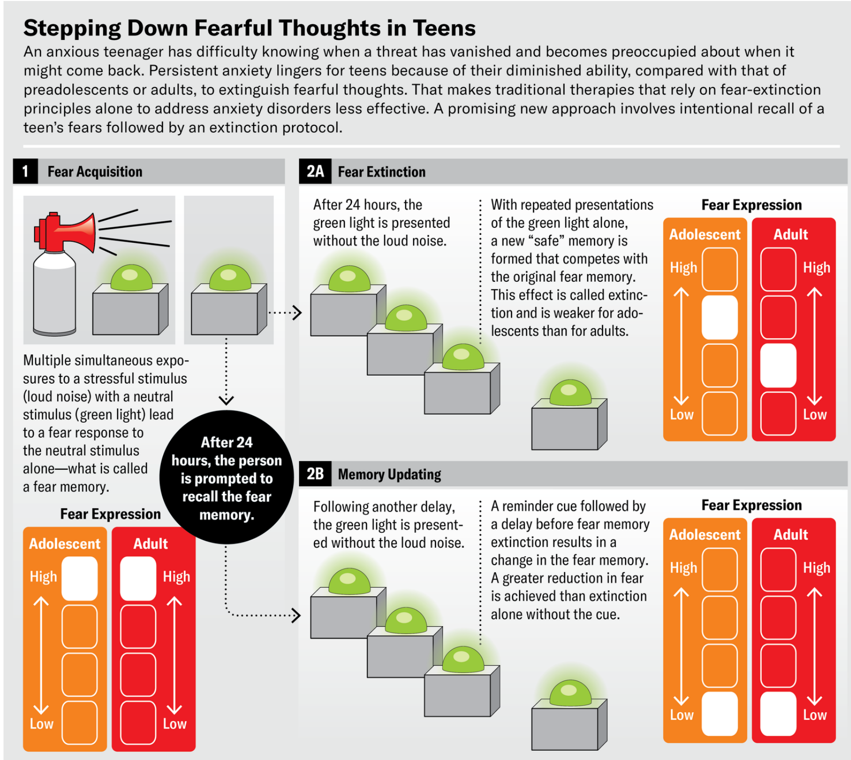
In the past two decades we have learned that the adolescent brain undergoes notable changes in structure and function, and these changes are distinct from those observed during early childhood and adulthood. They are localized, meaning certain brain areas change earlier in development than others. Regions involved in emotions, such as the amygdala and the hippocampus, show peak structural and functional changes during the teen years. For example, during adolescence the amygdala's volume increases (a structural change), and so does the way the amygdala is activated by certain emotional experiences (a functional change). In contrast, brain regions and circuitry associated with the regulation of emotions, thoughts and actions—the prefrontal cortex, for instance—change more gradually, with development continuing well into adulthood. These differences in developmental timing may lead to an imbalance in communication among brain regions, allowing one area to prevail over another in an adolescent's decision-making. Accordingly, in emotionally charged or threatening situations, early-developing emotional areas "win out" over later-developing ones, driving some of the reactions and responses linked with the behaviors of anxious and volatile teens. These regional differences might have served an evolutionary purpose. They have been linked to heightened sensitivity to emotional and social information that may be essential for reproductive success and the survival of the human species. Unfortunately, these same imbalances have also been associated with increased reactivity to stress and greater susceptibility to anxiety disorders.

A core emotion associated with anxiety disorders is fear. Although fear is an adaptive response to threats and therefore essential for survival, persistent fear long after a threat has been removed can lead to a pathological state of anxiety. People with anxiety disorders have difficulty identifying when previously threatening situations have become safe, and they may overgeneralize by thinking that a negative experience in one situation will recur in other scenarios.

Decades of animal and human research have identified the basic brain circuitry for remembering an acquired fear in adults. The amygdala is key to developing a fear memory, and parts of the prefrontal cortex are involved in decreasing the strength of fear memories—a process known as extinction. Both the amygdala and the prefrontal cortex are highly interconnected with a third region, the hippocampus, which plays a role not only in fear extinction but also in determining how we experience fear in different situations. In particular, the hippocampus provides information about the surrounding environment to help an individual decide whether a given situation is more likely to present a threat (for example, a bear in the woods) or an absence thereof (a bear at the zoo). Much of this circuitry is conserved across different species, enabling the translation of basic animal research to treatments in humans.

Recently researchers have focused attention on fear memory and extinction during adolescence. These studies show that adolescents, like preadolescents and adults, are capable of acquiring a fear memory, but they are less able to extinguish those memories than people in other age groups. After being exposed to a few simple pairings of a neutral stimulus (a colored square) with an aversive stimulus (a loud noise), children, adolescents and adults alike show a fear response, measured by sweat gland activity, to the colored square even when the loud noise no longer happens. When preteen children and adults are then presented repeatedly with the colored square *without* the loud noise, they begin to see the square not as something predicting the threat of the loud noise but rather as a safe refuge from it—the fear memory is extinguished. Adolescents, however, continue to react fearfully to the colored square.

In cases when fear does get diminished for adolescents, it regularly returns with the passage of time. The finding that adolescents "learn" to extinguish fear less readily than younger or older people has been replicated in studies across species (mice, rats and humans). Most notably, during this developmental period, the amygdala is much more involved in sustaining the fear memory than the prefrontal cortex is in initiating the extinction process. A lower ability to initiate fear-extinction learning is thought to confer a risk for anxiety. Thus, adolescents may innately be at higher risk.



Jen Christiansen

The discovery of differences in fear-extinction behavior and brain circuitry during adolescence has important implications not only for understanding the potential for increased susceptibility to anxiety disorders but also for choosing treatment options. Behavioral therapies such as CBT entail identifying triggers of anxiety, finding coping strategies and undergoing a process of desensitization built on the principles of fear extinction. But during adolescent fear extinction, the involvement of the prefrontal cortex, which is associated with the planning and control of behavior, is diminished—which implies that for adolescents, the effectiveness of conventional exposure-based CBT might also be diminished. Together, these facts raise the question of how we should tailor treatments for the developing brain. Specifically, how might we use what we know about the brain's fear circuitry and the development of fear learning during adolescence to guide interventions that may be more successful in altering teens' fear memories?

One strategy involves conceding the delayed maturation of the prefrontal cortex and circumventing the region in treatment. Rather than relying on prefrontal-based extinction learning, we have tested an alternative method called memory reconsolidation updating. Memory reconsolidation is based on the principle that memories are dynamic, not static. Every time a memory is retrieved, it gets modified. Reactivating a fear memory by presenting a reminder of the fear stimulus opens a time-limited window during which the memory itself becomes prone to disruption and change.

Studies in both humans and rodents suggest that fear-memory updating is mediated by changes to the memory in the amygdala. Unlike the prefrontal circuitry, which continues to show developmental changes into young adulthood, the amygdala undergoes peak maturation during midadolescence.

These findings suggest that one way to help adolescents overcome pathological fear is to introduce what is called a reminder cue to retrieve the memory, followed by a delay before subsequently extinguishing it. In our lab, we tested this idea in both healthy adolescents and adults by comparing their retention of a fear memory after extinction with and without a preceding reminder cue. We found that even though adolescents typically show diminished fear extinction relative to adults, those who were prompted to retrieve the fearful memory several minutes before extinction learning showed a dramatic reduction in fear the next day compared with those who underwent only extinction learning. In fact, those adolescents' fear memories diminished to the same degree as observed in adults.

> To help adolescents overcome fear, introduce a reminder cue to retrieve the memory, followed by a delay before then extinguishing it.

Traditionally, extinction learning involves forming a new, competing, safe memory that leaves the original fear memory intact, meaning it is possible for those fearful thoughts to return later. The current findings, however, suggest that with memory-reconsolidation updating, the original fear memory is altered. Thus, the reconsolidation approach has the potential to both reduce fear at the time of treatment and lessen the likelihood that it will return.

This research is exciting because it suggests a path to the clinical use of reconsolidation updating. Simple modifications to existing exposure-based CBT techniques might prove effective in reducing triggers of fear and anxiety in adolescent patients. This method could entail a step as simple as the therapist reminding patients why they are there when they arrive for their appointment—the equivalent of the reminder cue and fear-memory retrieval in the lab setting. Then the therapist could spend several minutes establishing a safe rapport with the patient while waiting for the memory to enter a labile state during the reconsolidation-updating window. Desensitization with exposure therapy could then begin during the time in which the updating process takes place. The current variable efficacy of CBT in adolescents with anxiety disorders may be explained by the fact that some clinicians already use procedures that inadvertently tap into components of reconsolidation updating.

Recent attempts to incorporate reconsolidation-updating approaches in treating adult patients with anxiety and trauma-related disorders have yielded some success, but to date they have not been used with adolescent patients. The studies in adults show short- and long-term reduction of symptoms, especially for patients with specific phobias and post-traumatic stress disorder. Although more basic and clinical research is needed, this method seems promising.

Another strategy that may help adolescents extinguish a fear memory involves the use of safety cues that signal there is nothing to be afraid of. In an experimental setting, a safety cue can be a simple stimulus—a symbol or a sound—that is distinguishable from and repeatedly contrasted with a fear cue. Outside the lab, safety cues come in many forms and are likely to be a stimulus unique to the individual: a small personal object, a photograph of a loved one, a specific scent. We and others have shown that in humans and rodents alike, safety cues act by recruiting brain regions that show elevated activity during adolescence, including the amygdala and the hippocampus. The anterior part of the hippocampus in particular shows a strong increase in activity when a safety cue is presented alongside a fear cue; the degree of activity corresponds to the reduction in fear. Furthermore, safety cues rely less on the prefrontal cortex than do other forms of fear regulation, such as extinction, highlighting the possible advantage of using a safety cue–based approach for anxiety during adolescence.

It is not feasible to avoid all triggers of excessive fear and anxiety, so it's important that patients do not become overly reliant on safety cues to the detriment of learning other coping skills. Safety cues may be a valuable tool for increasing the tolerability of the early stages of treatment so that patients do not drop out. Early treatment sessions could include guidance from the clinician on how to identify and properly deploy a safety cue.

As treatment progresses, cues can give patients a way to reduce their fear response long enough to evaluate the situation and use tools from CBT practice. Although research on integrating safety cues into treatment is in its earliest stages, the method shows great promise, particularly for adolescents. Our group recently demonstrated in mice that intermittently presenting a safety cue during an extinction protocol led to better fear extinction in adolescent mice than observed in either adolescent (28 to 50 days) or adult rodents trained without a safety cue.

The hope for these emerging therapeutic approaches is that we can tailor current anxiety treatments for young people by targeting the developingbrain. It is important to be mindful of the fact that the magnitude and intensity of the fear response in people diagnosed with anxiety are probably much greater than the fear evoked by aversive stimuli in lab experiments, which are often mild, narrowly targeted and transient. It is also important to remember that CBT and antidepressants can treat anxiety effectively in many people. Unfortunately, though, for some, these solutions offer only limited or brief benefits. Therefore, the most effective forms of treatment may require a combination of approaches, including desensitization techniques modified to incorporate reconsolidation updating or safety cues, possibly in conjunction with antidepressants.

The ultimate aim is for us to optimize current treatments for youths with anxiety by targeting the brain during a period of development accompanied by intensive learning and, in so doing, improve the quality of life for adolescents both in the immediate future and later in life.

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Superheavy Elements Are Breaking the Periodic Table

Extreme atoms are pushing the bounds of physics and chemistry

By Stephanie Pappas

Quarternative

At the far end of the periodic table is a realm where nothing is quite as it should be. The elements here, starting at atomic number 104 (rutherfordium), have never been found in nature. In fact, they'd emphatically prefer not to exist. Their nuclei, bursting with protons and neutrons, tear themselves apart via fission or radioactive decay within instants of their creation.

These are the superheavy elements: after rutherfordium come dubnium, seaborgium, bohrium, and other oddities, all the way up to the heaviest element ever created, oganesson, element 118. Humans have only ever made vanishingly small amounts of these elements. As of 2020, 18 years after the first successful creation of oganesson in a laboratory, scientists had reported making a total of five atoms of it. Even if they could make much more, it would never be the kind of stuff you could hold in your hand—oganesson is so radioactive that it would be less matter, more heat.

Using ultrafast, atom-at-a-time methods, researchers are starting to explore this unmapped region of the periodic table and finding it as fantastical as any medieval cartographer's imaginings. Here at the uncharted coastline of chemistry, atoms have a host of weird properties, from pumpkin-shaped nuclei to electrons bound so tightly to the nucleus they're subject to the rules of relativity, not unlike objects orbiting a black hole.

Their properties may reveal more about the primordial elements created in massive astrophysical phenomena such as supernovae and neutron star mergers. But more than that, studying this strange matter may help scientists understand the more typical matter that occurs naturally all around us. As researchers get better at pinning these atoms down and measuring them, they're pushing the boundaries of the way we organize matter in the first place.

“The periodic table is something fundamental,” says Witold Nazarewicz, a theoretical nuclear physicist and chief scientist at the Facility for Rare Isotope Beams at Michigan State University. “What are the limits of this concept? What are the limits of atomic physics? Where is the end of chemistry?”

Affixed to the wall in a concrete-block corridor known as Cave 1 in Lawrence Berkeley National Laboratory (LBNL), just steps from one of the few instruments in the world that can create superheavy atoms, is a poster-size printout of a table that organizes elements by nuclide, meaning based on the number of protons and neutrons in the nucleus. This graph shows all the known information about the nuclear structure and decay of the elements, as well as of their isotopes—variations on elements with the same number of protons in the nucleus but different numbers of neutrons.

It’s a living document. There’s a typo in the title, and there are tears along the poster’s edges where duct tape holds it to the wall. It’s been marked up with notations in Sharpie, added after the poster was printed in 2006. These notations are the atomic physics version of seafarers penciling in new islands as they sail, but in this case, the islands are isotopes of elements so heavy they can be seen only in particle accelerators like the one here. In a field where it can take a week to make just one atom of what you want, a record of progress is essential.

“Everybody likes the handwritten part,” says Jacklyn Gates, who leads LBNL’s Heavy Element Group. “If we were to print this out from 2023—”

“It’s not as fun,” chimes in Jennifer Pore, a staff scientist in the lab.

“It’s not as fun,” Gates agrees.

Gates is a nuclear chemist with a wry sense of humor and a clear fondness for the equipment that she and her team have developed to synthesize superheavy elements. They create these elements by smashing standard-size atoms together in a 2.2-meter-wide cyclotron—a drum-shaped particle accelerator—in a lab perched on a hillside above the city of Berkeley. Construction on the cyclotron started in 1958, after the fallout from the first nuclear bomb explosions began turning up in the form of new radioactive elements such as fermium (atomic number 100). Much of the original cyclotron persists today; in the control room, silver dials that wouldn't be out of place in a cold war–era thriller sit beside beige panels from the 1980s and blue banks of buttons from modern updates.

The first of the superheavies, rutherfordium, was synthesized here in 1969. Rutherfordium, named after Ernest Rutherford, who helped to explain the structure of atoms, was also made a few years prior by the Russian Joint Institute for Nuclear Research (JINR) in Dubna, the same group that first created oganesson in 2002 (named after Yuri Oganessian, who led the team that created it). Beginning in the late 1950s, the competition to add new elements got hotter than the ion beams used to make them. Today the vicious disputes over who synthesized what first, mostly between the Berkeley lab and JINR, are remembered as the Transferium Wars.

By the 1980s Germany had joined the fray with its nuclear research institute, Gesellschaft für Schwerionenforschung (GSI), or the Society for Heavy Ion Research. The numbers ticked higher, with the three teams trading off naming rights up to copernicium (element 112, named after Nicolaus Copernicus), discovered in 1996. Controversy continued to dog the superheavies; in 1999 researchers at LBNL announced the discovery of element 116, now known as livermorium after Lawrence Livermore National Laboratory, only to retract that claim after finding that one of their scientists had fabricated evidence. (JINR successfully created livermorium in 2000.) In 2004 Japan's Institute of Physical and Chemical Research (RIKEN) synthesized element 113, nihonium, after the Japanese word for "Japan." Although element 118 is the heaviest element ever synthesized, the most recently discovered is actually 117, tennessine, which was announced by JINR in 2010. The scientists behind the discovery named it in tribute to the state of Tennessee, home to several institutions that played a role in the experiments.

> "What are the limits of atomic physics? Where is the end of chemistry?"

—Witold Nazarewicz *Michigan State University*

The race to create ever heavier elements continues to this day, and not just because the researchers who succeed get to name a new element in the periodic table. It's also because theorists predict that certain combinations of protons and neutrons may land in an "island of stability" where these elements will stop decaying immediately. "Some theories predict a year half-life, or 100 or 1,000 days," says Hiromitsu Haba, a physicist and director of the Nuclear Chemistry Group at RIKEN, which is currently on the hunt for element 119.

A half-life—the time it takes for about half of a substance's atoms to decay—that long would be enough for serious experimentation or even use in new technologies. For now, though, research into superheavies is focused on their fundamental properties and what they can reveal about nuclear dynamics, not what they can do as materials themselves. That doesn't mean they won't eventually become useful, however.

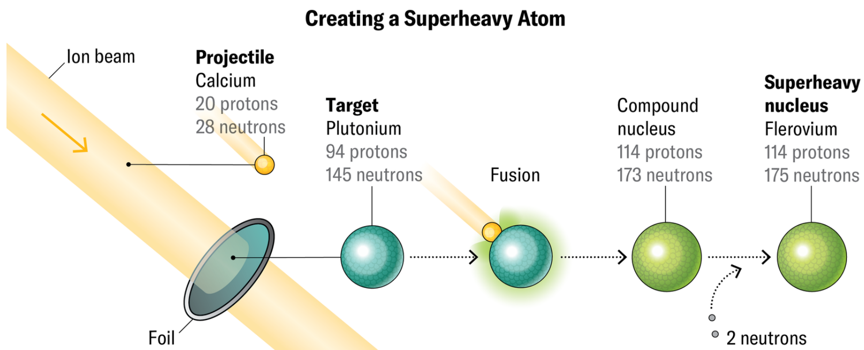
"Everything we're doing right now ... it doesn't have practical applications," Gates says. "But if you look at your cell phone and all the technology that went into that—that technology started back in the Bronze Age. People didn't know it would result in these devices that we're all glued to and utterly dependent on. So can superheavy elements be useful? Maybe not in my generation but maybe a generation or two down the road, when we have better technology and can make these things a little bit easier."

Making these elements is far from easy. Researchers do it by shooting a beam of heavy ions (in this case, large atomic nuclei without their electrons) at a target material in the hopes of overcoming the electrostatic repulsion between two positively charged nuclei and forcing them to fuse. At LBNL, the source of the ion beam is a device called VENUS (for "versatile electron cyclotron resonance ion source for nuclear science"), which sits at the top of the cyclotron behind fencing festooned with radiation warnings. Within VENUS, a combination of microwaves and strong magnetic fields strips electrons off a chosen element (often calcium or argon in Gates's experiments). The resulting ions shoot down a pipeline into the cyclotron, which sweeps the ions around in a spiral, accelerating the beam.

Technicians in the control room use electrostatic forces to direct the beam out of the cyclotron and into instruments in the "caves," low corridors that come off the cyclotron like spokes. The caves contain beam targets; the one in Cave 1 is a thin metal foil about the diameter of a salad plate. The targets rotate so the beam doesn't hit any single spot for too long. They can melt when bombarded with speeding ions, Gates says.

What the target is made of depends on how many protons the researchers want in the final product. For example, to make flerovium (114 protons, named after Russian physicist Georgy Flerov, who founded JINR), they need to hit plutonium (94 protons) with calcium (20 protons). To make element 118, oganesson, scientists beam calcium at californium (98 protons). The more neutrons they can pack into the ion beam, the more they can ultimately cram into the final product, making even heavier isotopes.

Most of the time the beam passes right through the target without any nuclear interactions. But with six trillion beam particles winging through the targets per second, an eventual nucleus-to-nucleus collision is inevitable. When conditions are just right, these pileups mash the nuclei together, creating a very temporary new superheavy atom moving at nearly 600,000 meters per second.



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To slow down these speeding heavyweights, the researchers use helium gas and electric fields to guide the particles into a trap for measurement. They can also pump in other gases to see what kinds of chemical reactions a superheavy element will undergo before it decays. But that's feasible only if the element lasts long enough, says Christoph E. Düllmann, head of the superheavy element chemistry research group at GSI. To conduct and study chemical reactions, researchers require an element with a half-life of at least half a second.

Scientists quantify superheavy elements and their reaction products by measuring the energy they give off during alpha decay, the shedding of bundles of two protons and two neutrons. In a room called the Shack at LBNL, researchers wait on tenterhooks for data points showing them where these alpha-decay particles land inside the detector; their journey reveals information about the composition of the original atoms and any reactions they've undergone. It's hard to imagine that chemistry physically happening, Pore says: "It almost feels like it exists somewhere else."

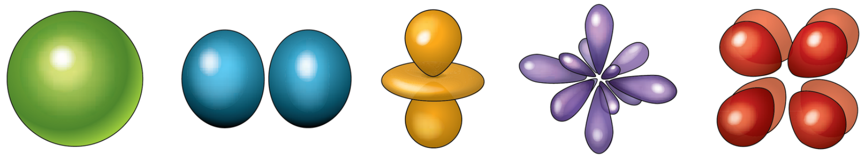
The heaviest element that researchers have studied chemically is flerovium (114)—the heaviest one that can be created in the quantities and with the duration needed for chemical experiments. Scientists can produce flerovium at a rate of about three atoms a day, Düllmann says. "A typical experiment needs about one month of total run time," he says. "Not every atom that is produced will reach your chemistry setup, and not every atom that reaches your chemistry setup will be detected in the end."

A few atoms can reveal a lot, however. Before flerovium was synthesized, some theories predicted that it might act like a noble gas—inert and nonreactive—and others suggested it might act like a metal, specifically, mercury. Experiments on the element published in 2022 in the journal *Frontiers in Chemistry* showed something weirder. At room temperature, flerovium forms a strong bond with gold, very unlike a noble gas. It also bonds with gold at liquid-nitrogen temperatures (–196 degrees Celsius). Oddly, though, at temperatures between these two, the element doesn't react.

Oganesson is grouped in the periodic table with the noble gases, but researchers think it is neither noble nor a gas. It's probably a solid at room temperature, according to research published in 2020 in *Angewandte Chemie*, and transitions to liquid around 52 degrees C. There are many such examples, says Peter Schwerdtfeger, a theoretical chemist at Massey University in New Zealand and senior author of the 2020 paper.

