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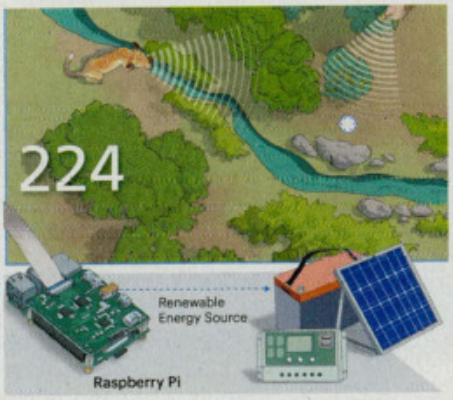
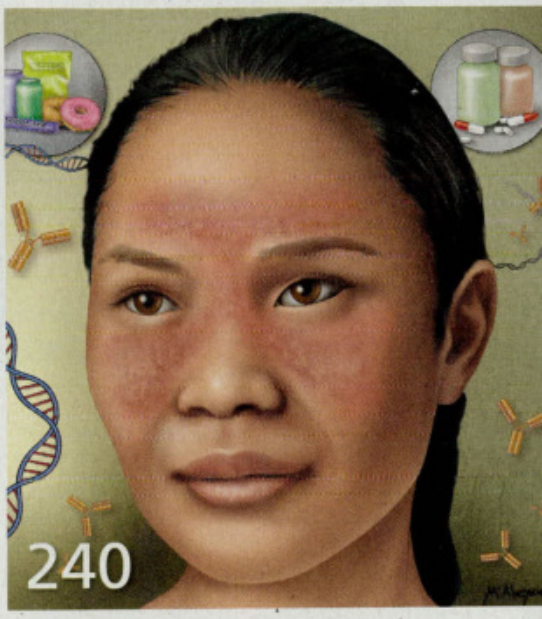
Scientists' Nightstand

From Sigma Xi

Feature Articles





The Cover

Unseen animals can often still be heard. That's part of the impetus behind the growing field of ecoacoustics, which aims to measure entire soundscapes in different habitats as a way of gauging an ecosystem's health over time. Becky E. Heath and her colleagues have been particularly interested in studying the tropical rainforests of Malaysian Borneo, as shown on the cover. But first, as Heath details in "The Ecoacoustics of Forests" (pages 224–231), they have to be able to make reliable, high-quality, directional recordings. Heath and her colleagues have been working on a spatial recording device, shown at center, which incorporates multiple microphones that each can pinpoint the direction from which a sound originates. The microphones also operate without any recording delays that would cause error in calculations of sound distance or direction. Working with animal sound databases and machine learning technologies, Heath and her team have shown that their recordings can be used to estimate species abundance in different areas. (Cover art by Beatriz Ortiz.)

Your Science Is Important

Caught in the Moment Photography

Tallies vary, but it appears that recent terminations of grants issued by the National Institutes of Health, the National Science Foundation, and other federal agencies number in the thousands and amount to billions of U.S. dollars. Many scientists who have been swept up in these terminations have been posting online about their research that has been cut short. A common thread from these posts is that there is little public understanding of the level of oversight that goes into both grant proposals and grant management. As one researcher posted on social media, "I feel like some people must think that grants are like medieval patronage arrangements or something. Like we just show up with an open burlap sack and they shake a lot of money into it, and we go away and do whatever we feel like doing."

The reality, as those working in science know well, is that researchers invest immense time and work into crafting grant proposals, which go through a grueling review process before they are selected. Then awardees are required to provide accounting for all funds, as well as to submit reports about the work conducted with the grant funding.

That gap between public perception of research and research as it is actually performed is one of the points made in this issue's Science Policy column by David Shiffman, "'Why Are We Funding This?'" (pages 220–223). As Shiffman writes, "Long before a public dollar goes to a research project, a whole team of experts in this kind of work must pass judgment and decide that it is important and worth funding."

Shiffman goes on to discuss how some scientific studies taken out of context can be made to sound frivolous, but many kinds of basic science research have led to surprising and transformative discoveries. There was no way to know up front which study would lead to that kind of success, however. "We therefore need to attack problems from many different angles, knowing that some approaches will fail," Shiffman notes. Training upcoming students to think like scientists, Shiffman adds, means supporting wide-ranging scientific curiosity, free thinking, and problem-solving.

The work being done by every researcher is important to the overall health of the scientific enterprise. At *American Scientist*, we have always looked for ways to increase support and visibility for scientists. Expanding on that tradition, we are opening up our Letters to the Editors page to any researcher who would like to share with readers why their research is important. If you have had your funding affected, if you are feeling like people aren't aware of how deeply scientific research is being undermined by sudden funding changes, or if you want to help increase understanding of what is at stake and why research matters, please consider writing in with your own research story.

Please keep your letter submissions to no more than 300 words. Let us know if you would like us to keep your letter anonymous, or if you are comfortable sharing your name, location, or both. Please note that as a nonprofit, *American Scientist* is not permitted to endorse any specific legislation or candidate, but we can support evidence-based science policy, so please keep your submissions nonpartisan. Focus your submission on why your work is important, effective, and worth carrying out. Send your submissions to editors@amscionline.org with the subject line "Science Is Important." Submissions may be published in print or on our website, and may also be featured on social media.