The reason for these strange characteristics has to do with the electrons. Electrons orbit nuclei at certain energy levels known as shells, each of which can hold a specific number of electrons. Electrons in outer shells—where there may not be enough electrons to completely fill the shell—are responsible for forging chemical bonds with other atoms. Each shell ostensibly represents a specific distance from the nucleus, although the actual path of an electron's orbit in that shell (called an orbital) is often far from a simple circle and can look more like a dumbbell, doughnut, teardrop, or other configuration. (According to quantum mechanics, these outlines merely represent the places where an electron is likely to be found if pinned down by an actual measurement. Otherwise, electrons mostly exist in a haze of probability somewhere around the nucleus.)

A Selection of Electron Orbital Models



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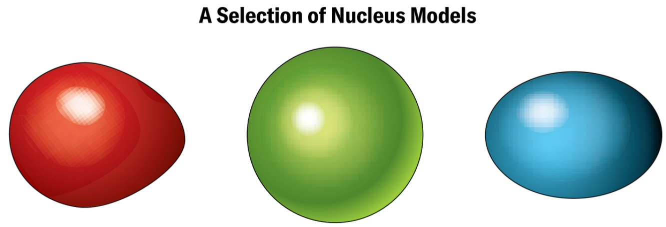
As a nucleus gets heavier, electrons near it feel an extreme pull from the glut of positive charges there, drawing them in closer and reducing the space they have to move around in. Because of the uncertainty principle, which states that a particle's position and speed can't be known precisely at the same time, this reduction in the electrons' elbow room means their velocity must increase via a kind of seesawing of fundamental physical laws. Soon the electrons are traveling at nearly the speed of light. As Einstein's special theory of relativity suggests, objects moving this fast gain mass and get weird.* In particular, the orbits of electrons in the lowest-energy states—the innermost shells—around a superheavy nucleus tend to contract, creating a greater density of electrons closer to the nucleus, Schwerdtfeger says. These changes are known as relativistic effects.

These effects show up even in naturally occurring elements of the periodic table. Gold is yellowish because relativistic effects shrink the gap between two of its electron shells, slightly shifting the wavelengths of light that the element absorbs and reflects. Yet relativistic effects don't usually play a huge role in the chemical behavior of most light elements. That's why the order of elements in the periodic table is based on the number of protons in each element's nucleus. This arrangement serves to group together substances with similar chemical properties, which are determined mainly by the number of electrons in outer shells that are available for chemical bonds.

"The periodic table is supposed to tell you what the chemical trends are," LBNL's Pore says. For heavier elements, in which relativistic effects start to rule, that's not necessarily true. In research published in 2018 in the journal *Physical Review Letters*, Schwerdtfeger and his colleagues found that because of relativistic effects, oganesson's electron cloud looks like a big, fuzzy smear with no major distinction between the shells.

Even outside superheavy territory, chemists debate the placement of certain elements in the periodic table. Since 2015 a working group at the International Union of Pure and Applied Chemistry has been refereeing a debate over which elements should go in the third column of the table: lanthanum and actinium (elements 57 and 89) or lutetium and lawrencium (71 and 103). The debate centers on misbehaving electrons: because of relativistic effects, the outermost electrons orbiting these elements aren't where they should be according to the periodic table. After nine years of official consideration, there is still no consensus on how to group these elements. Such problems only become more pressing at the heavier end of the table. "We're trying to probe where that organization begins to break down and where the periodic table begins to stop being useful," Gates says.

Along with a window into the limits of chemistry, the dance of electrons can provide a peek into the dynamics of the nucleus at the extremes. In a nucleus groaning with protons and neutrons, interactions between these particles often warp the shape into something other than the stereotypical sphere you'll see in diagrams of atoms. Most of the superheavy elements that have been probed so far have oblong nuclei shaped like footballs, says Michael Block, a physicist at GSI. Theoretically, heavier ones that haven't been synthesized yet might have nuclei shaped like flying saucers or even bubbles, with empty or low-density spots right in the center. Scientists "see" these shapes by measuring minuscule changes in electron orbits, which are affected by the arrangement of the positive charges in the nucleus. "This allows us to tell what the size of the nucleus is and what the shape of the nucleus is," Block says.



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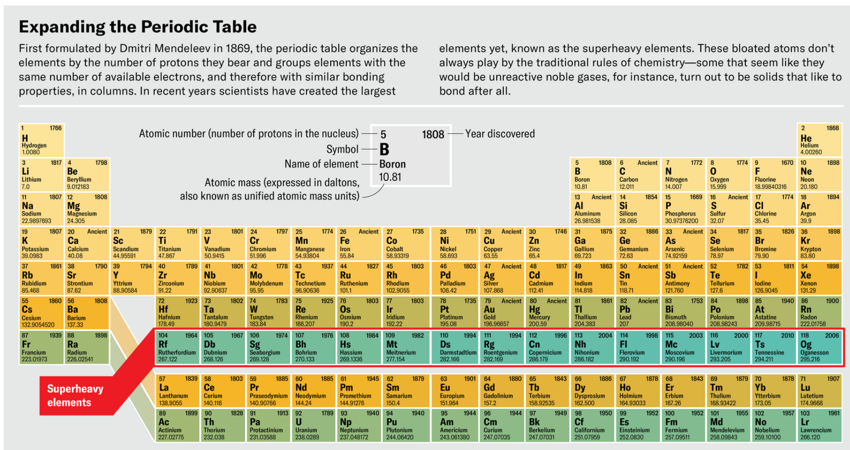
The layout of the nucleus holds the key to whether anyone will ever be able to synthesize a superheavy element that sticks around. Certain numbers of protons and neutrons (collectively dubbed nucleons) are known as magic numbers because nuclei with these numbers can hold together particularly well. Like electrons, nucleons occupy shells, and these magic numbers represent the tallies needed to fill nucleonic shells completely. The island of stability that researchers hope to find in a yet undiscovered superheavy element or isotope would be the result of "double magic"—theoretically ideal numbers of both protons and neutrons.

Whether such a thing exists is an open question because heavy nuclei might tear themselves apart rather than tolerating the required numbers of nucleons. "Fission is the killer," M.S.U.'s Nazarewicz observes.

Unlike the (relatively) gradual whittling down of a nucleus by alpha decay, nuclear fission is a sudden and utter dissolution. Different models yield different predictions about how many particles can be packed into a nucleus before fission becomes inevitable, Nazarewicz says. Theorists are trying to determine this limit to understand how large nuclei can truly get.

There is an interesting liminal space at the edges of what nuclei can bear, Nazarewicz notes. To be declared an element, a nucleus must survive for at least 10^{-14} second, the time it takes for electrons to glom on and form an atom. But in theory, nuclear lifetimes can be as short as 10^{-21} second. In this infinitesimal gap, you might find nuclei without electron clouds, incapable of chemistry, he says.

“The periodic table breaks with the heaviest elements already,” Nazarewicz says. The question is, Where do you break chemistry altogether? Another way to understand superheavy elements is to look for them in space. The elements heavier than iron (atomic number 26) form in nature through a process called rapid neutron capture, which often occurs in cataclysmic events such as a collision of two neutron stars.



Jen Christiansen; Source: National Center for Biotechnology Information; https://pubchem.ncbi.nlm.nih.gov/periodic-table/ (*reference*)

If superheavies have ever arisen naturally in the universe, they were made by this process, too, says Gabriel Martínez-Pinedo, an astrophysicist at GSI. In rapid neutron capture, also known as the r-process, a seed nucleus grabs free nearby neutrons, quickly taking on the mass to make heavy isotopes. This must happen in an environment with ample neutrons roaming freely, which is why neutron star mergers are opportune spots.

In 2017 scientists observed a neutron star merger for the first time by detecting gravitational waves created by the interaction. “That was the very first confirmation that, indeed, the r-process happens during the merger of two neutron stars,” Martínez-Pinedo says. Researchers detected isotopes of lanthanide elements (atomic numbers 57 to 71) in that merger but, as they reported in Nature at the time, couldn’t narrow down the exact elements present. Detecting any superheavy elements will be even trickier because researchers will need to know which unique wavelengths of light those elements emit and absorb and pick them out of what Martínez-Pinedo calls the “complicated soup of elements” that emerges from one of these events.

In December 2023, however, astronomers reported in the journal *Science* that there are excess amounts of several lighter elements—ruthenium, rhodium, palladium and silver—in some stars. These elements may be overrepresented because they are the result of heavy or superheavy elements breaking apart via fission. The findings hint that nuclei with as many as 260 protons and neutrons might form via the r-process.

Even if superheavy elements created in neutron star mergers were to decay away quickly, knowing they existed would help scientists write a history of matter in the universe, Martínez-Pinedo says. New observatories such as the James Webb Space Telescope and the upcoming Vera C. Rubin Observatory in Chile should make it possible to see other cosmic events capable of creating superheavy elements. “And there will be new gravitational-wave detectors that will allow us to see much larger distances and with higher precision,” he adds.

At the Facility for Rare Isotope Beams in Michigan, a new high-energy beam promises to give further insights into the r-process by packing more neutrons into isotopes than ever before possible. These are not new superheavies but beefed-up versions of lighter elements. In February researchers reported in the journal *Physical Review Letters* that they had created heavy isotopes of thulium, ytterbium and lutetium using just one 270th of their beams’ ultimate planned power output. At higher power levels they should be able to make the kinds of isotopes that eventually decay into heavier stable metals such as gold. “This may provide a pathway to some of the interesting isotopes for astrophysics,” says Brad Sherrill, a physicist at M.S.U. and a co-author of that study.

Meanwhile other scientists around the world are also looking to amp up their ion beams and targets to push past element 118. In addition, they're increasing the precision with which they can capture and measure these elements. Researchers at the Facility for Rare Isotope Beams plan to improve their ability to differentiate between particles by a factor of 10. GSI will soon have a next-generation accelerator for superheavy synthesis. And at LBNL, Gates and her team are installing instruments to take higher-precision measurements of the mass of single atoms.

These new tools should further reveal the contours of chemistry at the extremes. "When we do superheavy chemistry," Massey's Schwerdtfeger says, "we see surprises all over the place."

**Editor's Note (7/9/24): This sentence was edited after posting to correct the reference to Einstein's special theory of relativity.*

Stephanie Pappas is a freelance science journalist based in Denver, Colo.

Humans Are Driving a New Kind of Evolution in Animals

Anthropogenic evolution is affecting species across the planet

By Lee Alan Dugatkin

Tree Swallow.
Donald M. Jones/Minden Pictures

The peppered moth is an iconic example of Charles Darwin's theory of evolution by natural selection. For centuries peppered moths (*Biston betularia*) were common in the forests around Manchester, England, and elsewhere. With their light-colored wings, peppered moths were camouflaged from predators against the light-gray bark of the trees they rested on during the day. By the early 19th century, however, soot from the industrial revolution had forged a new evolutionary environment, one that favored dark-colored moths, which matched the soot-covered trees better than their lighter peers. In the 1950s and 1960s evolutionary biologists found that in industrial areas, 80 percent of the moths were dark-colored, and the dark moths had a 2:1 survival advantage over light-colored moths in those areas. Today, in our age of molecular genetics, we know the mutation that probably produced the dark-colored moths occurred around 1819 and was the result of "jumping genes"—bits of DNA that change position in a genome and may create a mutation in the process.

The darkening of the peppered moth is also an example of anthropogenic evolution: evolutionary change caused by alterations humans make to the environment. In recent years scientists have identified many more cases of human-mediated evolutionary change. The full scope and effects of anthropogenic evolution are only now coming into focus. But already we have ascertained that humans are shaping the evolutionary trajectories of animals across the globe, from insects to whales. As a result of our influence, key aspects of animal behavior are changing, including where they live, where they breed, what they eat, whom they fight and whom they help. We are remodeling more than just the environments species live in. We're altering the species themselves as they evolve in response to our impact on their surroundings.

One consequence of this change is that we are creating mismatches between animals and the settings in which they evolved. Creatures once well equipped to meet the challenges of their environment suddenly face a world in which their fine-tuned behavioral adaptations are no longer adaptive at all. In some species, natural selection is recalibrating behavior so that individuals are better suited to their new circumstances. The question is whether it will be able to do so fast enough to keep pace with human transformation of the planet we all share.

For long stretches of evolutionary time, natural selection has favored a tight link between ambient temperature and the start of the breeding season for many animals, including birds. Hormones associated with reproduction kick into gear when the weather warms; birds court, construct nests and bring food home to deposit into the mouths of their waiting young. For Tree Swallows (*Tachycineta bicolor*), the spring thaw is the trigger that sets that reproductive cascade into motion. But that trigger is now being pulled too early. Largely as a result of increased carbon dioxide emission, the average spring temperature for Tree Swallows living in northern New York increased about 1.9 degrees Celsius between 1972 and 2015, and the spring thaw is starting earlier. Over that same period Tree Swallows started breeding 13 days earlier. The environmental cue the birds use to time breeding has become mismatched with their altered conditions.

Peppered moth.
Alex Hyde/Getty Images

Because of this mismatch, breeding swallows risk experiencing cold snaps they otherwise would not have been exposed to. These cold snaps don’t directly affect the survival of adult birds, but they do reduce the activity of the insect prey that swallows bring back to their hungry nestlings. Parents are unable to find enough food for their brood, which leaves their young less likely to survive and reproduce.

Using data on 11,236 chicks from more than 2,000 nests, J. Ryan Shipley, now at the Swiss Federal Institute for Forest, Snow and Landscape Research, and his colleagues found that Tree Swallow nestlings that hatched between 2011 and 2015 were twice as likely to have experienced a cold snap during their early development as birds that had hatched in the 1970s. One upshot of that was an increase in the number of complete nest failures in which every single nestling in a nest died. A nasty cold snap in June 2016 led to the death of 71 percent of chicks in nests that year. Mass casualties were not the only detrimental effect Shipley and his team observed. They also found that nests in which eggs hatched before the last cold snap had, on average, one fewer surviving chick than nests in which eggs hatched after the last cold snap.

Of course, not every Tree Swallow responds to the onset of spring thaw in exactly the same way. Some may initiate breeding earlier than the average bird, others later. If that variation is based on underlying genetic differences, then it is reasonable to expect natural selection to favor birds that start breeding later. But this mismatch is a daunting problem for natural selection to solve. Unlike feather coloration getting a bit brighter or drabber, recalibrating the links between temperature and the onset of mating is incredibly complex, involving hormonal, neurobiological and behavioral changes. It may take more time than the swallows have.

Air pollution is not the only anthropogenic disturbance producing a discrepancy between environmental cues and the onset of reproduction. Artificial light at night (ALAN), caused by everything from streetlamps to car headlights to residential and commercial housing, is having similar effects. The problem isn’t just that birds migrating at night crash into lit buildings, although that is part of it.

To examine the impact of light pollution on the courtship displays of the firefly *Photuris versicolor*, a species in which both males and females flash light signals, Ariel Firebaugh and Kyle Haynes of the University of Virginia set up experimental plots, each of which contained a mesh canister. From 9:30 P.M. to 11:30 P.M. on 10 consecutive nights, they placed a female in each canister and recorded her flash rate, along with the number of males who approached her canister and how often they flashed. Some experimental plots were lit by two white floodlights, whereas others had no artificial light. Unlit plots drew in relatively few fireflies, but of the fireflies recorded in them, around 90 percent of stationary females and 65 percent of visiting males flashed courtship displays. Lit plots had significantly more firefly visitors, but not a single male or female in these plots flashed—not even once. Under ALAN, fireflies abandoned their normal courtship ritual. Just as with CO_2 emission and Tree Swallow breeding season, ALAN is placing animals in environments that are dramatically different from those in which their ancestors evolved. Whether *P. versicolor* can adapt to these changing environments over time remains to be seen.

Evolutionary mismatches are just one consequence of anthropogenic change; the creation of ecological traps is another. These traps occur when, after some relatively rapid change to the environment, animals display a preference for suboptimal habitats that reduce their reproductive success. Ecological traps need not be physical traps, but they can be. One such trap results from used tires. People toss roughly 30 million metric tons of tires every year, and although some are repurposed, many are dumped into the environment, often illegally.

Atsushi Sogabe and Kiichi Takatsuji of Hirosaki University in Japan studied the ecological traps that discarded tires create for hermit crabs. Their work began after they observed many small snail shells inside a tire on the floor of Japan's Mutsu Bay. In most hermit crab species, the head and thorax are protected by a calcified exoskeleton, but the abdomen is not. The crabs use discarded shells from mollusks, including snails, to shield their vulnerable abdomen. Hermit crabs are always looking to upgrade to a better shell. Sogabe and Takatsuji saw many a crab scrounging among the shells that had accumulated in the discarded tire. The researchers hypothesized that once inside, crabs wouldn't be able to climb the concave inner wall to leave and therefore would eventually die in the tire. When the scientists brought a discarded tire into their laboratory and placed hermit crabs inside it, not a single crab could get out.

Sogabe and Takatsuji then ran a field experiment in which they placed six tires on the seabed in Mutsu Bay. A year and a half later, after the tires had been in place long enough to acquire lots of shells—the remains of snails that were most likely drawn to the tires to feed on the algae that accumulates on them—the researchers began monthly collections of hermit crabs from the tires. Over the course of 12 months they collected 1,278 hermit crabs that had gotten stuck in those six tires. It's unclear whether the crabs will evolve physical or behavioral adaptations that can help them escape this ecological trap.

Urbanization is a driving force in anthropogenic evolution. One way to measure its extent is by using the so-called Human Footprint Index, a composite measure that takes into account human population density, land use, ALAN, roads, railroads, navigable rivers, and more. Marlee Tucker of Radboud University in the Netherlands and her colleagues analyzed GPS data from 803 individual animals belonging to 57 mammal species across the globe, including Mongolian wild ass (*Equus hemionus hemionus*), giraffe (*Giraffa camelopardalis*), brown bear (*Ursus arctos*), roe deer (*Capreolus capreolus*), European hare (*Lepus europaeus*) and brushtail possum (*Trichosurus vulpecula*). They found that in areas with a large human footprint, such as urban areas, animals moved around in their environment only half as much as animals in low-footprint areas.

Animals in and around the towns and cities we have built live radically different lives from those in nearby rural environments. They encounter different foods, predators, light and surfaces. Soundscapes are also extremely different in cities, where animal communication is often masked, garbled, and otherwise hindered by the hubbub we humans produce.

Black asphalt pavement and the metal in buildings are excellent heat conductors, and together they give rise to what are known as urban heat islands. One study of 57 cities across Scandinavia found that temperatures in urban areas were up to five degrees C higher than those in adjacent rural locales. Evolutionary biologists such as Shane Campbell-Staton of Princeton University are beginning to piece together how urban heat islands impose new selective forces on species that live in these settings. He and his colleagues have studied the effects of urban heat islands and anthropogenic evolution in crested anole lizards (*Anolis cristatellus*) living in Puerto Rico. They worked at four different locations, each of which had an urban site and a nearby forest site. As they had feared, ambient temperatures were higher in all the urban sites. Not only were the perches where the urban lizards spent much of the day hotter than the perches of the forest lizards, but the body temperature of the urban lizards was higher, too.

Crested anole.

reptiles4all/Getty Images

Urban heat islands should produce different natural selection pressures for thermal tolerance in urban populations of lizards compared with forest populations. To see whether this divergence is happening, Campbell-Staton and his team captured lizards at all the study sites and brought them to their lab, where they measured the animals' behavioral responses to increasing temperatures. They placed the anoles under heat lamps and raised the temperature one degree C each minute. As the temperature increased, a researcher would periodically flip a lizard onto its back and touch it with a pair of forceps to see whether it would flip itself back over. That scene might sound funny, but for lizards in the wild, ending up on their backs is no laughing matter. Righting themselves can be a matter of life or death, particularly when predators are nearby. Indeed, one reason a lizard may be on its back is because a predator has knocked it over. Campbell-Staton's team found that the maximum temperature at which a lizard could right itself was higher for the populations from urban heat islands than for forest animals.

Research into the genomes of these animals has revealed what may be the genetic basis for the urban lizards' heat tolerance. A follow-up genetic comparison of anoles from urban and forest environments found that one gene variant known to produce a moldable response to temperature change was more common in the city lizards than in their forest counterparts. We do not know whether this variant originated recently, like the peppered moth's gene for dark pigmentation, or had been present at low levels in the broader lizard population for a long time and only recently became more common. In either case, anthropogenic evolution has already reshaped the behavioral and genetic constitution of city lizards.

Cities aren't just hotter; they're brighter. Like early spring thaws, artificial lighting can cause evolutionary mismatches. To examine how ALAN has impacted reproduction in urban animals, Davide

Dominoni of the University of Glasgow and his colleagues captured male European Blackbirds (*Turdus merula*) in Munich, Germany, and in a forest 40 kilometers southwest of the city. They fitted the birds with a tiny light sensor that collected light readings every two minutes. Birds in the forest experienced very low ambient light levels at night (an average of 0.00006 lux); birds in Munich were exposed to much brighter nighttime environments (an average of 0.2 lux).

The researchers then brought blackbirds from both locations to an aviary for a long-term experiment on the effect of light pollution. Two groups of blackbirds were tested. Each group included 10 birds from Munich and 10 birds from the forest, and each bird was housed in its own cage within the aviary. Blackbirds in both groups experienced the same daytime light regime. But at night, birds in the control group had just enough light to orient themselves (0.0001 lux), whereas the birds in the experimental group were exposed to a much brighter nighttime environment (0.3 lux).

The results were striking: Birds in the experimental group reached sexual maturity 26 days earlier than birds in the control group. Over the course of the seven-month experiment, city birds in the experimental group had a reproductive season that was 12 days longer than that of city birds in the control group. A similar comparison for forest birds found that the experimental group's reproductive season was nine days longer. That longer reproductive season under ALAN came with a hefty price tag. The following year, when both groups were exposed to the same conditions as in year one, males in the experimental group showed no signs of reproductive activity. The lights that keep our cities aglow at night are disrupting reproduction in blackbirds and probably many other species.

Urbanization also affects the personalities of city-dwelling creatures. In animal behavior research, personality isa suite of behaviors that are engaged in consistently, across long stretches of time, and that differ among individuals of the same species. Melanie Dammhahn of the University of Münster in Germany and her collaborators studied personality in populations of striped field mice (*Apodemus agrarius*) across an urban-rural gradient that spanned four urban locations in Berlin and five rural areas north of the city. They trapped 96 mice from these nine populations and conducted behavioral tests on the mice in an enclosure set up in their natural habitats. The traps they used were attached to an opaque plastic pipe that opened on one side into a naturally lit arena built by the researchers.

To measure boldness, the investigators noted when mice left the dark pipe to enter the open arena. To measure exploration, they looked at the behavior of mice once they entered the open field, recording how long it took them to move into the center of the field and how much time they spent exploring across the entire field. Urban mice tended to be bolder and explore more than their rural counterparts, perhaps because bolder, more exploratory animals are more likely to venture into urban areas in the first place. Once urban colonization has taken place, these same traits may prove beneficial because urban environments are constantly being fragmented into smaller sections by roads and new construction. During the fragmentation process, bolder explorers are more likely to move into new habitats with better food or fewer predators. And because boldness and exploration have been shown to be at least partially genetically determined in other species, bold mice probably tend to beget more bold mice, leading to the observed population-level personality differences between urban and forest mice.

Not all animals’ responses to anthropogenic change are inborn, however. Some species may learn how to mitigate the detrimental effects of human influence, including mismatches, ecological traps and problems related to life in the city. The extent to which animals do so is difficult to gauge, largely because animal behaviorists have only recently investigated this possibility in the wild. That said, there is some evidence from birds that learning can reduce the impact of anthropogenic disturbance.

Most species of parrots in the neotropics build their nests inside tree cavities and are considered obligate cavity nesters, meaning they build nests *only* in cavities. The logging industry, however, is cutting down the trees in which parrots nest. Pedro Romero-Vidal of the University Pablo de Olavide in Spain and his colleagues systematically looked at cavity-nesting species of parrots at eight sites across Argentina, Bolivia, Costa Rica and Panama. The team found that in areas where tree cavities were particularly rare because of logging to clear land for cattle pastures, parrots became more innovative in their nest building. In Buenos Aires, parrots nested in holes in the walls of buildings and railway stations, and data from 137 pairs of birds from eight different parrot species show that they have nested in the bract leaves of palm trees that were spared logging rather than in the oak, beech and pine trees they prefer. Such innovation may provide some respite in the face of escalating deforestation, but for how long and for how many species?

Birds may also learn novel survival skills such as how to avoid a new predator. The Common Myna (*Acridotheres tristis*) was introduced into Australia about 150 years ago. Today this bird is widely regarded as an invasive pest because it outcompetes native birds for nesting sites. To protect native birds, Australia has developed programs for trapping and killing mynas. Between 2005 and 2012, more than 50,000 trapped birds were killed by a clever and ruthless new predator: humans. The survivors and their descendants have done a good job of adapting to this novel threat. Mynas in areas of intense trapping show heightened antipredator behavior, such as staying close to refuges, compared with mynas in areas where trapping is less frequent.

Until recently, it wasn’t clear whether mynas in high-trapping areas demonstrated different antipredator tactics because of natural selection favoring innate avoidance behavior or because they were learning about the increased danger while living in those areas. To find out, Marie C. Diquelou of the University of Rennes in France and Andrea Griffin of the University of Newcastle in Australia set up an experiment. For four days, either adorned in a mask, a white lab coat and a black top hat or wearing no mask or hat but draped in a dark jacket, the researchers approached mynas at feeding stations they had constructed. On the fifth day of the experiment, they approached the feeding station again wearing one costume or the other. But this time they carried a birdcage containing two live mynas and a portable amplifier, which played recordings of mynas emitting alarm calls.

During the final part of the experiment, one of the scientists approached the feeding station in costume, put out food and recorded the behavior of the mynas. Diquelou and Griffin found that mynas made the most alarm calls during the final days of the study but only when a researcher was dressed as they had been on day five, when the mynas could pair that researcher with the alarm calls of other birds. Mynas had learned that humans with particular characteristics (in this case, their apparel) were especially dangerous, giving them at least some relief from their new foe.

With a growing understanding of the effects of anthropogenic change on the environment, scientists are trying to generate predictions about which species are most likely to be subject to anthropogenic evolution. It may be, for example, that certain behavioral adaptations already in place make individuals more sensitive to anthropogenic disturbance. Patrick Miller of the University of St Andrews in Scotland and his team investigated this possibility by studying the antipredator behaviors of several whale species. They tested whether the degree to which whales rely on acoustic signals to detect predators predicts the degree to which the underwater noise pollution we generate—largely through seismic exploration, underwater drilling and the use of naval sonar—disrupts their feeding behavior. The scientists compared changes in the foraging behavior of northern bottlenose whales (*Hyperoodon ampullatus*), humpback whales (*Megaptera novaeangliae*), sperm whales (*Physeter macrocephalus*), and long-finned pilot whales (*Globicephala melas*) when exposed to the sound produced by naval sonar or the sounds of mammal-eating killer whales (*Orcinus orca*). To control for the possibility that any sound at all would adversely affect foraging behavior, the four test species were also exposed to broadband noise and the sounds produced by a population of fish-eating killer whales.

Humpback whale.
Chase Dekker/Minden Pictures

The study results were arresting: Northern bottlenose whales stopped feeding completely when they heard either the sounds of mammal-eating killer whales or sonar. More generally, the extent to which northern bottlenose, sperm, humpback and long-finned pilot whales reduced their feeding time in response to the sounds of a predator (a mammal-eating killer whale) correlated positively with their reduction in foraging time when they heard the sonar (but not broadband noise or sounds of the fish-eating killer whales). That is, the antipredator behavior of whales does predict the extent to which anthropogenic noise will play havoc with their feeding behavior.

People tend to think of evolutionary biology as a discipline focused on events that happened slowly and in the distant past. But anthropogenic evolution is happening here and now. We are driving massive and rapid evolutionary changes in species around us. If we want to ameliorate the undesirable, often unintended, consequences of our actions, we need to understand all we can about how animals respond to the alterations we have made, and continue to make, in our shared environment.

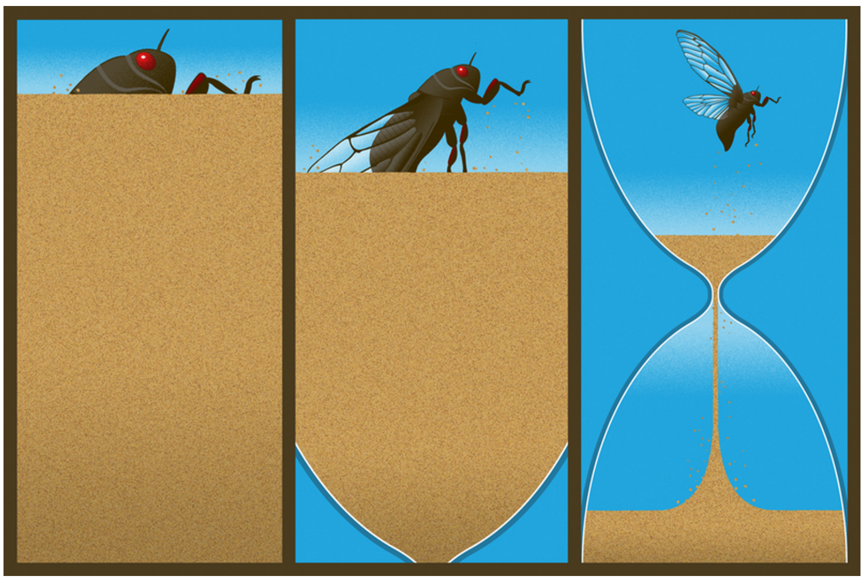
Lee Alan Dugatkin is a professor of biology at the University of Louisville. His newest book is *The Well-Connected Animal: Social Networks and the Wondrous Complexity of Animal Societies* (University of Chicago Press, 2024). Follow Dugatkin on Facebook at facebook.com/lee.dugatkin/.

Animals

Periodical Cicadas Emerge Every 13 or 17 Years. How Do They Keep Track of Time?

Periodical cicadas have a clever hack to help them figure out when to emerge after more than a decade underground

By Meghan Bartels



Thomas Fuchs

The year was 2011. Barack Obama was president, NASA's space shuttles were retiring and Taylor Swift was on her second tour—and across a huge swath of the southeastern U.S., billions of tiny newborn cicadas rained down from tree branches to burrow into the soil.

This spring those same cicadas, now grown, will venture aboveground for the first time in 13 years. It's a marvel of synchronization that allows them to thrive despite the vast range of animals that feast on the tasty, defenseless bugs. But how do periodical cicadas like these manage to coordinate their ear-rattling emergence every 13—or, for some species, 17—years? After all, cicadas aren’t equipped with an alarm clock or a calendar, and they spend more than a decade underground.

“Seventeen [years] is just an inordinately long time to keep track of anything,” says John Lill, an insect ecologist at George Washington University. “I can’t keep track of five years, let alone 17, myself—so how an insect does it is pretty remarkable.”

In 2024 two different periodical cicada groups will emerge: the 13-year Brood XIX, which will blanket much of the southeastern U.S., and the 17-year Brood XIII, which will be concentrated in northern Illinois. There will also be some stragglers from other broods. When they do make mistakes, cicadas most commonly mistime their emergence by either one or four years—and next year another massive cohort of 17-year cicadas, Brood XIV, is due across parts of the East Coast and the Ohio River Basin.

But none of these insects, whether punctual or early, are marking the passage of time. Instead periodical cicadas have a hack: they tally the growth cycles of the trees that they feed on.

This cicada species, *Magicicada septendecim*, is one of seven whose members will burst from the ground this spring and summer.
Levon Biss

During their long stint underground, the insects sip at xylem sap, the nutrient-poor but water-rich liquid that moves from a tree's root tips up to its canopy. Each year as a tree buds and blossoms, its xylem is briefly richer in amino acids, leading one team of researchers to call it "spring elixir." Cicadas appear to count each flush of spring elixir: when those researchers took 15-year-old cicadas from a 17-year brood and manipulated the insects' food trees so that they grew leaves twice in one year, voilà—the cicadas emerged a year early, having tallied the required 17 leaf growths.

"We know that's what they count. Where they're putting their little chalk marks on the wall, we don't know," says Martha Weiss, an insect ecologist at Georgetown University. "We don't really understand how they're keeping track of it."

The seven periodical cicada species in the U.S. are particularly flashy and well known because of their synchronized emergences, but the nation is home to about 150 species, all told. Nonperiodical species in the U.S. are dubbed "annual cicadas" because some of them emerge every year. But scientists don't yet know exactly how long these insects live or whether they carry an internal counter like the 13- and 17-year cicadas clearly do, says John Cooley, a biologist at the University of Connecticut who studies cicadas.

“They’re out every summer, so they’re hard to track, and underground it’s all kind of a mess,” he says of annual varieties.

Cooley says that discovering a counter, at least in the periodical cicadas, would be a comparatively straightforward endeavor—albeit a very expensive one. Researchers could simply analyze enough cicadas at stages from hatchling to adult and look for a pattern in the insects’ internal states, he says.

More challenging than finding the mysterious counter is understanding how the mechanism, and the bizarre lifestyle it enables, evolved in the first place, Cooley says. One hypothesis connects the periodic behavior to the glaciers that once blanketed much of cicadas’ current territory; other scientists point to the way the tactic helps the bugs avoid their predators.

But although neither a glacial history nor a bevy of predators is rare, periodical cicadas certainly are—just nine of the roughly 3,400 cicada species known worldwide synchronize periodical emergences—so something else is going on, Cooley argues. “Whatever the circumstances are that lead to the evolution of this life-history pattern, they are rare, and the rare things are always the hardest things to study,” he says. “We can’t tell you why this evolved; we just know it has to be some special collection of circumstances.”

So this spring and summer, if you live in or travel to the eastern U.S., try to revel in the mysteriousness of periodical cicadas, no matter how loud they get. This emergence “really is one of the seven biological wonders of the world. There is nowhere else in the entire world where you can see so many periodical cicada species,” Cooley says. “It’s something that really nobody else in the world gets the privilege of seeing.”

Meghan Bartels is a science journalist based in New York City. She joined *Scientific American* in 2023 and is now a senior news reporter there. Previously, she spent more than four years as a writer and editor at Space.com, as well as nearly a year as a science reporter at *Newsweek*, where she focused on space and Earth science. Her writing has also appeared in *Audubon, Nautilus, Astronomy*

and *Smithsonian*, among other publications. She attended Georgetown University and earned a master's degree in journalism at New York University's Science, Health and Environmental Reporting Program.

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Belugas Flirt and Fight by Morphing Their Squishy Forehead

Scientists are putting together a catalog of communications from belugas' forehead "melon"

By Monique Brouillette

David Merron Photography/Getty Images

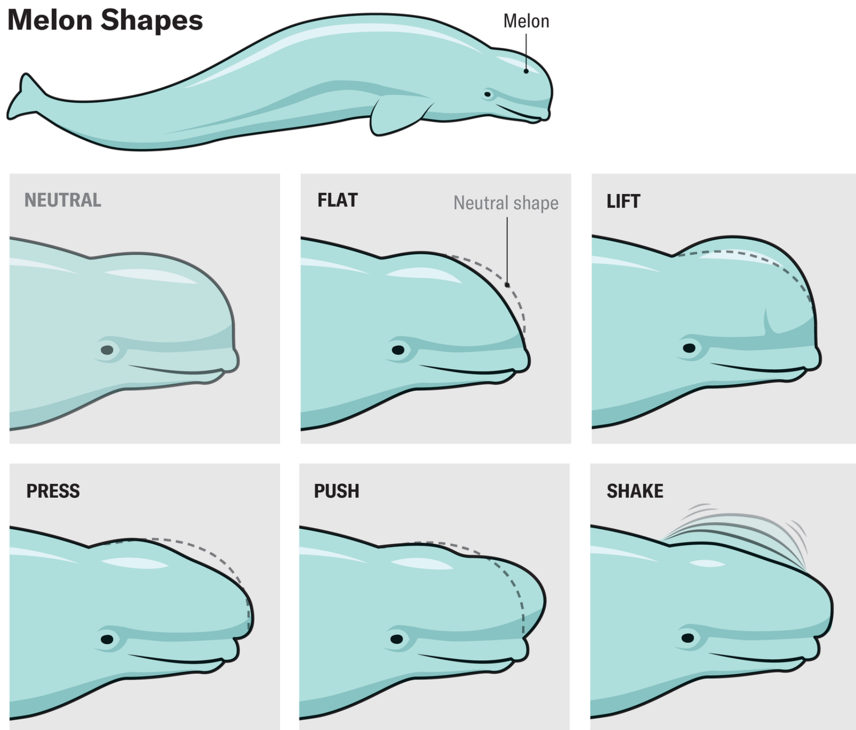
The beluga whale's "melon"—a technical term—is a mass of fat tissue on its forehead that helps to project sounds for echolocation. And new research suggests that despite whales' seemingly stone-faced countenances, they shake, wiggle, thrust and bump these bulbous blobs to convey something a little like facial expressions.

For a study in *Animal Cognition*, scientists tracked four beluga whales at Connecticut's Mystic Aquarium for more than 200 hours and observed roughly 2,500 instances of these mammals morphing their melons. To investigate if the movements might be intentional communication, the researchers carefully observed whether they occurred in a social context and within view of other whales. The team documented five distinct melon morphs used repeatedly in various situations.

> A “melon shake” appears to be used primarily by males toward females during courtship. A “melon push” seems to be a display of aggression.

“We have known, intuitively, that they do this,” says Justin Richard, the study’s lead author and an animal scientist at the University of Rhode Island. “But this is the first time we have documented it rigorously.”

Richard says scientists should be cautious about ascribing meaning to the shapes at this stage—but he does note some patterns. A jiggly “melon shake” appears to be used primarily by males and to be directed toward females during courtship. An elongating “melon push” seems to occur among both males and females and may be a display of aggression, as it makes the whales look larger. Researchers are still investigating what might prompt the other three distinctive moves.



Amanda Montañez; Source: “Belugas (*Delphinapterus leucas*) Create Facial Displays during Social Interactions by Changing the Shape of Their Melons,” by Justin T. Richard et al., in *Animal Cognition*, Vol. 27, No. 7; March 2, 2024 (*reference*)

“I certainly think they are able to use their melons in a communicative fashion,” says comparative psychologist Heather Hill, who researches marine mammal behavior at St. Mary’s University in Texas. “But whether the beluga movements are specific to all belugas or just that population, we don’t know that information yet.” She adds, however, that the study’s melon shapes are the same as the ones she sees in captive belugas in San Antonio.

The study “is a good first step at looking at facial displays in a highly social species that has been neglected in the communication field,” adds Simon W. Townsend, an animal-communication specialist at the University of Zurich. Next, he’d like to see whether other individuals respond to a shape-shifting melon.

Monique Brouillette is a freelance journalist who covers biology. Follow her on X (formerly Twitter) @mo_brouillette

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Why Insects Are Lured to Lights in the Night

Moths and other insects aren’t drawn to nighttime illumination for the reasons we think they are

By Gary Stix & Immy Smith

Immy Smith

The enduring image of a moth frantically circling a nocturnal light source—whether candle, campfire or electric bulb—has long intrigued both scientists and literary types, including Shakespeare. (“Thus hath the candle singed the moth,” Portia quips in *The Merchant of Venice*.) Entomologists have mulled possible explanations for insects’ attraction to all forms of artificial light. The creatures, some have suggested, are drawn to a flame’s heat, or they mistake fire or electric light for the moon, which is assumed to act as a kind of celestial compass.

In perhaps the most intensive study to date attempting to answer this question, researchers claim to have come up with “the most plausible model for why insects gather at artificial lights,” as reported in *Nature Communications*. Investigators at Imperial College London, Florida International University and the Council on International Educational Exchange discovered through fieldwork and laboratory experiments that insects grow increasingly disoriented around artificial light—so much so that they lose all perspective about which way is up. It turns out that insects ordinarily maintain their up-down orientation by turning their backs toward the sky, the brightest thing they perceive even at night. That allows them to stay properly aligned on a steady flight path.

This evolutionary strategy sufficed for many millions of years, until humans came on the scene with their fire and electricity. When insects encounter an outdoor bulb after dusk, confusion reigns. They tilt their backs toward the bulb as if it were the sky and initiate endless, sometimes erratic loops around it. With light pollution increasing and with drastic declines in insect numbers worldwide, new forms of lighting may be needed to preserve these populations, which are integral to the health of global ecosystems.

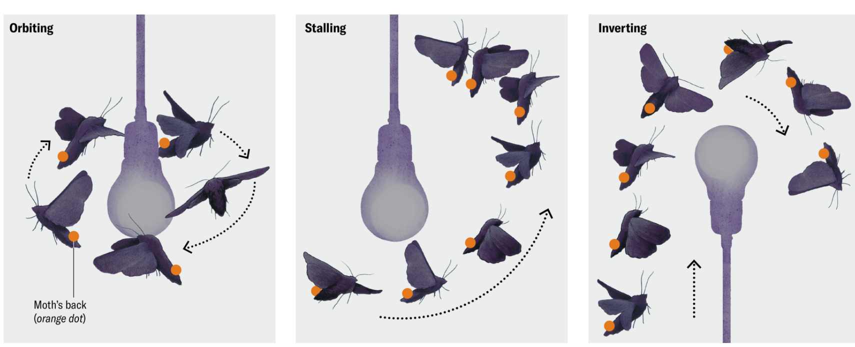
WITH THE SUN AT YOUR BACK

The tendency of insects to turn their backs toward the light is called the dorsal light response. Bigger animals such as humans can tell up from down based on the pull of gravity sensed directly by the inner ear, among other inputs. Insects' minute sensory organs and their rapid aerial accelerations prevent a moth or a wasp from distinguishing immediately above from below. As a result, they use the sky's brightness as a constant that allows them to self-orient by pointing their backs to the heavens—or at least they did before the arrival of human civilizations that always keep the lights on.

Immy Smith; Source: "Why Flying Insects Gather at Artificial Light," by Samuel T. Fabian et al., in *Nature Communications*, Vol. 15; January 2024 (*reference*)

LIGHT AND FLIGHT PATHS

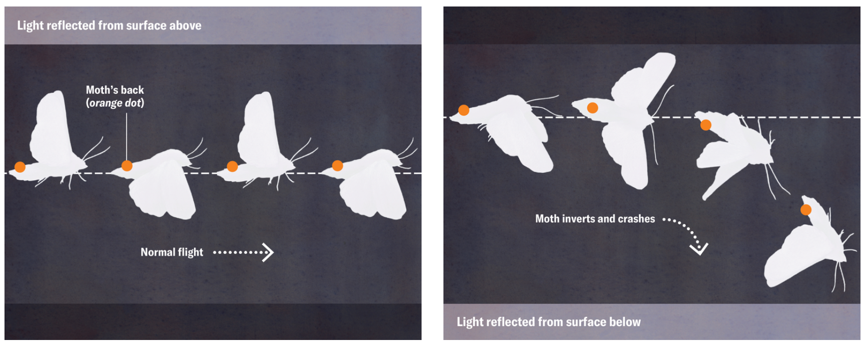
The sustained banking motion that a moth maintains to keep its back to the light results in a relatively unperturbed, orbiting flight path around the lightbulb. At times, though, the moth ends up flying under the bulb and begins a steep upward climb. The insect then begins to stall, losing speed as it climbs before crashing down. Similarly, when the moth flies over the bulb, its inverted orientation at the apex of its flight path can send it plummeting earthward.



Immy Smith; Source: "Why Flying Insects Gather at Artificial Light," by Samuel T. Fabian et al., in *Nature Communications*, Vol. 15; January 2024 (*reference*)

WHICH WAY IS UP?

To probe the validity of their back-to-the-light thesis, researchers in the lab at Imperial College London created two opposing scenarios and tested them using high-speed video. In one scenario, ultraviolet light shining from above (simulating the sky) enabled the moths to fly along a stable, linear path. In the other, UV light emitted from the floor caused the insects to tilt, fully invert and come crashing down.



Immy Smith; Source: “Why Flying Insects Gather at Artificial Light,” by Samuel T. Fabian et al., in *Nature Communications*, Vol. 15; January 2024 (*reference*)

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

Immy Smith is a UK-based interdisciplinary artist and scientist, focusing on illustration of invertebrates, plants, and lichens.

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Artificial Intelligence

- **Too Much Trust in AI Poses Unexpected Threats to the Scientific Process**
  It's vital to "keep humans in the loop" to avoid humanizing machine-learning models in research

Too Much Trust in AI Poses Unexpected Threats to the Scientific Process

It's vital to "keep humans in the loop" to avoid humanizing machine-learning models in research

By Lauren Leffer

Shideh Ghandeharizadeh

Machine-learning models are quickly becoming common tools in scientific research. These artificial-intelligence systems are helping bioengineers discover new potential antibiotics, veterinarians interpret animals' facial expressions, papyrologists read words on ancient scrolls, mathematicians solve baffling problems and climatologists predict sea-ice movements. Some scientists are even probing large language models' potential as proxies or replacements for human participants in psychology and behavioral research. In one recent example, computer scientists ran ChatGPT through the conditions of the Milgram shock experiment—a study on obedience, begun in 1961, in which people gave what they believed were increasingly painful electric shocks to an unseen person when told to do so by an authority figure—and other well-known psychology studies. The AI model responded similarly to humans: 75 percent of simulated participants administered shocks of 300 volts or more.

But relying on these machine-learning algorithms also carries risks. Some of those risks are commonly acknowledged, such as generative AI's tendency to produce occasional "hallucinations" (factual inaccuracies or nonsense). AI tools can also replicate and even amplify human biases about characteristics such as race and gender. And the AI boom, which has given rise to complex, trillion-variable models, requires water- and energy-hungry data centers that are likely to have high environmental costs.