We hope that you will take the time to publicly describe your research. We know that your science is rigorous and meaningful, and others should know that as well. —*Fenella Saunders (@fsaundersamsci.bsky.social)*

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Origins of Consciousness

To the Editors:
In "Consciousness: The Road to Reductionism" (March–April), Alan J. McComas presented an interesting history of research on neural activity and its relationship to consciousness. The key issue is whether a reductionist view of the brain as pure biology—which for some extends to questioning whether humans possess free will—is better than earlier syntheses in which some nonbiological entity (such as a soul or psychic energy) is the source of consciousness. Although McComas often uses qualifying phrases such as "interpreted by some," I suspect that he favors the reductionist viewpoint by the absence of arguments as to why it might not be right.

I'm not supporting the idea of a nonbiological entity, but I would suggest that biology may still be able to provide an explanation of why humans overwhelmingly think that they possess the ability to make decisions that influence future events. I accept that the deterministic alternative may be true, but if it is not, then the adoption of a fatalistic attitude may lead to suboptimal decision-making.

It's easy to see why a random mutation in the brain that led to decision-making would provide an evolutionary advantage. It's harder to see why a mutation that led one to believe in free will when it didn't really exist would be advantageous. I'm unlikely to give up on free will until a good biological explanation is provided of how innovation and creativity arise without intent.

Stephen L. Brown
Alameda, CA

To the Editors:
Alan J. McComas has laid out with great clarity the reductionist's perspective on consciousness. That clarity permits one to examine the perspective's strengths considering that *consciousness* remains undefined and there is a more parsimonious perspective for explaining what is more accurately referred to as "behaving consciously."

By concentrating on the brain to hopefully reveal the neural structures that explain consciousness, what is overlooked is the human organism that is said to be conscious. It is the living organism that reports that it is conscious of something—that is, there is no consciousness in the abstract.

The cumbersome model composed of sensation, perception, memory, and information processing ignores the living organism interacting with the environment. The organism responding to the social and physical environment produces effects that research has repeatedly shown can result in new behavior as well as increasingly complex antecedent–behavior–environment relationships.

When the response-environment contingencies are of a particular character, a person acquires responses that we call *conscious*. Rather than searching for consciousness in the brain, we can observe the characteristics of behaviors that we define as conscious. We can then examine the environmental circumstances that encourage the person to behave consciously and discover the consequences to strengthen and maintain conscious behaviors.

Continued neurological research is to be valued in its own right. But the search for how we become conscious requires investigation into environmental contingencies that lead to learning such responses. Neural correlates are also present, but they are not a sufficient explanation on their own.

Robert Jensen
Carbondale, IL

Dr. McComas responds:
I agree with several of the points Dr. Brown and Dr. Jensen raise. On one point, however, I will not budge—consciousness is entirely a product of the brain (or its counterpart in invertebrate nervous systems). Consciousness has functional value, as would be expected of any life feature that, during evolution, has become ever more prominent.

In the case of free will, it is true that we can nearly always find a reason for an action or thought, namely something we have seen, heard, read about, or imagined. On the other hand, consciousness, though a product of neurons, influences their further activity. As an example, conscious images of possible actions and their consequences will determine the next phase of neural activity (an apparent choice based on the pleasure or discomfort associated with the imagery). More than that, consciousness provides us with memory, justifies our actions,

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Now in its third decade, the American Scientist *lunchtime seminar series,* Science by the Slice, *invites scientists to share and discuss new results. Below are summaries of two recent talks, now available on our website as videos with social media highlights.*

When to Trim Up Your Garden
Hannah Levenson discusses new data that show at what time of year bees take up residence and lay eggs in woody plant stems, providing new advice on when it's safe to trim back dead plants while still providing pollinator habitat.
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Environmental Change and Indigenous Rights on the Swamp
Ryan Emanuel discusses his book, *On the Swamp: Fighting for Indigenous Environmental Justice* and his hydrology research related to the Lumbee people and their Indigenous neighbors.
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and gives us the indispensable illusion that we are in charge of ourselves.

I agree with Dr. Jensen that consciousness is a property that the nervous system learns following receipt of information from the internal and external environments. In other words, consciousness is acquired rather than an innate feature of the fetal and neonatal nervous systems. Dr. Jensen's point that "neural correlates may be necessary but they are not sufficient" is the "hard" problem of consciousness—the mechanism whereby impulse activity in neurons is transformed into our thoughts and sensations. Not only have we neuroscientists not solved this problem, but it is impossible to conceive of the basis for a solution. Though that response may be seen as a cop-out, I wonder whether, given the underlying neural activity, consciousness is a natural phenomenon—making it a fact rather than a problem.

Finally, an apology for an error that somehow crept into the text of my article. Subjects in the Los Angeles concept cell experiments viewed an image on the computer screen for a second rather than a minute.