One big risk is less obvious, though potentially very consequential: humans tend to attribute a great deal of authority and trustworthiness to machines. This misplaced faith could cause serious problems when AI systems are used for research, according to a recent paper in *Nature*.

"These tools are being anthropomorphized and framed as humanlike and superhuman. We risk inappropriately extending trust to the information produced by AI," says Molly Crockett, a cognitive psychologist and neuroscientist at Princeton University and a co-author of the study. AI models are human-made products, and they "represent the views and positions of the people who developed them," says Lisa Messeri, a Yale University sociocultural anthropologist who worked with Crockett on the paper. *Scientific American* spoke with both researchers to learn more about the ways scientists use AI—and the potential effects of trusting this technology too much.

An edited transcript of the interview follows.

Why did you write this paper?

LISA MESSERI: [Crockett] and I started seeing and sharing all sorts of large, lofty promises of what AI could offer the scientific pipeline and scientific community. When we really started to think we needed to write something was when we saw claims that large language models could become substitutes for human subjects in research. These claims, given our years of conversation, seemed wrong-footed.

MOLLY CROCKETT: I have been using machine learning in my own research for several years, and advances in AI are enabling scientists to ask questions we couldn't ask before. But as I've been doing this research and observing that excitement among colleagues, I have developed a sense of uneasiness that's been difficult to shake.

Beyond using large language models to replace human participants, how are scientists thinking about deploying AI?

CROCKETT: Previously we helped write a response to a study in [the *Proceedings of the National Academy of Sciences USA*] that claimed machine learning could be used to predict whether research would [be replicable] just from the words in a paper. That struck us as technically implausible. But more broadly, we've discovered that scientists are talking about using AI tools to make their work more objective and to be more productive.

We found that both those goals are quite risky and open up scientists to producing more while understanding less. The worry is that we're going to think these tools are helping us to understand the world better, when in reality, they might be distorting our view.

MESSERI: We categorize the AI uses we observed in our review into four categories: the Surrogate, the Oracle, the Quant and the Arbiter. The Surrogate is what we've already discussed—it replaces human subjects. The Oracle is an AI tool that is asked to synthesize the existing corpus of research and produce something, such as a review or new hypotheses. The Quant is AI that is used by scientists to process the intense amount of data out there—maybe produced by those machine surrogates. AI Arbiters are like [the tools described] in the *PNAS* replication study Crockett mentioned—tools for evaluating and adducting research. We call these visions for AI because they're not necessarily being executed today in a successful or clean way, but they're all being explored and proposed.

You've pointed out that even if AI's hallucinations and other technical problems are solved, risks remain.

CROCKETT: The overarching metaphor we use is this idea of monoculture, which comes from agriculture. Monocultures are very efficient. They improve productivity. But they're vulnerable to being invaded by pests or disease; you're more likely to lose the whole crop when you have a monoculture versus diversity in what you're growing. Scientific monocultures, too, are vulnerable to risks such as errors propagating throughout the whole system. This is especially the case with the foundation models in AI research, where one infrastructure is being used and applied across many domains. If there's some error in that system, it can have widespread effects.

We identify two kinds of scientific monocultures that can arise with widespread AI adoption. The first is the monoculture of knowing.

AI tools are suited to answer only certain kinds of questions. Because these tools boost productivity, the overall set of research questions being explored could become tailored to what AI is good at.

Then there's the monoculture of the knower, where AI tools come to replace human thinkers. And because AI tools have a specific standpoint, this shift eliminates the diversity of human perspectives from research production. When you have many kinds of minds working on a problem, you're more likely to spot false assumptions or missed opportunities. Both monocultures could lead to cognitive illusions.

What do you mean by "illusions"?

MESSERI: One example that's already out there in psychology is the illusion of explanatory depth. Basically, when someone in your community claims they know something, you tend to assume you know that thing as well.

In your paper, you cite research demonstrating that using a search engine can trick someone into believing they know something when really they only have online access to that knowledge. And students who use AI assistant tools to respond to test questions end up thinking they understand a topic better than they do.

MESSERI: Exactly. Building off that illusion of explanatory depth, we also identify two others. One is the illusion of exploratory breadth, where someone thinks they're examining more than they are. There are an infinite number of questions we could ask about science and about the world. We worry that with the expansion of AI, the questions that AI is well suited to answer will be mistaken for the entire field of questions one could ask. Then there's the risk of the illusion of objectivity. Either there's an assumption that AI represents all standpoints, or there's an assumption that AI has no standpoint at all. But at the end of the day, AI tools are created by humans coming from a particular perspective.

How can scientists avoid falling into these traps? How can we mitigate these risks?

MESSERI: There's the institutional level where universities and publishers dictate research. These institutions are developing partnerships with AI companies. We have to be very circumspect about the motivations behind that. One mitigation strategy is just to be incredibly forthright about where the funding for AI is coming from and who benefits from the work being done on it.

CROCKETT: At the institutional level, funders, journal editors and universities can be mindful of developing a diverse portfolio of research to ensure that they're not putting all the resources into research that uses a single-AI approach. In the future it might be necessary to consciously protect resources for the kinds of research that can't be addressed with AI tools.

And what type of research is that?

CROCKETT: Well, as of right now, AI cannot think like a human. Any research about human thought and behavior, as well as qualitative research, is not addressable with AI tools.

Would you say that in the worst-case scenario, AI poses an existential threat to human scientific knowledge production? Or is that an overstatement?

CROCKETT: I don't think it's an overstatement. I think we are at a crossroads: How do we decide what knowledge is, and how do we proceed in the endeavor of knowledge production?

Is there anything else you think is important for the public to really understand about what's happening with AI and

scientific research?

MESSERI: From the perspective of reading media coverage of AI, it seems as though this is some preordained, inevitable "evolution" of scientific and technical development. But as an anthropologist of science and technology, I would really like to emphasize that science and tech don't proceed in an inevitable direction. It is always human-driven. These narratives of inevitability are themselves a product of human imagination and come from mistaking the desire by some for a prophecy for all. Everyone, even nonscientists, can be part of questioning this narrative of inevitability by imagining the different futures that might come true instead.

CROCKETT: Being skeptical about AI in science doesn't require being a hater of AI in science. We love science. I'm excited about its potential for science. But just because an AI tool is being used in science does not mean that it is automatically better science.

As scientists, we are trained to deny our humanness. We're trained to think human experience, bias and opinion have no place in the scientific method. The future of autonomous AI "self-driving" labs is the pinnacle of realizing that sort of training. But increasingly, we are seeing evidence that diversity of thought, experience and training in humans who do the science is vital for producing robust, innovative and creative knowledge. We don't want to lose that. To keep the vitality of scientific-knowledge production, we need to keep humans in the loop.

Lauren Leffer is a contributing writer and former tech reporting fellow at *Scientific American*. She covers many subjects, including artificial intelligence, climate and weird biology, because she's curious to a fault. Follow her on X @lauren_leffer and on Bluesky @laurenleffer.bsky.social

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Arts

- ## Poem: ‘Chrysalis’
  Science in meter and verse

Poem: ‘Chrysalis’

Science in meter and verse

By Michael Simms

Masha Foya

Edited by Dava Sobel

We think of metamorphoses
as glorious and beautiful,
a quiescent

chrysalis emerging
as a yellow butterfly
slowly unfolding her

On supporting science journalism

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translucent wings
letting them dry
in the open air

and flying off
in a flittering arc
reminding us

of our emergence from
the chrysalis of self-conscious
adolescence

into the less tumultuous
uncertainties
of adulthood and of

the final transformation
we yearn for, the moldering body
releasing the immortal spirit, but imagine

how the wormlike
caterpillar feels after a life
of serenely munching leaves

to curl herself
on the underside of a chosen leaf
secreting a fiber

spinning a cocoon, incorporating
twigs, urticating hairs,
fecal pellets, bits of leaf and bark

disguised from
predatory bats and nightjars
while the arrival works its magic and

if she’s aware
as all things are aware
rock, tree, wind

she must feel
her skin stretching, covering
her body now

a thing with wings
that doesn’t resemble
hope so much

as grace, the undeserved love
that comes into our lives
as a gift.

Michael Simms has written four full-length poetry collections, the latest of which is *Strange Meadowlark* (Ragged Sky Press, 2023). In 2011 the Pennsylvania State Legislature awarded him a Certificate of Recognition for his service to the arts.

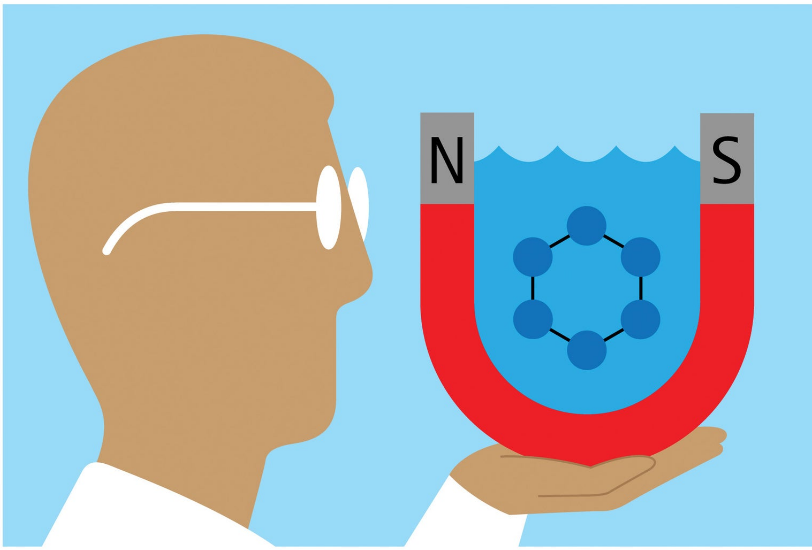
Basic Chemistry

- **Like-Charge Particles Are Supposed to Repel—But Sometimes They Attract**
  Scientists think they’ve cracked the long-standing mystery of attraction among particles with a similar charge

Like-Charge Particles Are Supposed to Repel—But Sometimes They Attract

Scientists think they've cracked the long-standing mystery of attraction among particles with a similar charge

By Lori Youmshajekian



Thomas Fuchs

The fact that like charges repel and opposites attract is basic electromagnetism. But for decades scientists have occasionally made a counterintuitive, and controversial, observation: similarly charged particles can sometimes also attract one another when dispersed in a liquid solvent such as water or alcohol.

Researchers now propose in *Nature Nanotechnology* that this phenomenon arises from the solvent's molecular nature. The team observed that negatively charged silica particles pulled together and formed hexagonal clusters in water, and positively charged silica variants were mutually attracted in alcohol. Modeling water molecules' behavior near charged particles helped to reveal why.

In previous experiments, researchers considered a fluid to be one continuous substance, but this ignores the influence of its tiny atomic building blocks. Water, for instance, is made up of individual molecules that are dipoles—you can think of them as having more charge on one side than on the other, like a battery, says University of Oxford chemist and study co-author Madhavi Krishnan. And water molecules prefer to bond with other water molecules, so when they're near a suspended particle they tend to point their two slightly positive hydrogen atoms toward the rest of the liquid and their slightly negative oxygen atom toward the particle.

As negatively charged silica particles in water approach one another, they experience an effect called charge regulation, whereby the repulsion between them pulls nearby protons onto each particle's surface, reducing the particles' negative charge. That then weakens their repulsion from the water's oxygen atoms, too, a phenomenon that intensifies as the silica particles move toward one another. This change draws the silica particles together from about a micron away.

The team observed the opposite effect in alcohol, because its molecules prefer to steer the other way at a particle's surface: positively charged particles suspended in alcohol pull together instead. A solvent's acidity also influences charge and thus whether particles in it form clusters.

Scientists were long uncertain whether such strange attraction was an experimental artifact or a real physical phenomenon, Krishnan says. Critics have disputed previous observations of this effect citing optical distortions, weak particle attraction, or hydrodynamic forces causing particles to drift together. “This paper solves a mystery that has been out there for 20-plus years,” says Jay T. Groves, a chemist at the University of California, Berkeley. “It’s very thorough, and I think [it’s] indisputable that this effect is a property of the solvent.”

This finding’s potential uses are “limited to one’s own creativity,” Krishnan says. The team’s future work will investigate particle behavior in other solvents, as well as applications to fields such as biology: how molecules—many of which carry lots of electrical charge—organize themselves in cells.

Lori Youmshajekian is a freelance science journalist who reports on advances in health, environmental issues and scientific misconduct. She holds a master's degree in Science Journalism from New York University and has written for New Scientist, Yale E360, Retraction Watch and Medscape, among other outlets.

Book Reviews

- ## Book Review: Your Life Is Ruled by Games You Don’t Even Know You’re Playing
  Our overreliance on the simplicity of game logic explains why capitalism got out of control
- ## Book Review: Imagining a Radical New Relationship with the Mississippi River
  The Mississippi River has been manipulated for decades. A new book considers alternative forms of control
- ## Book Review: Rats, Gardens, and Stories from a "Post-Impact" Future
  Rats as you’ve never seen them; the journey of restoring a garden; stories from a “post-Impact” future

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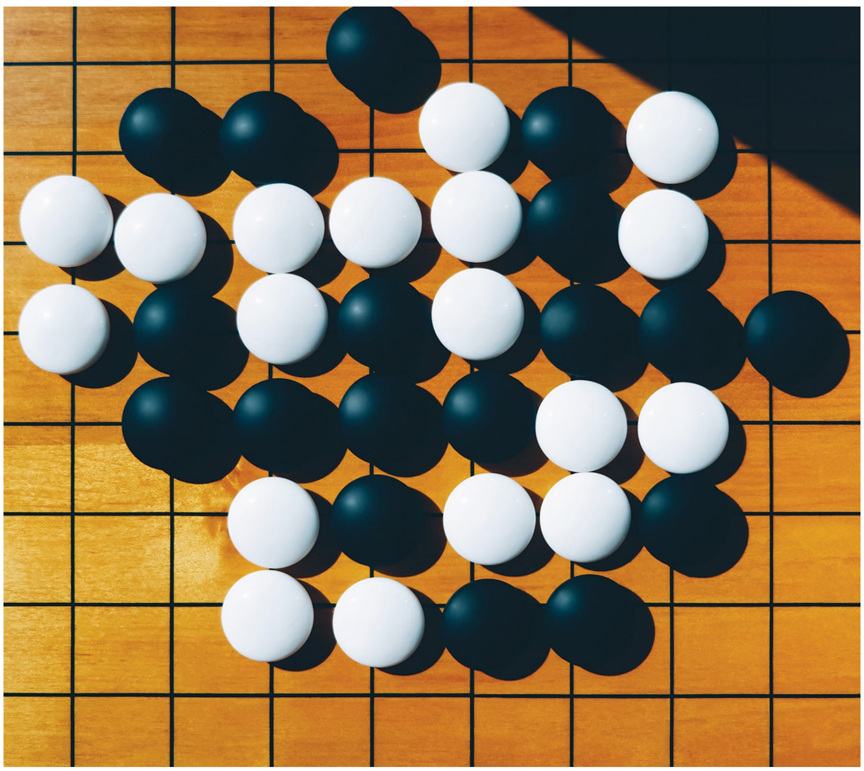
Your Life Is Ruled by Games You Don't Even Know You're Playing

Our overreliance on the simplicity of game logic explains why capitalism got out of control

By Carmen Maria Machado



Olena Ruban/Getty Images

NONFICTION

Playing with Reality: How Games Have Shaped Our World

by Kelly Clancy.
Riverhead, 2024 ($30)

When was the last time you played a game? Maybe you beat a friend at chess, or played Sushi Go! with your kids, or recently lost hours of your life to *Baldur's Gate 3* (raises hand). But even if you can't remember, the fact is, you probably played a game today.

Have you felt the languorous tug of swiping or scrolling through videos or dating profiles? Counted your steps? Been subject to the forces of the economy or the government? Applied for a loan? Used the Internet? Worked for a company? Experienced desire, motivation, pleasure?

Games have developed a contemporary, ahistorical reputation for triviality—a way people lose themselves instead of understanding themselves. But as Kelly Clancy explains in *Playing with Reality*, games are not only not unserious but also an essential tool for growth, learning and survival, as well as a way of understanding our own bodies, history and future. She argues that games—with their mix of play, choices, tactics, goals and rewards—touch on every single natural and artificial aspect of our lives. They can reflect biological impulses, evolutionary strategies, social structures, military operations, and the way we have historically conceptualized morality, fairness and God. The game is not something you can choose to play or not; it’s a shadow in the Plato’s cave you didn’t even realize you were living in.

Clancy weaves a clear-eyed account of games from ancient history—they predate written language, she tells us—to the modern world of computers and the Internet. She explores the role of dopamine in learning, the essential value of randomness and chance, and the addictive qualities of maybes and surprises. She covers multiple tangles between humans and computers on the battlefields of Go, checkers and chess; unpacks the long and disturbing history of war games; and dispatches the thorny question of artificial intelligence—especially large language models such as ChatGPT—with ruthless efficiency. (It is dangerous, she concludes, to "[treat] language like a game without meaning.")

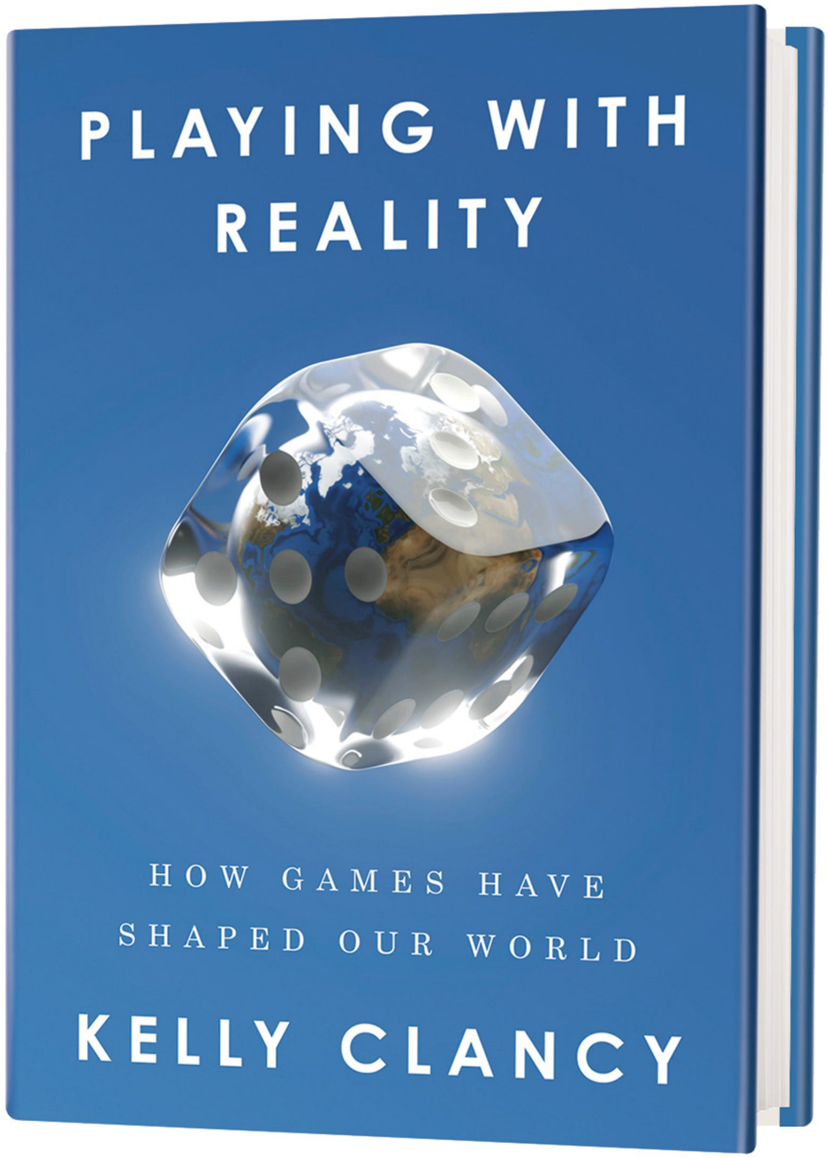
Clancy carefully puts these historical moments and developments in context. This approach is particularly pleasurable when it takes the form of deep dives into specific games. There's Kriegsspiel, a war game beloved by 19th- and 20th-century leaders (including Adolf Hitler), whose influence lives on in Dungeons and Dragons, Settlers of Catan and Risk; *SimCity,* whose sandbox structure became the darling of radical libertarians seeking to strip resources from the government; and Snakes and Ladders, which is based on a 13th-century Indian game, Moksha Patam, meant to elucidate ideas about karma and fate.

But no sooner does Clancy establish games' ubiquitous power than she demonstrates how overreliance on the simplicity of game logic has destroyed empires, expedited war crimes, undermined education, aided unfettered capitalism and—at least once—brought the world to the brink of nuclear disaster. Capitalism is perhaps the best example of this simplifying logic gone awry. Technology and gamified work promised to free us from labor but instead generate more, with rewards not for workers but for shareholders. And yet this unrestrained, amoral growth possesses a kind of logic familiar to anyone who has played Monopoly—even if that same person, in their real life, struggles to support themselves.

Our knack for adapting to a game's rules—even when they deviate significantly from our values or experience—illustrates one of games' most simultaneously charming and sinister qualities: the ease with which we can use games as a proxy to divorce ourselves from the things they stand in for. Clancy is, rightfully, pessimistic about this faculty and how whatever strengths it lends us seem to be outweighed by its potential for disaster. "Game theorists sought universal solutions in abstract mathematics, and the world is worse off for our leaders' faith in their technocratic solutions," she argues. And those who seek to win at any cost—so-called maximizers who view life as a zero-sum game—are already among us.

This discussion may make the reader feel slightly cornered. Is there any way to escape the most damaging philosophies that have emerged from games' omnipresence? Is anything in our lives untouched by the push and pull of these models?

Clancy is not trying to fix these problems. Hers is a descriptive, not prescriptive, project. But it's one that contextualizes and clarifies the upshot of losing perspective. "Games have always been about discovering who we are," she writes. At the end of the book, the question remains: In the many kinds of games we join in, what kind of player will you choose to be?



Carmen Maria Machado is author of *In the Dream House* (Graywolf Press, 2019) and *Her Body and Other Parties* (Graywolf Press, 2017), which was a finalist for the National Book Award.

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Imagining a Radical New Relationship with the Mississippi River

The Mississippi River has been manipulated for decades. A new book considers alternative forms of control

By Meera Subramanian

A tugboat pushes cargo on the Mississippi River at dawn.
Riddhish Chakraborty/Getty Images

NONFICTION

The Great River: The Making and Unmaking of the Mississippi

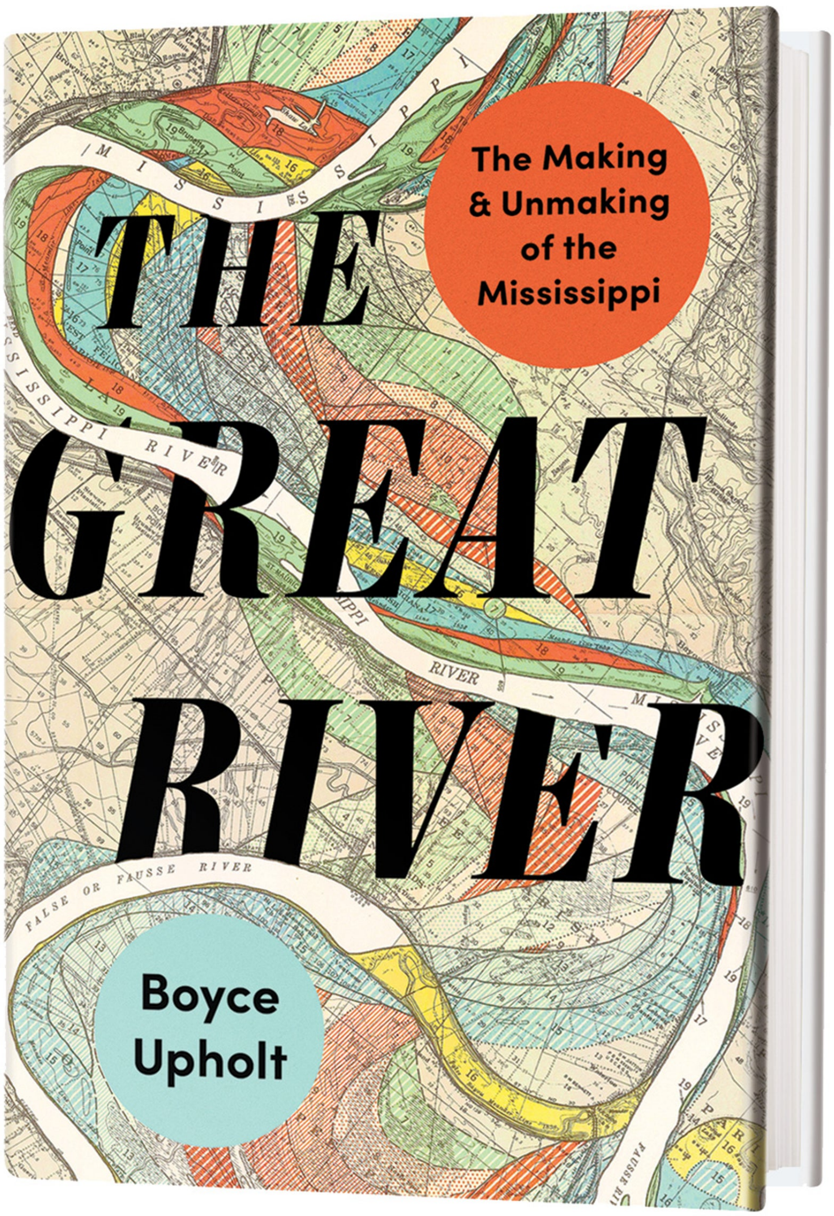
by Boyce Upholt.
W.W. Norton, 2024 ($29.99)

Blast. Carve. Dredge. Smash. Such powerful verbs fill a single paragraph midstream in Boyce Upholt's sweeping ecological history of the Mississippi River. It's fitting, given that brute force has been the dominant paradigm since settler times for contending with the river, whose watershed encompasses 40 percent of the continental U.S. There was a time when humans had a more intimate relationship with the river the Ojibwe people called the *Misi-ziibi*, which Upholt translates as "the Great River," and in this fascinating and troubling book, he argues that we could choose this path again.

Upholt, a New Orleans–based journalist, deftly weaves the river's story with deep historical research, as well as reporting from canoes and atop levees. Four thousand years ago the continent's native inhabitants built enormous earthworks along the river, mysterious testaments from great civilizations. But too quickly, both on the continent and in Upholt's telling, Indigenous peoples were forced offstage. Enter settlers and swindlers, pioneers and politicians, all bent on unbending the river, ecosystems and human bodies deemed expendable along the way as engineers forced their will on the landscape. "It's an imagined canvas," Upholt writes, "that we've stretched atop the geological frame of the continent."

Upholt's narrative can loop like the river's oxbows, folding back on itself in an at times confusing chronology, but such is the complexity of the Mississippi. The river that once was will never be again, so altered is its shape and so transformed the world it courses through, a warmer place that swings more frequently between drought and flood. Upholt reckons with his own uncertainty about how to move forward. Break down all the barriers and let the river run free again along the sinewy paths depicted in cartographer Harold Fisk's 1940s maps, one of which graces the cover of *The Great River*? Pursue green infrastructure as relentlessly as it has been denied? Whom or what to prioritize? Farmers or cypress or shrimpers? Commerce or communities?

Even if we can rekindle our relationship with the river, what we may not be able to choose is the path of the river itself. Water finds its way. Can we?



Meera Subramanian is an award-winning independent journalist, author of *A River Runs Again* (PublicAffairs, 2015) and a contributing editor at *Orion* magazine.

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imagining-a-radical-new-relationship-with-the-mississippi-river

Rats, Gardens, and Stories from a "Post-Impact" Future

Rats as you've never seen them; the journey of restoring a garden; stories from a "post-Impact" future

By Maddie Bender, Lucy Tu & Alan Scherstuhl

IN BRIEF

Stowaway: The Disreputable Exploits of the Rat

by Joe Shute.
Bloomsbury Wildlife, 2024 ($26)

New Yorkers will recall a sanitation commissioner's now infamous proclamation: "The rats don't run this city. We do." Rat chroniclers often show disdain toward their subjects, but in Stowaway, journalist Joe Shute positions himself instead as a kind of Lorax, speaking for the rats when few others will. He guides readers down sewers, into bustling (rat-filled) metropolises and through mounds of research in pursuit of a deeper understanding of rats and, by extension, humans. Shute's earnest, playful descriptions of these creatures—"a shadow of us," "the ultimate transgressors"—betray some bias. But his enthusiasm spreads easily, much like the ultrasonic laughter that his pet rats, Molly and Ermintrude, make when tickled. —*Maddie Bender*

On supporting science journalism

The Garden against Time: In Search of a Common Paradise
by Olivia Laing.
W. W. Norton, 2024 ($27.99)

When the COVID pandemic shuttered communal outdoor spaces, author Olivia Laing began restoring a private 18th-century garden in Suffolk, England. Her memoir alternates between vignettes of this restoration process—from uprooting obnoxious nettles to planting floors of wallflowers—and thoughtful research on the cultural significance of reconstructing Eden. As Laing guides readers through the exclusionary history of plant domestication and land ownership, she seeks to transform her garden into a place of universal refuge. Written in lyrical prose that almost begs to be sung, this book offers captivating insights into “the cost of building paradise.” —*Lucy Tu*

Honeymoons in Temporary Locations
by Ashley Shelby.
University of Minnesota Press, 2024 ($22.95)

Unsettling and satirical, this collection of stories and errata from a “post-Impact” near future considers life amid escalating climate disasters, focused on the lived experience of change as it’s happening. Freighters relocate Arctic life to the Antarctic;

“Internally Displaced Persons of Means” flee America’s coasts and head to heartland Resettlement Zones; and a pharmaceutical company offers Climafeel, “a recombinant DNA biologic that blunts the effects of solastalgia,” the psychological distress afflicting survivors in a world upended. Writer Ashley Shelby’s storytelling is brisk, sharp-elbowed and deeply empathetic, even as she experiments with a host of forms, including the brochure text for a cruise to flooded cities. —*Alan Scherstuhl*

Maddie Bender is a science writer and a producer at Hawaii Public Radio. She was a 2021 AAAS Mass Media Fellow at *Scientific American.*

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

Alan Scherstuhl is a reviewer and editor who covers books for a variety of publications and jazz for the *New York Times*.

Cognition

- **We Learn and Make Connections Better When Information Comes from People We Like**
  The way we’re “wired” to learn may divide us

We Learn and Make Connections Better When Information Comes from People We Like

The way we're "wired" to learn may divide us

By Kate Graham-Shaw

Thomas Fuchs

The human brain tends to play favorites. Its prejudices, well demonstrated by psychological studies, include the "halo effect": if we like a certain quality in a person, we're more likely to perceive their unrelated traits positively as well. There's also "affinity bias," which refers to how we gravitate toward people with backgrounds or characteristics similar to our own.

Now a study shows how cognitive biases could profoundly affect our most basic learning and memory processes. "What we show is not that people are biased; that we already kind of know," says Inês Bramão, a psychologist at Sweden's Lund University and co-author of the new study, published in *Communications Psychology*. "We give an explanation of why people are biased. The fundamental mechanism may be that we are more likely to expand our knowledge based on information provided by people we like." Such bias could help explain how people develop strongly polarized views.

Study participants first chose "teammates" and "opponents" from among images of random faces based on their like or dislike of the faces. Then they created imaginary personas for each chosen face, giving characteristics and identities they liked to teammates and ones they disliked to opponents.

Next, participants viewed images of each face set in a landscape or other background alongside a common household object, as if the person were "showing" the participant the object. Later, the participants tried to match up objects that had shared the same background—this time, without the faces displayed. This tested their ability to learn new information through a process called memory integration: linking memories of multiple past events to make new inferences. The participants did significantly better when linking objects that had initially been "presented" by a persona they liked, which the researchers say indicates a fundamental bias in how we associate previously learned information with a new, partially related event.

The study authors suggest this finding helps to show how people's opinions can become intensely polarized and increasingly extreme. If we tend to build understanding based mostly on what we learn from a limited set of liked individuals—largely because of their similarities to us—these beliefs can remain unchallenged, leading to narrowing viewpoints.

Psychologist Charles Stone of the City University of New York says that this study is just the beginning and that further research could move beyond images to test learning with real-world events. “This could have important implications for how people make inferences and connect dots about their beliefs that then match their worldviews,” he says. “There’s a lot of fodder moving forward.”

Kate Graham-Shaw is a journalist based in New York City. She covers international news for Japanese media and also covers health and science topics as a freelancer.

Consciousness

- **How Do Babies Realize They Can Influence the World?**
  An infant’s aha! moment may hold secrets to the origins of agency

How Do Babies Realize They Can Influence the World?

An infant's aha! moment may hold secrets to the origins of agency

By Aliza Sloan & Scott Kelso

Guido Mieth/Getty Images

Sometimes the simplest questions are the hardest to answer. How, for example, do you decide to wiggle your fingers? A lot is known about the muscles and neural structures involved—the puppet and the strings, as it were—but what about the puppeteer?

How humans develop the ability to willfully make things happen still remains mysterious. In a recent study, we tried to catch infants in the act of discovering their ability to influence the world. As we reported last September in the *Proceedings of the National Academy of Sciences USA*, we identified these aha! moments and the events surrounding them, revealing for the first time how agency forms.

For more than 50 years researchers have used a very simple method to investigate learning in infancy. They place a baby into a crib with a mobile suspended above it. Then a scientist ties one end of a string to the mobile and the other to the infant’s foot. If the baby moves, the toy will, too. Over multiple sessions, scientists can observe as the infants learn and recall a simple cause-and-effect interaction: kick a foot, and the mobile moves.

We used that setup to identify the moment when babies first realize they can control the mobile’s motion. We worked with 16 infants who were three to four months of age, employing motion-capture technology to measure the movements of both infant and mobile in three-dimensional space. As in past such experiments, infants kicked significantly more when their foot was tethered to the mobile than when it was not. But did they know that their movements were propelling the mobile?

One clue came when an experimenter pulled the string to make the mobile move instead of letting the baby do it. Infants moved less in that situation than when the mobile was stationary. This finding rules out the idea that babies simply kick in excitement when they see the mobile moving. In fact, our data indicated that it was the coordinated movement of the foot and the mobile that prompted a baby’s activity.

Further, when we removed the string, the babies kept on kicking at the highest rate they had reached while tied to the mobile, suggesting that they expected the toy to respond. Some infants were visibly frustrated when that did not happen.

At some point while they were tethered, then, the infants must have figured out that they were in control. To pinpoint this aha! moment, we developed an algorithm to search for spikes in the rate of foot movement during tethering. For some infants, we found a sudden burst of activity coupled with dramatic changes in the rate of movement, including pauses and abrupt increases or decreases in speed. Such fluctuations and shifts are typical signatures of complex systems—from stock markets to brain activity—that are on the verge of change. We believe those initial spikes in activity coincided with those babies' aha! discovery.

Our observations also revealed a pattern: in the first minute or so of tethering, each time the mobile responded to the infants' movements, they froze and waited for the mobile to stop before kicking again. The mobile's unfamiliar and unexpected movement triggered a strange, dynamic dance on the babies' part: move, pause, move, pause. We suspect that they were, in a sense, running their own experiment: "If I do this (kick), I see that (the mobile moves)," and, conversely, "if I do not kick, I do not see the mobile move."

Notably, the infants did not all behave in the same way. In fact, one child showed no such signs of discovering how her behavior might affect the mobile, even though she doubled her activity while interacting with it. This approach could therefore help us understand and predict individual paths of motor and cognitive development for both healthy infants and those at risk of developmental delays.

But what does this experiment tell us about the origins of agency? Quite a lot, we would argue. Several years ago one of us (Kelso) proposed that the birth of agency is a dynamic, self-organizing process and, together with the late physicist Armin Fuchs, developed a model of it. To break that down: “Dynamic” means that patterns and relationships evolve over time. “Self-organization” refers to the fact that many complex systems in nature organize themselves into specific forms without any instructions. In these cases, to return to our opening question, there is no concrete puppeteer pulling the strings. Rather patterns emerge and change spontaneously in systems that are open to exchanges of energy, matter and information with their surroundings.

Our theory is that when an organism (here, a baby) and its environment (the mobile) interact, they form a self-organizing dynamic system. Goal-directed action emerges spontaneously when the organism realizes that its movements cause the world to change.

Our findings align beautifully with our theory. The babies’ initial movements consisted of squirming and thrusting without discernible purpose or direction. But once tethered to the mobile, the more intensely they moved, the more their attention was drawn to the effect their kicking had (both the feeling of the string tugging and the sight of the mobile responding). When babies’ attention to their relationship with the toy reached a critical level, they realized they could make the mobile spin. Spontaneous movements became purposeful action. At that point of transformation, we observed a burst of foot activity and tight coordination between the infant and the mobile.

Historically, the entire issue of purpose and agency in living things—and, dare one say, “free will”—has been clouded in philosophical debate and controversy. Many arguments land at one of two extremes: either there must be an inner director—a self that makes decisions—or free will does not actually exist, because the environment and circumstances predetermine a person’s behavior. But our infant study emphasizes how understanding the relationship between an organism and its environment is essential to uncovering the origins of directed behavior. As our model proposes, the experience of agency emerges *only* when an organism (the baby) senses it is coupled to its environment (in this case, the mobile setup). In this way of thinking, the interaction and relationship between the two are crucial for purpose to arise.

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 pitchmindmatters@gmail.com.*

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

Aliza Sloan is a research scientist at Florida Atlantic University's Center for Complex Systems and Brain Sciences. She studies organizing processes in human development.

Scott Kelso holds the Glenwood and Martha Creech Eminent Scholar Chair in Science at Florida Atlantic University and is a professor emeritus of intelligent systems at the University of Ulster in Northern Ireland.

Culture

- **RNA, Grizzly Bears and Anxiety Treatments Show That Science Is Never Done**
  Explore the new science of weird chemistry, anthropogenic evolution and near-death experiences
- **Contributors to Scientific American's June 2024 Issue**
  Writers, artists, photographers and researchers share the stories behind the stories
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RNA, Grizzly Bears and Anxiety Treatments Show That Science Is Never Done

Explore the new science of weird chemistry, anthropogenic evolution and near-death experiences

By Laura Helmuth

Scientific American, June 2024

One of the best things about being an editor at *Scientific American* is hearing from people whose careers were transformed by our publication. I recently read the autobiography of Joe Coulombe, who founded Trader Joe’s, and he cited three occasions when a *Scientific American* article (having to do with demographics, the biosphere and computers, respectively) gave him a brilliant idea that helped him build his grocery chain. At a recent Innovators in Science awards event sponsored by Takeda and the New York Academy of Sciences, several people told me about articles that inspired them to take on a career in research. One person made a great observation: textbooks make science seem like it’s finished, like everything is already known. But *Scientific American* shows people that science is alive. There is always more to learn, and there are plenty of opportunities for people to participate in science themselves or appreciate new discoveries.

Not to pick on textbooks too much, but you probably learned from them that DNA is transcribed by RNA into proteins that create and sustain our bodies. True enough—but that's not at all the full story. Author Philip Ball invites us into the ongoing RNA revolution. RNAs that don't produce proteins can still influence physiology in huge ways, and new ones are being discovered all the time. They may be extremely short, extremely long or circular; they may work alone but often work in different combinations for a more versatile response to the environment.

"Anthropogenic evolution" is a relatively new term describing adaptations in plant and animal species prompted by changes people have made to the environment. A classic example is the peppered moth, which evolved to have darker coloring to blend into soot-blackened habitats in industrial revolution–era England. Biologist Lee Alan Dugatkin shows how animals today are changing their migrations, vocalizations, activity patterns, and more.

A bold experiment to undo some of the damage people have done to wildlife will likely start soon in Washington State. The U.S. Forest Service and the National Park Service announced this spring that they want to move forward with a plan to reintroduce grizzly bears in the North Cascades mountain range. Journalist Benjamin Cassidy reports on how this controversial plan began and what we’ve learned about grizzlies in other recovery areas as they have begun to come back after being eliminated from much of the U.S. The fabulous photography is by Brooke Bartleson; read more about her in our Contributors column.

Chemistry gets weird at the far end of the periodic table. The elements with atomic numbers 104 through 118 do not exist in nature as far as we know, and they only fleetingly exist in high-power physics laboratories. But as science journalist Stephanie Pappas explains, new research at the “uncharted coastline of chemistry” reveals that these oddities are even odder than expected, with relativistic forces acting within their atoms that are similar to those that govern objects around a black hole. It’s another great case of the very small helping us grasp the very large, with implications for what happens in a supernova.

Some people who recover from a cardiac arrest or another major medical trauma report having had a “near-death experience.” They may remember a sense of transcendence and transformation and visions of lost loved ones. Author Rachel Nuwer describes how scientists have started studying these experiences to understand the almost-dying brain and what altered states of consciousness can tell us about the mind.

Anxiety disorders are becoming more common in teens. They are undertreated, and existing therapies don’t help everyone. Neuroscientists BJ Casey and Heidi Meyer discuss treatments that could enable young people to control distressing fears, memories and thoughts. Please enjoy this issue and spread the word that science is never done.

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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Contributors to *Scientific American*’s June 2024 Issue

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

By Allison Parshall

Brooke Bartleson.
Tara Julie

Brooke Bartleson
A Grizzly Question

As a teenager in New Jersey, Brooke Bartleson encountered a black bear and her two cubs while running along the side of a road. She was petrified, until a driver in a pickup truck pulled over and assured her that the mama bear did not seem agitated. Then he gave her a can of bear spray. That experience turned Bartleson into a bear aficionado, which led to a career in wildlife photography.

“Bears are like the chocolate cake—they’re the dessert that I want really badly,” she says. “And the photography is the spoon to bring it into my mouth.”

Bartleson is constantly on the move in her “super retro” RV, but she often stays near Lake Clark National Park. There her ursine neighbors have an abundance of food in the natural environment—“like a buffet at the Ritz Carlton”—making them more relaxed than populations in other regions. These circumstances allow Bartleson to get extraordinarily close to her subjects.

This issue’s cover story, written by journalist Benjamin Cassidy on a grizzly reintroduction program in Washington State, features some of Bartleson’s favorite photos. She loves all bears but is especially fond of grizzlies, partly because “their habitat is my preferred habitat as well.” Grizzly territory in North America once stretched from the West Coast to the Mississippi River. Now the bears exist mostly in remote areas in Alaska, Canada and pockets of the lower 48. These “aren’t necessarily the habitats they evolved in,” she says, but “they’re making the best out of what they have left.”

Stephanie Pappas
Superheavies

Stephanie Pappas’s home state has an element named in its honor: tennessine, atomic number 117. It’s one of several “superheavy” elements, which don’t exist in nature, and it was first synthesized in 2010 thanks to the contributions of laboratories in the region. For this issue’s feature on these exotic elements, Pappas, a science journalist based in Colorado, explored the frontier of the periodic table to learn how scientists are giving shape to matter that bends the rules of chemistry. “All of this happens at this atomic level. You can’t see any of it; you can’t feel any of it,” she says.

Yet the story of so-called superheavies is about human ingenuity and perseverance just as much as it is about protons and neutrons. So Pappas traveled to Lawrence Berkeley National Laboratory in California, where scientists have been creating these strange, short-lived atoms since the 1960s. In the control room, which “has stuff in there from the ’60s,” she was struck by the history and creativity on display. The researchers were “patching things together and making it work.” They were also “often finishing each other’s sentences,” she says. “You could tell they had been working closely for a while.”

BJ Casey
Treating the Anxious Teen

As a postdoc at the National Institutes of Mental Health in the early 1990s, BJ Casey became one of the first people to have their brain scanned using functional magnetic resonance imaging, or fMRI. The scanning room “looked like an old NASA project,” she recalls. “The magnet was just huge.” Casey volunteered to be a guinea pig because she knew the technology had “tremendous” potential—it allowed neuroscientists to noninvasively observe the brain in action for the first time. Ever since that experience, Casey, who is now a neuroscience professor at Barnard College, has used the technique in her work to understand the adolescent brain.

In this article Casey co-wrote with neuroscientist Heidi Meyer of Boston University, she describes the way changes in how different brain regions talk to one another can make teens more sensitive to threats—and vulnerable to anxiety.

While reading through her own teenage diaries, Casey realized she had no memories of the emotions she had written about so intensely. “There’s so much passion” in adolescence, she says, and adults often forget what this tumultuous yet beautiful time was like. So “just as we tell teens, ‘take a deep breath,’ parents need to do that, too—to [take] a moment and just listen to their child.”

Immy Smith
Graphic Science

Every other day Immy Smith wakes up just after dawn to check the moth trap. The light in their backyard in southern England draws in these insects overnight, and Smith photographs them and logs the finds in a community science database for researchers to use. For this issue’s column, written by senior editor Gary Stix, they illustrated how moths get drawn toward light sources. “It’s the kind of thing you take for granted—that moths fly toward the light,” Smith says. But new research shows that they’re flying orthogonal to the light and getting trapped, and “it’s really fascinating.”

Smith is a pharmacologist as well as an artist, although these days they’re more focused on their art, which has depicted everything from plants to brain tumors—and, of course, insects. As a kid, “I used to bring all of the insects into the house and just unleash them.” While working on a project about lichen symbiosis, Smith learned that many moth species blend in with lichen—such as the Merveille du Jour moth, which is now tattooed on their forearm. “I ended up completely falling in love with moths” and even describes themself as “moths in a human suit.”

These underappreciated four-winged insects aren’t just fun to draw; they’re also important pollinators and a critical food source for many birds. For anyone still on the fence about these creatures, Smith has a message: “If you like birds, you like moths. I don’t make the rules!”

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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Readers Respond to the February 2024 Issue

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

By Aaron Shattuck

Scientific American, February 2024

MILKY WAY BACKSTORY

I thoroughly enjoyed "Our Turbulent Galaxy," Ann Finkbeiner's article on how recent star maps have revealed more about the events that led to the Milky Way's current state. But some questions remain. When in the timeline did our galaxy acquire its central supermassive black hole, Sagittarius A* (Sgr A*)? And how did Sgr A* come to be? Did the other galaxies that merged with the Milky Way also have black holes?

JOHN SOLTESZ *LOGANDALE, NEV.*

On supporting science journalism

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How can random collisions of galaxies result in an orderly spiral like the Milky Way? I had thought the common result was an elliptical galaxy. For example, that is expected to be the case when Andromeda and the Milky Way eventually collide to form Milkomeda.

K. CYRUS ROBINSON *TAMPA BAY, FLA.*

FINKBEINER REPLIES: *Soltesz asks lovely questions. The answers are hard to find, but in theory, Sgr A* would have formed during the gravitational collapse of the primordial gas cloud that created our galaxy around 13 billion years ago. Regarding the mergers in the Milky Way's history: If galaxies that merged with ours were dwarf galaxies, the formation of supermassive central black holes like Sgr A* would have been unlikely but not impossible. If the mergers involved globular clusters, any black holes were probably star-sized.*

Robinson asks another lovely question. I think the idea of two large spiral galaxies merging to form an elliptical one comes mainly from theories and simulations of galaxy evolution. But the dwarf galaxies or globular clusters that collided with the Milky Way were a fraction of its size and eventually just merged into the spiral. When I asked astronomers this question, they said that even the bean-shaped batch of stars called the Gaia-Enceladus Sausage was not massive enough to perturb the Milky Way for long.

COGNITION AND TRAUMA

I read "Minds Everywhere," Rowan Jacobsen's article on how simple cells show basic cognitive abilities, with a mix of astonishment and confirmation bias. The information about how bioelectric cellular activity in plants allows them to sense and respond to their environment was truly astounding. And although the information about cellular intelligence in the animal kingdom was just as enlightening, I received it with the joy that comes from seeing new discoveries that shed light on old mysteries.

As anyone who's been paying attention to the field of psychotherapy and to treatment for post-traumatic stress disorder knows, many recent developments in counseling have focused on the growing awareness that trauma is stored not just in our minds but in our bodies as well. My wife and I have experienced this dynamic firsthand. We are well acquainted with traditional approaches to mental health. But the healing modalities we've found most beneficial all include some mechanism for releasing trauma stored in the physical body.

The reported findings about the behavior of planaria and slime molds provide the first hard scientific underpinning I've seen for these approaches to trauma therapy. I hope someone thinks to start an interdisciplinary dialogue with the psychiatric profession so this understanding of cellular memory can remove some of the stigma and inform more advances in treating trauma and mental illness.

JERRY BARRAX *SHERMAN*, *TEX*.

> "We must not console ourselves by imagining a future where things are humming along much as they do now."
> —Tobias D. Robison *Princeton*, *N.J.*

Jacobsen's article suggests that human intelligence and cognition might be exceptional in degree but not in kind. As the article notes, "People are just another animal species. But real cognition—that was supposed to set us apart." This topic was by far the most significant in the February issue.

TOM WELCHEL *CHARLOTTE, N.C.*

PREDICTIVE PRIORITIES

"Quantum-Proof Secrets," by Kelsey Houston-Edwards, has a problem that occurs in a number of other articles in *Scientific American* and other outlets. Houston-Edwards asks us to imagine the future as a technological race: When people manage to develop a powerful quantum computer, it will crack codes that are routinely used for encryption. Meanwhile other people seek to develop effective encryption methods that will be secure even from quantum computers. We must remember that while this race is going on, we are also dealing with the effects of global warming, overpopulation, and all the results of poisoning and tinkering with Earth's ecology. We must not forget the much greater risks we face, and we must not console ourselves by imagining a future where things are humming along much as they do now except for the effects of quantum computers on decryption.

TOBIAS D. ROBISON *PRINCETON, N.J.*

ROOT OF RUST

In "Rusting Rivers" [January], Alec Luhn describes how streams in Alaska are turning orange with iron and sulfuric acid. I grew up in south-central Alaska. As a child, when I lived in the state's city of Kenai during the early 1990s, I often played in a small creek that ran from a large patch of muskeg riddled with kettle ponds across a flat of magnetite sand. The stream was bright orange, its water almost gelatinous at the edges. My friends and I always assumed that this effect was caused by the acidic muskeg water interacting with the magnetite sand. Your article was a fascinating treatment of a phenomenon I had always thought isolated and fairly straightforward.

MARCUS GOTTSCHE *VIA E-MAIL*

VITAMIN SUPERPOWER?

Kudos to Christie Aschwanden for "The Rise and Fall of Vitamin D" [January], her article on vitamin D deficiency and the vitamin's purported health benefits. I appreciated the excellent history that highlighted how claims of vitamin D's superhealing powers have been overstated. I especially appreciated her explanation of co-occurrence versus a cause-and-effect relation: as she notes in her apt analogy, rich people are likely to purchase expensive cars, but buying an expensive car does not make you rich.

JAN COTE-MEROW *VIA E-MAIL*

ERRATA

"The Great Eclipse," by Rebecca Boyle [March], should have described magnetic fields as rising from the sun's core, not from iron in its core.

"Touching the Stars," by Nia Imara [March], should have said that molecular clouds contain a significant amount of helium, not a trace amount. Additionally, the box "The Birth of a Star" should have said that collapsing cores become dense and hot enough to ignite the fusion of hydrogen into helium, not the merging of two hydrogen atoms to create helium.

"Total Eclipse of the Heartland," by Katie Peek [Graphic Science, March], should have said that the moon's shadow will run up to Newfoundland, Canada, not Labrador.

“A Truly Intelligent Machine,” by George Musser [April], should have said that Nancy Kanwisher is at the Massachusetts Institute of Technology and that Anna Ivanova is at the Georgia Institute of Technology.

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

Education

- **Children Deserve Uniform Standards in Homeschooling**
  With few states tracking who is being homeschooled and what they are learning, an untold number of U.S. children are at risk of a poor education or even abuse

Children Deserve Uniform Standards in Homeschooling

With few states tracking who is being homeschooled and what they are learning, an untold number of U.S. children are at risk of a poor education or even abuse

By The Editors

Thomas Fuchs

The number of children being educated at home has been growing for the past few decades. No one knows by how much, and that is part of the problem. Homeschooling is barely tracked or regulated in the U.S. But children deserve a safe and robust education, whether they attend a traditional school or are educated at home.

The National Center for Education Statistics (NCES) reported that by last count, in 2019, nearly 3 percent of U.S. children—1.5 million—were being homeschooled. This number, calculated from a nationwide survey, is surely an undercount because the homeschooling population is notoriously hard to survey, and more children have been homeschooled since the COVID pandemic began. Eleven states do not require parents to inform anyone that they are homeschooling a child, and in most of the country, once a child has exited the traditional schoolroom environment, no one checks to ensure they are receiving an education at all.

Homeschooled students have won the National Spelling Bee; one was the most prolific mathematician in history. Many are well-rounded and well-adjusted children who go on to thrive as adults. But others do not receive a meaningful education—and too many have suffered horrific abuse. The federal government must develop basic standards for safety and quality of education in homeschooling across the country.

When a traditional classroom setting cannot meet the educational, social or emotional needs of a child, homeschooling can allow parents to take over. For children facing bullying or gun violence or who need more challenging or more advanced schoolwork, a homeschooling environment may be best.

But many parents are attracted to homeschooling because they want to have more say in what their child learns and what they do not. Nearly 60 percent of homeschool parents who responded to the 2019 NCES survey said that religious instruction was a motivation in their decision to educate at home. Some Christian homeschooling curricula teach Young Earth Creationism instead of evolution. Other curricula describe slavery as “Black immigration” or extol the virtues of Nazism.

Some children may not be receiving any instruction at all. Most states don’t require homeschooled kids to be assessed on specific topics the way their classroom-based peers are. This practice enables educational neglect that can have long-lasting consequences for a child’s development.

In the worst cases, homeschooling hides abuse. In 2020 an 11-year-old boy, originally from Michigan, was found dead in California after his stepmother used homeschooling to conceal years of torture.* A small study of children who had been seriously abused found that eight of 17 school-age victims were ostensibly being homeschooled. In these cases, homeschooling was a farce—a hole in children’s social safety net for abusers to exploit.

Although it’s impossible to say how commonly homeschooling conceals abuse, data from Connecticut paint a concerning picture. Following the abuse and 2017 death of an autistic teenager whose mother had removed him from school, Connecticut’s Office of the Child Advocate found that 36 percent of children withdrawn from six nearby districts to be homeschooled lived in homes that had been subject to at least one report of suspected abuse or neglect. Not one state checks with Child Protective Services to determine whether the parents of children being homeschooled have a history of abuse or neglect.

Homeschooling advocacy organizations promote studies that claim to show equal or higher levels of academic achievement among homeschooled students. But these studies often are conducted by homeschooling advocates and are methodologically flawed. It’s difficult for social scientists to recruit representative samples for more rigorous research because of lax reporting requirements and the underground nature of homeschooling, making the kind of sweeping comparison between homeschooling and nonhomeschooling students that some groups report impossible. Still, studies of different homeschooled populations have shown that children's success depends heavily on their parents' education background. Despite this, in 40 states parents do not need to have even a high school–level education to educate their children at home.

The federal government usually leaves issues of education for states to decide, and homeschooling is no exception. A dizzying maze of laws and legal precedents governs parents' ability to homeschool, and the rules differ in each state and sometimes even differ between school districts. Whenever a piece of state legislation is suggested or introduced to regulate some aspect of homeschooling, advocacy organizations such as the Homeschool Legal Defense Association fight back. This year Michigan's Education Department proposed a registry of homeschooled students in the state and was met with fierce pushback. In 2023 Ohio removed all assessment requirements for homeschooled students. South Dakota, Vermont and New Hampshire have also removed some oversight requirements in the past few years.

It is clear that homeschooling will continue to lack accountability for outcomes or even basic safety in most states. But federal mandates for reporting and assessment to protect children don't need to be onerous. For example, homeschool parents could be required to pass an initial background check, as every state requires for all K–12 teachers. Homeschool instructors could be required to submit documents every year to their local school district or to a state agency to show that their children are learning.

Education is a basic human right. We need to make sure kids have chances to investigate what makes them curious, study history and science and reading, and ask questions and learn from others. We want them to reach adulthood ready to take on the world.

**Editor's Note (8/27/24): This sentence was edited after posting to correct the description of where the boy was found.*

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Engineering

- ## An Autonomous Logging Machine Could Make Forestry Safer
  Forestry is deadly. Could automating some logging tasks help?

An Autonomous Logging Machine Could Make Forestry Safer

Forestry is deadly. Could automating some logging tasks help?

By Susan Cosier

Michael Hall/Getty Images

The first autonomous logging machine rumbled down a Swedish forest path and scanned for stacked logs to transport. It then scooped them up with a crane and loaded them onto its trailer. A new study of the truck-size robot, called a forwarder, suggests it could help forest workers with at least some deadly jobs.

“It’s the first trial for us to see that the machine we built is perhaps capable of doing what we were dreaming it could do,” says Pedro La Hera, a roboticist at the Swedish University of Agricultural Sciences and lead author of the study, published in the *Journal of Field Robotics*.

Logging jobs are often demanding, requiring operators to multitask and endure nearly constant vibration while operating logging vehicles. Fatigued foresters don’t always pay attention to other foliage in the area, the researchers say, and can damage the ecosystems around them. Logging is also dangerous; in the U.S., it has one of the highest fatality rates of any industry.

Roboticists, software engineers and forestry scholars in Sweden set out to automate some onerous logging tasks. They used GPS to set a path in a clear-cut area and equipped the vehicle with a computer vision system to help it identify, pick up and release cut logs. The predetermined task sequence demonstrates how, in a controlled environment, a machine with little to no human oversight could operate.

“It’s definitely an advancement,” says Thomas Douglass, a logger who owns Thomas Logging and Forestry in Guilford, Maine. “I, along with other contractors in this area, have problems getting help working in the woods, so I can see why at least making the forwarder an automated process would be helpful.”

For now these vehicles’ use may be limited to Sweden, where nearly all forests are managed for commercial logging, paths are well identified, and satellites provide information on logged areas. Loggers in the U.S., in contrast, harvest trees both in plantations and in natural stands where self-piloted machinery would face more challenges.

Still, the research highlights aspects of autonomous machinery that are worth developing further, says Dalia Abbas, a forester who has investigated the effects of logging operations in environmentally sensitive areas. Eventually, Abbas says, she “would definitely hope that it takes into account the fuller range of where it’s operating, whether it includes wildlife, other contaminants or bugs that come with the logs to avoid any infestations, and its sensitivity to the terrain.”

Since the experiments took place, engineers have already improved the machine’s maneuvering capabilities. The researchers are also pursuing other autonomous efforts such as planting seedlings. Although logging may always need human oversight, automating certain steps could make the process safer and more efficient, benefiting both workers and the environment, La Hera says.

Susan Cosier is a freelance journalist focused on science and the environment. She is based in Chicago. Follow Cosier on Twitter @susancosier

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Genetics

- **Stolen Bacterial Genes Helped Whiteflies to Become the Ultimate Pests**
  Rather than relying on bacteria, whiteflies cut out the middleman and acquired their own genes to process nitrogen

Stolen Bacterial Genes Helped Whiteflies to Become the Ultimate Pests

Rather than relying on bacteria, whiteflies cut out the middleman and acquired their own genes to process nitrogen

By Rohini Subrahmanyam

Whiteflies.
Nigel Cattlin/Alamy Stock Photo

Tiny, sap-eating whiteflies wreak agricultural havoc by spreading multiple plant viruses and secreting sticky, mold-attracting goo on the 500-odd plant species they eat. Now a study in *Science Advances* reveals one secret to their outsize clout. Scientists led by Youjun Zhang of the Chinese Academy of Agricultural Sciences found that these persistent pests have acquired bacterial genes that let them process nitrogen with incredible efficiency.

“Nitrogen makes the world go round,” as Harvard University evolutionary biologist Naomi Pierce puts it. Animals use nitrogen-containing amino acids to make proteins and DNA, but those processes create toxic by-products. Some insects have evolved relationships with symbiotic bacteria that recycle usable nitrogen from this waste.

The new study suggests whiteflies were able to leave this partnership millions of years ago by incorporating two nitrogen-recycling genes from such bacteria into their own DNA. Ted Turlings, a chemical ecologist at Switzerland's University of Neuchâtel and one of the study's senior authors, says viruses—which are known experts in transferring DNA—most likely took those genes from bacteria and happened to deposit them in a nearby insect genome. This process is called horizontal gene transfer.

The "in-house" genes now help whiteflies convert more amino acids into waste when they have too much nitrogen in their bodies, then recycle that waste back into amino acids when they don't have enough. Plants vary a lot in amino acid content; the captured genes may be what lets these pests thrive on such a wide variety of them, the study authors say.

Cooperating with bacteria to recycle nitrogen would be more energetically expensive for the flies than cutting out the middleman and just doing it themselves. And it takes still more energy to make sure the relationship doesn't turn parasitic, Pierce says: "If you have a symbiont living in your body, you need to have ways to control it. Otherwise, it could end up controlling you."

The transferred genes may be a helpful survival tactic for whiteflies, but Turlings says they could also be an Achilles' heel. Because these genes are particular to whiteflies, pest-control strategies such as modifying plants to disrupt the flies' genes will not harm other organisms. "This is as close to perfect as you can get in terms of specificity," he says.

Whiteflies' acquisition history goes beyond this case; they are also known to have gained plant genes that let them neutralize the plants' defensive toxins, says University of Amsterdam's Petra Bleeker, who studies plant-insect interactions. "It seems that horizontal gene transfer is not uncommon in insects," she says, "but whiteflies appear to be champions."

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

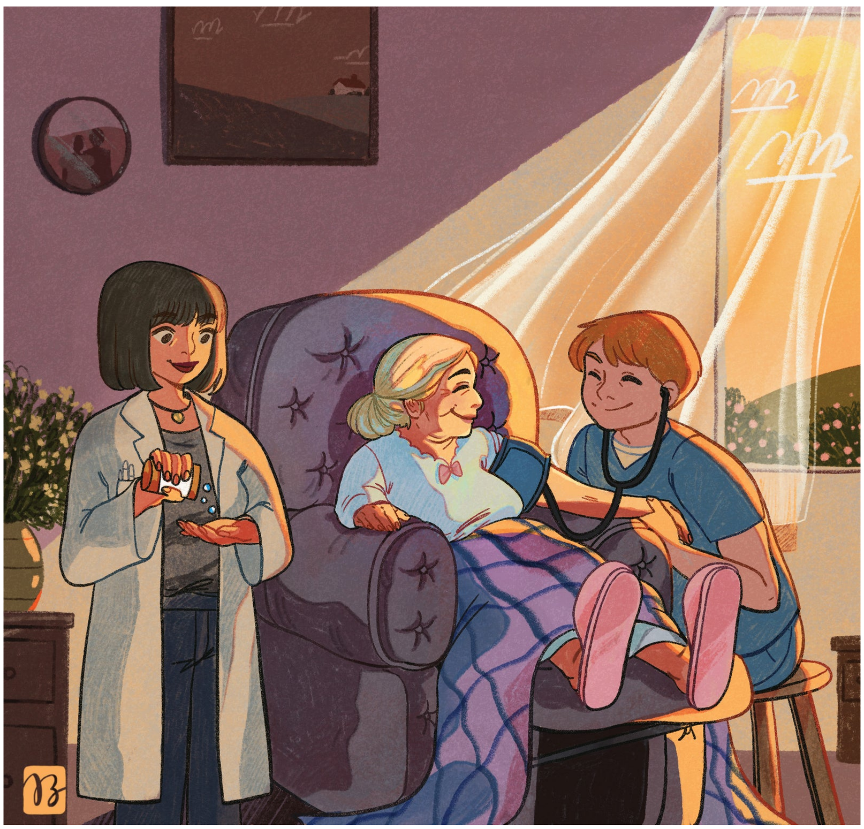
Health Care

- **Patients Fare Better When They Get Palliative Care Sooner, Not Later**
  Supportive care is often started late in an illness, but that may not be the best way

Patients Fare Better When They Get Palliative Care Sooner, Not Later

Supportive care is often started late in an illness, but that may not be the best way

By Lydia Denworth



Jay Bendt

In the last months of my mother's life, before she went into hospice, she was seen at home by a nurse practitioner who specialized in palliative care. The focus is on improving patients' quality of life and reducing pain rather than on treating disease. Mom had end-stage Alzheimer's disease and could no longer communicate. It was a relief to have someone on hand who knew how to read her behavior (she ground her teeth, for instance, a possible sign of pain) for clues as to what she might be experiencing.

I was happy to have the help but wished it had been available earlier. I'm not alone in that. Evidence of the benefits of palliative care continues to grow. For people with advanced illnesses, it helps to control physical symptoms such as pain and shortness of breath. It addresses mental health issues, including depression and anxiety. And it can reduce unnecessary trips to the hospital. But barriers to access persist—especially a lack of providers. As a result, palliative care is too often offered late, when "the opportunity to benefit is limited," says physician Kate Courtright of the Perelman School of Medicine at the University of Pennsylvania.

In 2021 only an estimated one in 10 people worldwide who needed palliative care received it, according to the World Health Organization. In the U.S., the numbers are better—the great majority of large hospitals include palliative care units—but it's still hard for people who depend on small local hospitals or live in rural areas. Outpatient palliative care is especially hard to find.

Experts are also working to correct misconceptions. "When people hear the words 'palliative care,' they think 'end-of-life care—I'm going to die,' " says physician Helen Senderovich, a palliative care expert at the University of Toronto. Although palliative medicine grew out of the hospice movement, it has evolved into a multidisciplinary specialty encompassing physical, psychological and spiritual needs of patients and their families throughout the trajectory of disease, Senderovich says. That path includes the time when treatments are still being tried.

So palliative care specialists have begun referring broadly to “supportive care”— “anything that is not directly modifying the disease,” says medical oncologist and palliative care specialist David Hui of the MD Anderson Cancer Center. For example, wound care and infusions to improve red blood cell counts in cancer patients are supportive; chemotherapy is not.

Generally, the earlier that supportive care is offered, the more satisfied patients report feeling. And ideally, people who need it now get referred to palliative medicine around the time they are diagnosed with a serious illness. An influential study in 2010 found that patients with lung cancer who received palliative care within eight weeks of diagnosis showed significant improvements in both quality of life and mood compared with patients who got only standard cancer care. Even though those receiving early palliative care had less aggressive care at the end of life, they lived an average of almost three months longer.

More recent studies have confirmed the life-quality advantages of earlier palliative care, although not all studies have shown longer survival. “Patients don’t just start having pain and anxiety and weight loss and tiredness only in the last days of life,” Hui says. Starting palliative care earlier allows patients and the care team to “think ahead and plan a little bit,” he adds.

Nor is palliative care effective only for cancer, although that’s where much of the research has been done. It benefits those with heart failure, chronic kidney disease, dementia, chronic obstructive pulmonary disease (COPD), Parkinson’s, and other serious illnesses.

In January 2024 the *Journal of the American Medical Association* published a pair of studies that broke “new ground” in developing sustainable, scalable palliative care programs, according to an accompanying editorial. One, the largest-ever randomized trial of palliative care, included more than 24,000 people with COPD, kidney failure and dementia across 11 hospitals in eight states. The researchers made palliative care an automated order, where doctors had to opt out of such care for their patients instead of going through an extra step of opting in. The rate of referrals to palliative care increased from 16.6 to 43.9 percent, says Courtright, lead author of the study. Length of hospital stay did not decline overall, but it did drop by 9.6 percent among those who received palliative care only because of the automated order.

The second study looked at 306 patients with advanced COPD, heart failure or interstitial lung disease. Half these people participated in palliative care via telehealth visits with a nurse to handle symptom management and a social worker to address psychosocial needs; the other people in the study did not get such care. Those who received the calls quickly showed improved quality of life, and the positive effects persisted for months after the calls concluded.

Because there are not enough palliative care providers, Hui advocates for a system that directs them to patients who would benefit most. Usually, and not surprisingly, those are people with the most severe symptoms. This system uses early screening of symptoms to identify these people. Hui calls the approach “timely” palliative care. “In reality, not every patient needs palliative care up front,” Hui says, so timely care uses scarce resources as effectively as possible.

I don’t know exactly when my mother needed to start palliative care, but I hope that going forward more caregivers and more families know to ask about it sooner.

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).

History

- **June 2024: Science History from 50, 100 and 150 Years Ago**
  Walking barefoot on hot stones; what makes bluebirds blue

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

Walking barefoot on hot stones; what makes bluebirds blue

By Mark Fischetti

1974, Spiral Reaction: “Spirals of chemical activity form in a shallow dish of red reagent. A blue ring was induced by touching the surface of the solution with a hot filament, then the dish was rocked to break the ring. The free ends of the fragmented circular wave each curl around a pivot point, winding up into spirals.” Photographs were taken over eight minutes.
Scientific American, Vol. 230, No. 6; June 1974

1974

Pleistocene Humans Found in Ukraine

“The systematic study of Pleistocene humans was first focused in France. Yet the first occupation sites to be discovered in central and eastern Europe, many of them spectacularly rich, were unearthed almost as long ago. The information they contain is vital to understanding how early humans survived and perhaps even thrived under ice-age conditions in Europe, perhaps best demonstrated by nearly 100 Pleistocene sites in and around the Ukraine. The earliest sites are between 80,000 and 75,000 years old.”

1924

Walking Barefoot on Red-Hot Stones

“In some parts of Asia the priests, in order to show their magical powers, walk on red-hot stones spread over a fierce fire, without any protection to their feet. This achievement has always puzzled scientists. Many times the feet have been closely examined and have not shown any signs of being burned. The real explanation has only just come to light. A shallow pit is dug and in the bottom is placed the wood. This is overlaid with several layers of round stones, and the fire is lighted. When everything is apparently at a great heat the priest walks across. It has been discovered that one kind of stone, basalt, is used. This is of volcanic origin, is extremely porous and is one of the worst conductors of heat known. It is quite possible to have a lump of basalt red-hot at one end and yet cool enough to hold in the hand at the other end. Thus the cunning priest knows exactly where to put his feet."

What Makes Bluebirds Blue?

"The average person is apt to think that all the color effects seen in nature are produced by certain substances, dyes or the like. This is true to a certain extent, as has been found in flowers. But the feathers of the bluebird, the kingfisher and other birds are colored blue due to the dispersion of the light striking minute air cells in the horny structure of the feathers. So far no blue pigment has been extracted from these feathers."

The Largest Map in the World

"Showing all natural and man-made features, the largest map in the world is being erected in the Ferry Building in San Francisco. The map, about two thirds completed, is 600 feet long, a 'working model' of the state of California, made to scale. All the rivers, bays, lakes and coastline are modeled on data from the United States Geodetic and Geological surveys and various state departments. The mountains were colored according to survey reports, and volcanic craters were formed. The lowlands were put in, including depths of water. Cliffs, marshes and beaches were reproduced in exact colors. Forests of redwood, oak and pine were made from carved fragments of sponges, painted the natural shades. Paved and unpaved roads, railroads and all the mountain trails were carved out as trenches, and filled in with magnesite, white-surfaced for every mile of the 6,000 of paved highways. No railroad is too small to be shown. Ties and rails were laid, tunnels were cut through the mountain walls, and trestles and bridges put in. Mine shafts were bored. Steamers and barges are placed on the rivers to indicate directions and limits of inland water traffic."

1874

Statue Wanders Atop the U.S. Capitol

“The iron dome of the Capitol at Washington is 300 feet high, and is surmounted by a metallic statue. It has a motion resulting from the unequal expansion of the opposite sides of the dome. The length of the oscillation from the eastern limit to the western limit is four and a half inches. In the morning the east side of the dome is rapidly heated, while the west side is chilled by radiation through the night. As the sun passes to the western side, this side is heated, but because the east side still retains a good portion of its heat, the expansion is more nearly equalized. [Overall,] the statue inclination to the west is a little greater than that toward the east.”

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

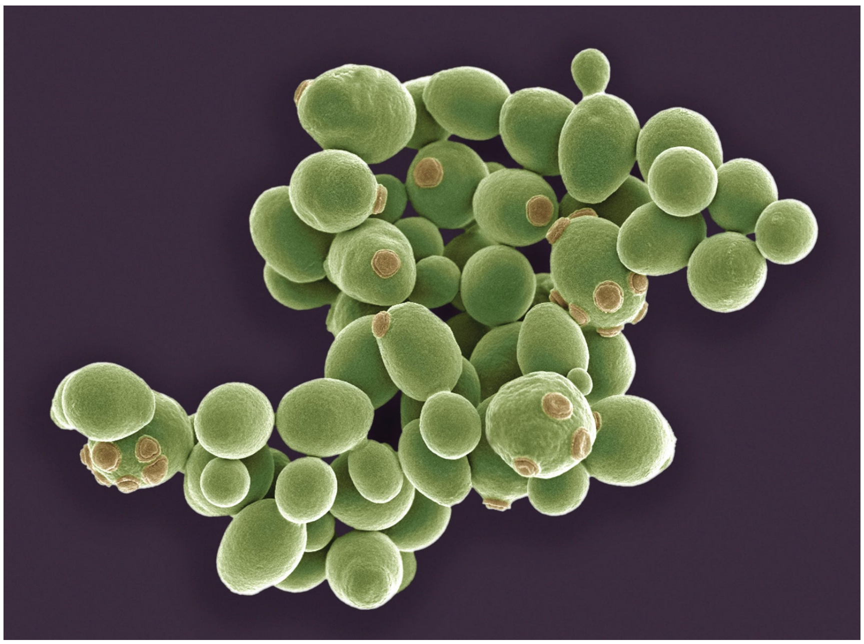
Materials Science

- **After Brewing Beer, Yeast Can Help Recycle Metals from E-waste**
  This beer-making by-product could offer a sustainable way to isolate metals for recycling electronic waste

After Brewing Beer, Yeast Can Help Recycle Metals from E-waste

This beer-making by-product could offer a sustainable way to isolate metals for recycling electronic waste

By Riis Williams



Microscopic view of brewer's yeast.
Science Photo Library/Steve Gschmeissner/Getty Images

When brewer's yeast left over from beer making is mixed with the right seasonings, it makes a bitter, earthy paste called Marmite that is especially popular in the U.K. Smeared on toast, it's a snack that can be an acquired taste. But a study published recently in *Frontiers in Bioengineering and Biotechnology* found that residual yeast sludge can also be used to bind to electronic-waste metals—a capability the research suggests could help recycle the world's growing mountains of discarded gadgets.

When the study authors added brewer's yeast, a single-cell fungus, to a watery solution of mixed metals, they noticed the yeast could isolate and take up specific metals—and be reused at least five times without losing binding strength. The team says this method offers a more environmentally sustainable alternative to current extraction techniques such as pyrometallurgy, an energy-intensive melting process that can release toxic fumes. And even though brewer’s yeast may be tasty to some, much of it still gets dumped, and it is extremely cheap and plentiful.

“In Austria, we produce a lot of beer and have a lot of brewer’s yeast that goes to waste,” says study lead author Anna Sieber, a graduate student at the University of Natural Resources and Life Sciences in Vienna. Knowing the yeast can bind to metals and be used multiple times, she says, “we think this method could actually help limit both the yeast and electronic-waste streams.”

The researchers rinsed, froze, dried and ground up 20 liters of residue with inactive yeast from a brewery. Next they added some of the yeast to solutions containing a laboratory-made mix of aluminum, copper, nickel and zinc, then added some to solutions with those same metals leached directly from scrapped printed circuit boards. The researchers adjusted the mixtures’ acidity and temperature to alter the charge of sugar molecules on the yeast organisms’ surfaces; particular metals are drawn to specific charges on the sugars, so this process controlled which metals the yeast attracted and bound. After each attempt, the scientists extracted the yeast and soaked it in an acid bath to remove the metals from it, leaving the yeast ready for another round.

The four tested metals are relatively inexpensive, and most e-waste recyclers currently prioritize recovering more valuable ones such as gold, silver and platinum. But the study's metals are still beneficial and widely used—which "justifies the recycling process," says Treavor Boyer, an environmental engineer at Arizona State University. Kerry Bloom, a biologist at the University of North Carolina at Chapel Hill, adds that the yeast's low price and sheer abundance could make the technique relatively feasible at a large scale if e-waste recycling facilities prove willing to invest in something new. "There are huge vats of yeast that often have nowhere to go once brewers are done with them," he says. "So this is a fantastic source for it. It's the master recycler."

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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Mathematics

- **Math Explains Why Your Friends Are More Popular Than You**
  The inspection paradox makes sense of social networks, long train wait times and why the call center is always busy

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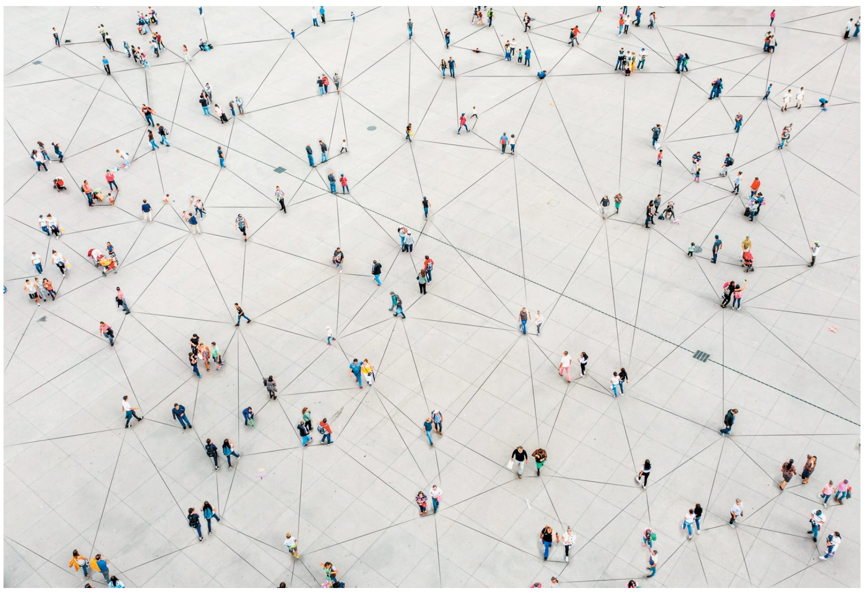
Math Explains Why Your Friends Are More Popular Than You

The inspection paradox makes sense of social networks, long train wait times and why the call center is always busy

By Jack Murtagh



Orbon Alija/Getty Images

Do you ever feel like your friends have more friends than you do? Although your mom might insist that you're just as popular as they are, math's inspection paradox explains why you're probably right. It also reveals why it often feels like you're waiting too long for the train or bus, why call centers always seem to be experiencing higher-than-average call volume, and other daily frustrations.

Consider a social network like Facebook, where the average user has a few hundred friends. Someone with 10,000 friends appears in 10,000 other users' friend lists, making many of those (average) people feel unpopular by comparison. On the flip side, someone with five friends appears only in their five friends' lists, making at most only five people feel popular by comparison. That's the key idea: a person’s representation in other users’ friend circles is proportional to their own popularity. You’re more likely to have very popular friends precisely because they’re popular. Don’t tell your mom.

Just consider the simple social network below:

On supporting science journalism

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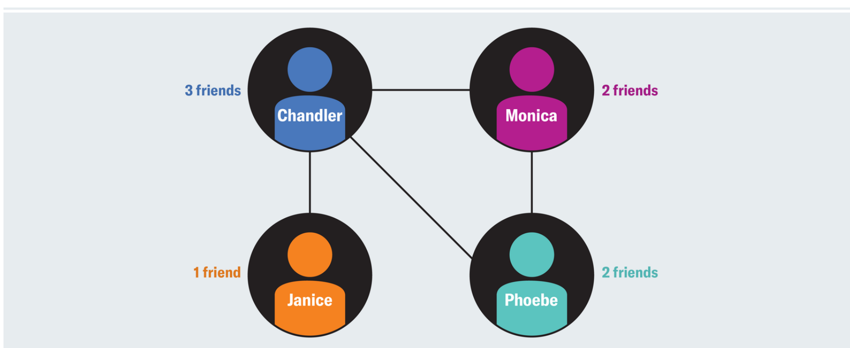


Credit: Amanda Montañez

Chandler has three friends, Monica and Phoebe each have two, and Janice has one, for a total of eight. We then divide those eight friends by the four people in the network to get an average of two friends. Notice, though, that Monica’s friends have 2.5 friends on average (Chandler’s three plus Phoebe’s two, all divided by two). Monica’s friends have more friends on average than she does (2.5 > 2), which could make her feel relatively unpopular even though she’s actually perfectly average. Her local perspective on her immediate friend circle tells a different story than the global perspective of her status in the network as a whole.

The same happens to Phoebe and Janice, whose friends have 2.5 and three friends on average, respectively. Only Chandler's friend group is relatively unpopular, with an average that rounds to 1.67 friends. The majority of people in this group are less popular than their friends. Another way to quantify this situation is to look at the average number of friends that one's friends have in this network, which is approximately (2.5 + 2.5 + 3 + 1.67)/4 = 2.42. That number is larger than the average person's friend count of two.

Surprisingly, this will always happen in every network (unless everybody has an identical number of friends, in which case the counts will be equal). On average, people's co-authors have had more co-authors than they have, and their sexual partners have had more sexual partners than they've had. Although such network dynamics are sometimes dubbed the friendship paradox, they fall under a more general phenomenon known as the inspection paradox.

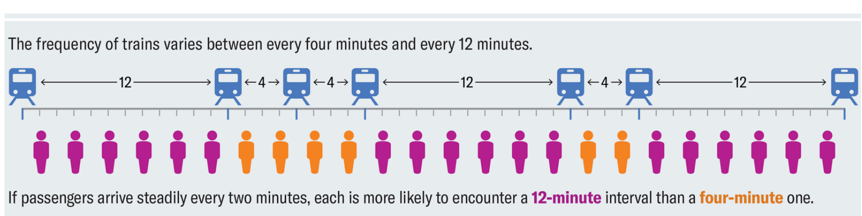
The inspection paradox is not a paradox at all, because both perspectives can be valid simultaneously. The apparent contradiction arises when individuals perceive an average to be larger than a global perspective would suggest because they are more likely to encounter large instances. Monica's friends in our hypothetical network are more popular than she is, and she also has a typical number of friends.

Confused? Here's another example. Ask university students what their average class size is, and the answer will always skew larger than the administration's official reports of average class size. Are these students exaggerating? Is the administration deflating numbers to make their student-teacher ratio look more favorable? No—both perspectives are correct. Students in big lecture courses naturally report larger class-size averages, whereas students who take only intimate seminars report smaller class-size averages, but both are giving accurate reports. There are far more people in the former group because lecture halls contain more people than intimate seminars. Polling the students counts high-enrollment classes more often than low-enrollment classes, whereas when the university tallies average class size, it counts big lectures and small seminars each only once.

> On average, people's friends have more friends than they have, and their sexual partners have had more sexual partners than they've had.

The inspection paradox is at work in some of the most mundane places. Suppose a transit authority promises that its metro trains pull through a station every eight minutes on average. If you arrive at the station at a random time between trains (ignore rush hour), then sometimes you'll sit for seven minutes and 50 seconds, and other times you'll hear the oncoming whistle just as you cross the turnstile. You might expect these cases to even out over time to about a four-minute wait on average.

So why does it always feel longer than that? Sure, train arrivals every eight minutes on average don't imply every eight minutes on the dot. The schedule usually is staggered. But why does your bad luck always plunk you in a long interval? It's not bad luck; it's just probability. You're more likely to arrive during long intervals simply because they're longer.



Credit: Amanda Montañez

The sample timeline below depicts six intervals between trains—half of these last 12 minutes, and the other half last four. The transit authority could advertise an average of eight minutes between trains, but individual commuters are three times as likely to show up during a long interval and experience a frustrating wait.

Scientists need to stay diligent about the inspection paradox and the biases it can cause. To conduct a study on average university class size, for example, one must specify exactly what one means to measure and tailor the polling methodology accordingly.

But some clever researchers have also exploited the phenomenon to improve their random sampling. A particularly interesting example comes from a study on the spread of flu. During an outbreak, well-connected people tend to contract diseases earlier because of their high social contact. To detect outbreaks quickly, epidemiologists could prioritize monitoring those people, if they knew who they were in advance. The naive method of checking the flu status of random members of the population gives no priority to well-connected people, and mapping out the structure of the social network would take too much time. Instead researchers tried picking random people and monitoring their friends. This slight tweak greatly improves the chances that well-connected people will show up in the sample because, as we've seen, people's friends tend to be more popular than they are. This technique allowed the researchers to detect a flu outbreak two weeks earlier than with traditional random sampling.

Even for those of us who don't work in research, the inspection paradox can help explain our everyday observations. Why is it that call centers always seem to be experiencing higher-than-normal call volume? Maybe they just say that to excuse understaffing, or maybe we all tend to call at the same time, such as during our lunch breaks. But perhaps we're just more likely to belong to a bigger group of simultaneous callers precisely because it's bigger. If airlines are complaining that not enough people buy tickets and they're forced to fly nearly empty planes, why do you so rarely enjoy the luxury of an uncontested armrest? Because few people do overall. Sometimes when you feel down on your luck, a broader perspective really can help. At least it's something to ponder while you wait for the next train.

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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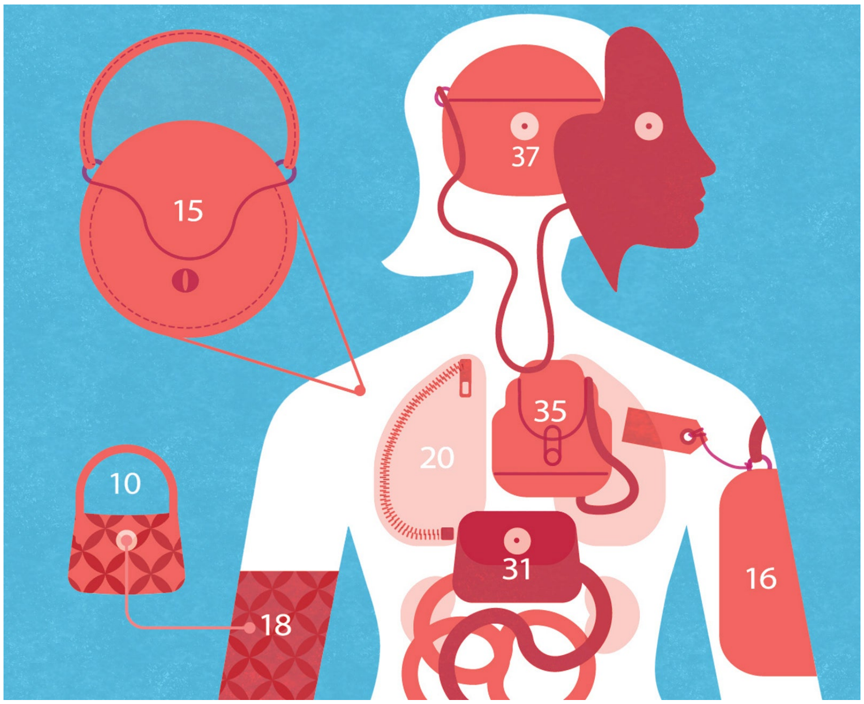
Medicine

- ## The Human Body Is Bags, Bags and More Bags
  Your brain might be like a computer, and your digestive system might be like a tube. But in the end, your whole body is just a bag full of bags

The Human Body Is Bags, Bags and More Bags

Your brain might be like a computer, and your digestive system might be like a tube. But in the end, your whole body is just a bag full of bags

By Bethany Brookshire



Andrew Baker

Your kidneys are like filters. Your brain is like a computer. Your digestive system is like a tube. Your hands are controlled a bit like a marionette. These comparisons exist in part because doctors and scientists are desperate to find ways to visualize our bodies, in search of aids to understanding—with the bonus that it's not quite as visceral as the real thing.

All of these are useful, but one, I've discovered, is missing. Our bodies are like tubes or levers or computers, but they are, above all things, like bags. Bags that are stuffed in other bags, stuffed in still more bags. Our bodies are nesting bag situations like the used bags stuffed under your kitchen sink, with the added bonus of thumbs and anxiety. The analogy gives me clarity—when I have trouble understanding anatomy, I look for the bag. It gives me context—figuring out how to replicate or get inside our various bags is a critical part of modern medicine. Finally, it gives me comfort. Life isn't that complex after all. It's just a series of bags, getting more and more fancy and specialized.

If this sounds like the sort of thought that would come to someone sleep-deprived in the middle of the night, it is. I've been having difficulty sleeping since sometime in 2020, and I'm sure I'm not alone. Through trial, error, prescriptions and meditation apps, I have found the one thing that truly works for me—studying human anatomy. My insomnia led me on an exhaustive, 18-month-long search for boring, self-improving books, to be read by the light of a carefully dimmed lamp. After a perusal of classical literature, my eye fell on the holy grail. A brick of a tome, clocking in at 1,153 pages and a solid six pounds. Moore, Dalley and Agur's *Clinically Oriented Anatomy*, the medical textbook of the Harvard Medical School's "Human Functional Anatomy" course. Six months later, my book is as battered as any first-year medical student's, and I am obsessed. I share the most fascinating anatomy facts on Bluesky, TikTok and Instagram, in a series I call Insomnia Anatomy Academy.

In the many hours waiting for sleep to finally set in, I've discovered all sorts of captivating tidbits—human anatomy can, paradoxically, really keep you up at night. Teeth are joints, and scientists are still learning about the ligaments that hold them in place. Some people have an extra set of ribs—coming from the last vertebrae in their neck. People who can breastfeed can have extra breast tissue that forms and releases milk—into their armpits. Every page offers a new weird fact that emphasizes our evolutionary history and our wild individual variability.

I can barely flip a page without running into a bag. Your skin? A many-layered sack, holding in all of your insides. Inside, the skin, bags abound. It's perhaps easy to think of the stomach, which is a tube, closed off at the top and bottom by the esophageal and pyloric sphincters, as a bag. Or the bladder, a temporary storage bag for urine.

That's not all. The heart gets not one but two bags: a tough outer fibrous pericardium and a serous pericardium, protecting the heart and fixing it firmly in place in our constantly moving thorax. The brain and spinal cord are triple-wrapped, with three layers of the meninges. These sacks physically protect our most delicate and essential bits. Inside, there's another, different sack—a blood-brain barrier of linked cells that prevents most infections from touching the brain. Even the uterus is a bag—one that can be filled with a fetus. That fetus builds its own inner bag in conjunction with the parent, creating the placenta, layers of parental and fetal cells that protect and provide.

Your muscles even have bags. Groups of muscles that do the same thing, along with the nerves and vessels that keep them going, are bundled together into what are called fascial compartments. These bags are so tight they might be better described as flesh vacuum-packing cubes. These bags are more than just packaging. They reduce friction, and often merge into tendons. When one of these bags is injured or infected, the blood or infection will spread first inside the bag, allowing doctors to predict where it will go and intervene.

Nerves infest these bags as well, and so the network of bags might be sensory as well as storage. Scientists are still trying to figure out how manipulating our muscular packets could help with mobility or pain.

The bags don't stop there. Joints are surrounded by joint capsules—tight, double-layered bags with thin layers of fluid that help our bones rub neatly against each other, allowing us to pivot without pain.

Bags don't end with what we can see with the naked eye. Each cell on its own is a bag, a membrane separating its contents from the outside world. Within those cellular bags, like especially gooey *matryoshka* dolls, are organelles, minute bags separating out their own microchemistry. The organelles can each have a different pH and hold some molecules inside and keep others out.

Much like you may with the bags under your kitchen sink, cells even reuse and recycle some of their bags. Tiny bags called vesicles contain chemical messengers. Those bags dump their contents outside the cell, and merge with the larger bag of the cell itself, only to get pinched off and reused again when more packaging is required. Life itself can be drilled down to bags: the first cell wasn't a cell until it was separated off from the outside world—until it had a bag.

Bags aren't just a thought exercise for insomniacs—but something our medical knowledge grapples with daily. Scientists and doctors are still studying and often trying to replicate our many natural bags. Some are studying how to make synthetic vesicles, to release chemicals where and when we want them. Others are trying to build artificial placentas for premature infants. Some bags might be allies, while others might serve more as worthy adversaries. It's a constant fight for new medicines to get past our determined brain bags to cure our mental ills.

Sitting with my anatomy text, and waiting patiently for sleep, I find my many bags both wonderous and comforting. The world can seem endlessly complex, full of the things we should have known, the things we did or didn’t do well enough. But human life, the physical stuff that makes us love and hate and judge and care? It’s just bags all the way down.

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

A version of this article with the title “The Human Body Is Made of Bags” was adapted for inclusion in the June 2024 issue of Scientific American.

Bethany Brookshire is an award-winning science journalist and author of the book *Pests: How Humans Create Animal Villains* (Ecco, 2022). Her work has appeared in *Scientific American*, the *New York Times*, the *Washington Post*, the *Atlantic* and other outlets.

Neuroscience

- **Why Some Songs Make Everyone Want to Dance**
  A syncopated rhythm may prompt our brain to find the beat

Why Some Songs Make Everyone Want to Dance

A syncopated rhythm may prompt our brain to find the beat

By Anna von Hopffgarten

Flashpop/Getty Images

Experts have gained deeper insight into why people spontaneously dance to music. New research suggests the impulse to bop to the beat—what some scientists call the “groove experience”—depends on the music’s degree of syncopation, a feature that affects how predictable the rhythm is.

The work reveals “why we cannot resist moving in sync with the beat when we listen to music with an optimal level of syncopation,” says Benoît Bardy, a movement-science researcher at the University of Montpellier in France. Bardy, who was not involved in the new study, describes it as “a very innovative piece of science.”

Syncopations are rhythmic patterns in which accented or unaccented beats in a melody appear in surprising places relative to the standard beat. The more syncopation a piece of music contains, the less accurately you can guess the rhythm of the next few bars as you listen.

On supporting science journalism

In a series of experiments with more than 60 participants, cognitive neuroscientist Benjamin Morillon of France's Aix-Marseille University and his team examined how syncopation relates to the groove experience. In one test, they played 12 different melodies. The main beat was always two hertz, or roughly two events per second. But the melody's rhythmic shifts varied so that each tune was played with three different degrees of syncopation. Participants then rated how much they wanted to dance to each track.

As Morillon and his colleagues report in *Science Advances*, a medium degree of syncopation triggered a strong desire to move to the music. In contrast, neither very high nor low degrees of syncopation had that same result. In other words, people didn't particularly want to dance to an entirely predictable rhythm or a highly surprising one.

In addition, the groove experience seems to be all about finding the music's underlying pulse, the study shows. When a group of participants had to tap their finger to imagined dance steps, they did so almost exclusively to the basic 2-Hz beat, not to the melody's rhythm.

To better understand how the brain derives these movements from the tune, Morillon and his colleagues measured brain activity in 29 people using magnetoencephalography, a process that measures magnetic fields produced by the brain, as the participants listened to music. Analysis showed that the brain's auditory cortex—the main region for processing auditory stimuli—primarily follows the melody's rhythm. Meanwhile the dorsal auditory pathway, the brain area that connects the auditory cortex with movement areas, is where the rhythm apparently matches the basic beat. It's therefore likely that the impulse to dance arises in this pathway and is then passed on to the motor areas as a movement impulse.

The researchers also modeled their findings mathematically with a quadratic relationship; this produced an inverted U-curve in which the highest desire to move came at a medium level of syncopation. That modeling, Morillon says, suggests that with a moderate level of syncopation, our brain "can still extract the periodic beat from the melodies." Putting the evidence together, he and his colleagues contend that the brain is essentially trying to anticipate upcoming beats amid a melody's syncopation. The result is the impulse to dance.

"For a long time music and dance have been studied separately [in the brain]," says Constantina Theofanopoulou, a neuroscientist at the Rockefeller University and director of the school's Neurobiology of Social Communication Lab. Theofanopoulou, who did not contribute to the new study, explains that much research to date has focused on either auditory perception in music or motor production in dance, and "this study takes a step toward bridging the gap between the two." She adds that the complexity of coordinating and integrating brain areas may help elucidate why some people have impaired rhythmic movement.

Morillon, meanwhile, explains that a key motivator for his work is understanding how people make sense of time—and how the motor system helps us recognize temporal patterns and anticipate future events. "What I find fascinating is our lack of a dedicated sense of time,” he says. “We have specialized systems for processing sound and light, but time perception remains elusive.”

This article originally appeared in Spektrum der Wissenschaft *and was reproduced with permission with additional reporting by Daisy Yuhas. It was further adapted for inclusion in the June 2024 issue of* Scientific American.

Anna von Hopffgarten is a biologist and a brain research, psychology and medicine editor at *Spektrum der Wissenschaft*

Public Health

- **Asbestos Is Finally Banned in the U.S. Here’s Why It Took So Long**
  The carcinogenic effects of asbestos have been known for decades. We should have banned it long ago

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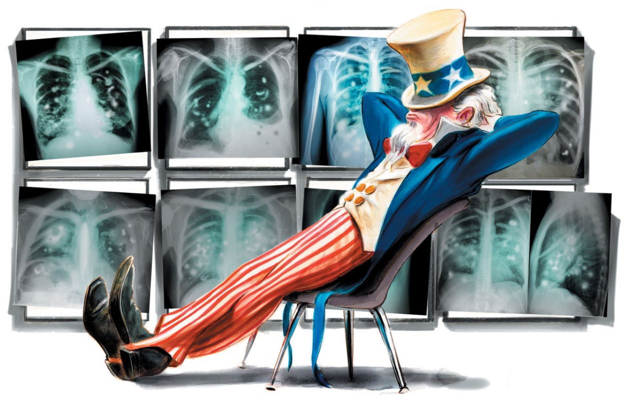
Asbestos Is Finally Banned in the U.S. Here's Why It Took So Long

The carcinogenic effects of asbestos have been known for decades. We should have banned it long ago

By Naomi Oreskes



Scott Brundage

In March the U.S. Environmental Protection Agency announced that it was banning ongoing uses of asbestos. People might have thought, Wait—what? Wasn't it already banned? After all, many remember asbestos—a naturally occurring, fibrous mineral that is resistant to heat and flame but is also toxic and carcinogenic—being removed from schools and hospitals across the U.S. starting in the 1970s. The new EPA decision is welcome, of course, but it highlights the need to figure out a better process for dispensing with deadly products.

Scientific understanding of the harms of asbestos can be traced back to 1898, when British factory inspector Lucy Deane described asbestos manufacturing as one of four dusty occupations worthy of scientific observation because of "their easily demonstrated danger to the health of workers.” In 1927 the term “asbestosis” was adopted to describe a devastating lung disease often seen in asbestos workers, and doctors began to notice that victims of asbestosis often also developed lung cancer.

More than 30 years passed before the asbestos-cancer link was firmly established, however. In 1960 a book published by E. I. du Pont de Nemours & Company openly acknowledged that “pulmonary carcinoma has been observed with such high frequency in employees of the asbestos industry that a causal relationship has been accepted by most authorities.” Four years later Irving J. Selikoff, a doctor and researcher at Mount Sinai Hospital in New York City, tied together various lines of investigation in a now classic study. He found a statistically significant higher incidence of mesothelioma—an otherwise extremely rare cancer—in workers exposed to asbestos compared with that in the general population. Asbestos exposure also led to increased rates of lung, pleura, stomach, colon and rectal cancers. Crucially, the evidence indicated that there was no safe level of exposure.

At a 1964 New York Academy of Sciences conference on asbestos, industry representatives agreed that the only way to prevent cancers caused by asbestos exposure was to eliminate that exposure. And so, in the 1970s, many nations began to ban asbestos. As of 2020, at least 67 countries had banned asbestos use either entirely or with very limited exemptions.

Because of the long latency period of many cancers caused by asbestos—and the difficulty of knowing all the circumstances in which people might have been exposed to asbestos outside industrial settings—it is hard to say just how many people have died or are still dying from asbestos. The University of Washington–based Institute for Health Metrics and Evaluation estimates that asbestos caused more than 40,764 worker deaths in 2019 alone; this figure does not include deaths outside industrial settings, such as those of family members exposed to asbestos brought home on a worker's clothes or shoes.

According to the U.S. Centers for Disease Control and Prevention, between 1999 and 2015 there were 45,221 mesothelioma deaths in the U.S. The cumulative number of occupational deaths that were caused by asbestos over the course of the 20th century may be something on the order of 17 million, with perhaps another two million deaths from nonoccupational exposures.

Yet until now, only various partial and limited bans have been in place in the U.S.

It's generally impossible to say why something didn't happen in a given situation. But in this case, industry pushback, aided by antiregulatory attitudes that have dominated in the U.S. since the 1980s, clearly played a role. In 1989 the EPA tried to use its authority under the Toxic Substances Control Act (TOSCA) to phase out and ultimately ban most asbestos-containing products. But a company named Corrosion Proof Fittings, backed by several trade associations, successfully challenged the rule in federal court. The plaintiffs claimed that the agency's rule would save only three lives over the course of 13 years and at "an approximate cost of $128–277 million." That was patently false, and the court did not accept it. But it did accept a different complaint about the procedure by which the EPA had come to its proposed remedy.

The EPA could have proposed a new rule, but during the 1990s the political tide had turned against “big government” as various industry groups worked to demonize “regulation,” and the EPA stood back. Rather than attempting to propose a new, broad rule under TOSCA, the agency focused on more limited and specific regulations, such as developing guidelines to accredit asbestos-removal personnel, or regulations that were explicitly authorized by Congress.

One such regulation was the 1990 Asbestos School Hazard Abatement Reauthorization Act, which empowered the EPA to help schools deal with asbestos on their grounds. As a result of these choices, asbestos use was greatly reduced, but it was not eliminated, and a number of asbestos-bearing products remained on the market.

Moreover, throughout the 1990s and 2000s industry groups pursued a strategy similar to that of the tobacco industry, attempting to cast doubt on the science that demonstrated the harms of asbestos. Among other things, they attempted to discredit asbestos researchers—particularly Selikoff—as zealots and to muddy the scientific waters by claiming that only certain mineralogical forms of asbestos were hazardous, when in fact the science supported no such distinction.

In 2016 Congress amended TOSCA to restore to the EPA some of the authority that had been stripped from it by the courts. The asbestos ban is the EPA’s first new rule under the amended law.

America was once a leader in occupational health and safety. Now we are laggards. It took 126 years for us to heed Lucy Deane’s warning about the dangers of asbestos. We need a better way to translate science into policy.

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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Space Exploration

- ## The Scale of Space Will Break Your Brain
  The scale of the cosmos exceeds the bounds of human comprehension. But that doesn't mean the universe is beyond our understanding

The Scale of Space Will Break Your Brain

The scale of the cosmos exceeds the bounds of human comprehension. But that doesn't mean the universe is beyond our understanding

By Phil Plait

Hasbi Sahin/Getty Images

Space is big. That's why we call it space. But how big is "big"?

That's relative. When an astronomer says something is nearby, they might mean it's a few million kilometers away (if they're talking asteroids) or a few tens of trillions (for stars) or a few tens of quintillions (for galaxies).

No matter the destination, it's a long walk. We make it easier on ourselves by using huge units to measure distance, such as a light-year, the distance traveled in a year by light—the fastest thing in the universe. A light-year is about 10 trillion kilometers (km). But that's still fairly abstract to the typical person reading casually about "nearby" exoplanets or "distant" galaxies. One way to better grasp this scale is to take it step by step. The moon is the closest astronomical object to us in the entire universe. On average across its orbital path, it’s about 380,000 km from Earth. That’s already a pretty long way; nearly 30 Earths could fit side by side over that distance! Or think of it this way: the Apollo astronauts, traveling faster than any human before them, took three days to reach the moon’s vicinity.

> If you could pave a road between Earth and the sun, it would take you about 170 years to drive there at highway speeds. Better pack a lunch.

The sun is about 400 times farther away from us than the moon is: 150 million km. How far is that? If you could pave a road between Earth and the sun, it would take you about 170 years to drive there at highway speeds. Better pack a lunch. A commercial jet would be better—it would take a mere 17 years.

When we work with objects inside the solar system, it’s convenient to use the Earth-sun distance as a kind of cosmic meter stick. We call it the astronomical unit, or AU, and it is defined by the International Astronomical Union (the keeper of all astronomical numbers, names, and other such agreed-on conventions) as exactly 149,597,870.7 km. Mercury is about 0.4 AU from the sun and Venus about 0.7. Their distances from Earth depend on where all the planets are in their orbits and increase when respective planets are on opposite sides of the sun, so Venus will range from about 0.3 to 1.7 AU from Earth.

Neptune, the farthest major planet from the sun, is 4.5 billion km out, or 30 AU. Pluto's at roughly the same distance, and it's a long way from us. The New Horizons spacecraft took more than nine years to get there despite moving at speeds of more 50,000 km per hour.

These numbers are still difficult to grasp. When I traveled to schools to give demonstrations to kids about astronomy, one of my favorite props was the solar system rope: a hefty 15-meter cord that represented the average sun-to-Pluto distance. The students were given photos of planets, and we'd place them at the proper scaled distance from the sun. The inner four planets were so close together that the kids were practically on top of one another, but the outer planets were spread out a long way; we had to either find a long hallway or go outside for the demo.

That lesson proved so popular that I created a spreadsheet allowing anyone to calculate the solar system to scale. It's based on the size of the sun, so you can change it from the default of one meter to, say, the size of a grape and find out how big and how far-off the planets become. It's fun—and eye-opening.

But it's useful, too, to consider the separation between objects in terms of their size. For example, the sun is 1.4 million km wide. The nearest star system to the sun is Alpha Centauri, which is 41 trillion km away. If we divide the second number by the first, we find that Alpha Centauri is about 30 million "suns" away. Stars are very small compared with the distance between them, and that is one reason you really don't need to worry about one ever colliding with our sun!

That's also why we use light-years to measure these distances; it's a more palatable unit for dealing with interstellar journeys. Alpha

Centauri is 4.3 light-years away. The Orion Nebula is about 1,250 light-years from the sun. The center of the Milky Way is 26,000 light-years away, and the galaxy itself is a flattish disk some 120,000 light-years across.

The nearest big galaxy to the Milky Way is Andromeda, which is 2.5 million light-years from us. That's an interesting number because it's "only" 20 times the size of the Milky Way. Most galaxies are pretty close in size.

Inside galaxies, stars collide extremely rarely because they're so far apart relative to their size. But galaxies are more crowded together in space, so it's not too big a surprise that galaxy collisions are not only common but ubiquitous. The Milky Way grew to its tremendous size by colliding and merging with other galaxies, and in fact every big galaxy has undergone multiple collisions.

The Milky Way and Andromeda are the two biggest galaxies in a clutch of about 100 galaxies that we call the Local Group. It's about 10 million light-years across. There are even bigger and more populous groups, called galaxy clusters. The nearest big one is the Virgo Cluster, with well over 1,000 galaxies in it, located about 50 million light-years from us. And smaller groups exist that are closer to us.

Galaxy clusters are held together by the gravity of their members and can be tens of millions of light-years wide. But we're not done! Clusters can clump up in the cosmos to form clusters of clusters, called superclusters. The Virgo Cluster and the Local Group are part of the Laniakea Supercluster, which may have more than 100,000 galaxies in it and stretches for 500 million light-years.

The universe is 13.8 billion years old, so you might think the most distant objects we can see are roughly that distance away in light-years. But the cosmos is expanding, and in the time it's taken for the light from distant objects to reach us, that expansion has swept them farther from us. Because of this movement, the observable universe is estimated to be more like 90 or so billion light-years across!

After all that, I'll let you in on a secret: even astronomers can't truly grasp these scales. We work with them, and we can do math and physics with them, but our ape brains still struggle to comprehend even the distance to the moon—and the universe is two million trillion times bigger than that.

So, yeah—space is big. And it's true that we are very, very small. These scales can seem crushing. But I'll leave you with this: although the cosmos is immense beyond what we can grasp, by using math and physics and our brain, we can actually understand it.

And that makes us pretty big, too.

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

Water

- ## Is Cold-Water Swimming Good for You?
  Though sometimes overstated, the benefits of cold-water swimming are slowly becoming clearer
- ## Strangely Shaped Bubbles Tell the Story of Ice’s Formation and Composition
  Bubbles shaped like teardrops, flattened eggs and worms reveal ice’s inner life

Is Cold-Water Swimming Good for You?

Though sometimes overstated, the benefits of cold-water swimming are slowly becoming clearer

By Jesse Greenspan

mihtiander/Getty Images

Cold-water swimming is surging in popularity, particularly in northern Europe, where groups such as the BluetitsChill Swimmers eschew tropical beach vacations in favor of frigid winter dips. Celebrity practitioners, including actors Kate Winslet and Bradley Cooper, have enhanced this icy pastime's cachet.

As far back as 400 B.C.E., Hippocrates claimed that cold-water swimming relieves fatigue. Aficionados have since credited it with benefits ranging from improved sleep to enhanced libido.

In a recent survey of 1,114 female cold-water swimmers, published in *Post Reproductive Health*, more than one third reported that their hobby eased mood swings associated with menstruation and menopause. Among menopausal respondents, 47 percent said it reduced anxiety, 30 percent said it reduced hot flashes, and 20 percent said it reduced night sweats.

Cold-water bathers have also reported pain relief from musculoskeletal injuries and decreased symptoms of depression, as well as feeling more alert and attentive overall. In one study, they reported improvements in mood after just one dip.

“You never find anybody who’s doing this activity who says it isn’t great,” says James B. Mercer, an emeritus physiologist at UiT the Arctic University of Norway and lead author of a scientific review of 104 studies on cold-water immersion. “They all swear by it. They think it’s the most wonderful thing in the world.”

But Mercer adds that the health claims about cold-water swimming have been “quite difficult” to assess, partly because most studies on the subject have been small, with generally healthy participants and widely varying water temperatures and salinity levels. Researchers have struggled to tease out whether the cold water itself is helpful or whether the benefits come from, say, having an active lifestyle and socializing with friends.

“Most claims have no or very weak evidence,” says Heather Massey, a physiologist at the University of Portsmouth. Besides co-authoring several cold-water-immersion papers, Massey has swum the English Channel and dabbled in competitive “ice swimming” (in water colder than 41 degrees Fahrenheit).

Still, science doesn't simply throw cold water on the perceived benefits. Although more research is needed, rigorous studies have suggested that regular cold-water exposure might combat obesity, cardiovascular disease, inflammation, muscle soreness and diabetes, and it may also prepare the body to cope with other stressors. Mental health improvements have been largely anecdotal; one 2018 case study followed a young woman who weaned herself off antidepressants with a cold-water-swimming regimen. Recruiting is currently underway for a randomized, controlled trial on outdoor swimming and depression.

Cold-water swimming does carry risks: it can cause hypothermia, drowning and cardiac arrhythmia, and experts caution that people with health conditions should consult their doctors before trying a polar bear plunge. They also suggest easing in slowly when possible and not going alone.

Adherents insist there's no replacement for "that feeling of euphoria and then peace," says University College London reproductive researcher Joyce C. Harper, lead author of the menstrual and menopause survey.

"I recently swam in a semifrozen lake, and I was overcome with uncontrollable laughter," Harper says. When water's too warm, she adds, it "loses some of its buzz."

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Strangely Shaped Bubbles Tell the Story of Ice’s Formation and Composition

Bubbles shaped like teardrops, flattened eggs and worms reveal ice’s inner life

By Rachel Berkowitz

Anton Petrus/Getty Images

Look closely at an ice cube, and you might spot minuscule bubbles shaped like teardrops, flattened eggs or even winding worms. Bubble patterns in Russia’s Lake Baikal (*shown here*) are even more vivid. Researchers have found that ice bubbles’ peculiar shapes can reveal how fast the water froze and how much gas was dissolved in it, providing key insights for glaciologists and engineers.

As water freezes, most of its dissolved gases get expelled. But some tiny bubbles near the freezing edge can get trapped in the solidifying ice, where they keep growing. Virgile Thiévenaz, who studies fluid mechanics at Paris’s Industrial Physics and Chemistry Higher Education Institute, and Alban Sauret, a mechanical engineer at the University of California, Santa Barbara, re-created this process in the laboratory to tease apart the factors that affect growing bubbles' shapes and sizes.

As Thiévenaz explained during a presentation at an American Physical Society meeting, the researchers observed that ice bubbles are never spherical but instead elongate in the direction of freezing. The researchers found that an ice sample hosting many small, slightly elongated bubbles suggests a high freezing rate and a high gas concentration, whereas a sample with a few larger, longer pores froze more slowly. These variations are predictable mathematically: "We can match most bubbles with the same equation," Thiévenaz says. If you know a sample's freezing rate, you can work out the gas concentration, and vice versa. Their equation predicts that long, cylindrical ice-bubble "worms" will sometimes grow unchecked, weakening the surrounding structure.

Environmental ice tells a story about the past, but determining past freezing conditions is tricky. Thiévenaz and Sauret say that making inferences based on bubble shape could be a boon for researchers studying lake ice and glacier cores. Erin Pettit, a glaciologist at Oregon State University, agrees. "I've always been puzzled by the wormy bubbles in pockets of refreezing water within glaciers," she says. "It's exciting to see the physics behind their formation."

Additionally, many engineers favor porous solids for certain applications because of their light weight. By controlling gas concentration and freezing speed, scientists could theoretically dictate a material’s pore shape, leading to strong and light metals, glasses and ceramics, the researchers suggest.

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