Quantity and Quality

To the Editors:
Publishing is an integral part of the job and the joy of doing science. I still recall the thrill when invited to publish findings from my doctoral dissertation in *Scientific American*, which I had read since I was a teenager. Combining published Dryopithecine tooth dimensions and molecular data, I hypothesized shifting the ape-human divergence from 14 to 15 million years ago to 6 to 8 million years ago. Three decades later, my lab analyzed MRI scans of fossil femoral fragments and found internal bone structure diagnostic of upright posture at 6 million years ago (published in *Science*, with support from a Sigma Xi GIAR). My personal experience is reinforced by much better-known examples, such as the discovery by Barry Marshall and Robin Warren that the primary cause of peptic ulcers is infection by *Helicobacter pylori*, and the invention of polymerase chain reactions by Kary Mullis. Both Nobel Prize–level breakthroughs were preceded by very few publications by the investigators.

Against this background I offer two reflections on the article "The Case for Quantity in Science Publishing" by David B. Allison and Brian B. Boutwell (May–June). First, the primary objective of scientific research is not publication but rather solving problems. Second, the quantity of publications is not a reliable indicator of the importance of the problem or of progress toward solving it.

Robert B. Eckhardt
State College, PA

Dr. Allison and Dr. Boutwell respond:
Dr. Eckhardt does not wish for quantity of publications to serve as the primary objective of science, and neither do we. We concur that continually proposing and empirically scrutinizing novel solutions to problems might rightly be seen as our primary objective as scientists. Yet the practical utility we glean from science does nothing to diminish the esoteric beauty and wonder we often experience when the last puzzle pieces on some topic fall into place.

Dr. Eckhardt argues that science is about solving problems and that only counting the number of publications would be a poor barometer for gauging success on that front, and on that point we agree. But if we think problem-solving is a process of discarding ineffective solutions in favor of better ones, it seems that the following excerpt from our essay should also be a point of agreement: "Quantity makes it easier for investigators to engage in competition and probe for weaknesses in an idea."

We sought to challenge the view that quantity and quality are diametrically opposed, and that encouraging quality must involve discouraging quantity. One will not find any objection from us to striving to improve the quality of scientific research. What readers will find in our essay are reasons why better quality will not emerge from strategies simply designed to discourage quantity.

How to Write to *American Scientist*

Brief letters commenting on articles appearing in the magazine are welcomed. The editors reserve the right to edit submissions. Please include an email address if possible. Address: Letters to the Editors, P.O. Box 13975, Research Triangle Park, NC 27709 or editors@amscionline.org.

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Systematizing Scents

Researchers have compiled the largest-ever catalog of olfactory perception to build a universal dictionary describing smells.

Poets and novelists have long lamented our lack of a language to describe smell. Attend a wine tasting, watch a cooking show, or visit a local perfume counter, and you'll hear visual terms such as "bright," "shimmering," or "sparkling." Compared with our brief olfactory glossary, our visual vocabulary, like our sense of eyesight, is vibrant and specific. We broadly agree on colors and even systematize them by wavelength, Pantone swatch, or Crayola crayon equivalent.

The authors of an olfactory perception study published in the February issue of *Scientific Data* are hoping to expand our perceptual glossary to include a full-blown dictionary of odors. A better understanding of olfactory perception could help diagnose and treat people who suffer from smell sense reduction, or *anosmia*, a potential complication during and after COVID-19 infection. A lingua franca of scents could also support research into digital olfaction (*see "Artificial Noses," January–February 2012*), which combines sensors and algorithms to detect and analyze smells. Developing such "electronic noses" is an emerging field with potential applications in the health care, food, environmental monitoring, security, consumer electronics, and entertainment industries.

But compiling a comprehensive dictionary of odors is no easy task, because smells are highly nuanced and personal. We smell scents only when molecules become airborne and waft noseward to meet our *olfactory receptors*—specialized proteins located on the cilia lining our nasal cavities—and reach our brain via the olfactory nerve.

The lead author of the *Scientific Data* paper, psychologist Antonie Louise Bierling of the Friedrich Schiller University in Jena, Germany, describes the olfactory process as "messy." "There are all these factors—culture, background, what experience I've had with this odor, what genetics I have," she says. "Genetics determines, for example, what olfactory receptors I express." In other words, experts only partly understand the link between perception and an odor molecule's composition and structure. Solving this puzzle, which researchers call the *stimulus perception problem in olfaction*, could help scientists understand why people react to smells differently.

Take benzyl acetate, a fruity organic ester. Not unlike the fictional Shimmer Floor Wax touted in the classic *Saturday Night Live* sketch ("It's a floor wax!" "It's a dessert topping!"), benzyl acetate is used in fragrances and flavorings as well as in solvents. When study participants sampled the scent of it, they split over whether it smelled like bananas or nail polish remover. "There's no true answer to the question," Bierling says. "The smell of the molecule is the smell of benzyl acetate."

Study participants split over whether benzyl acetate smelled like bananas or nail polish remover.

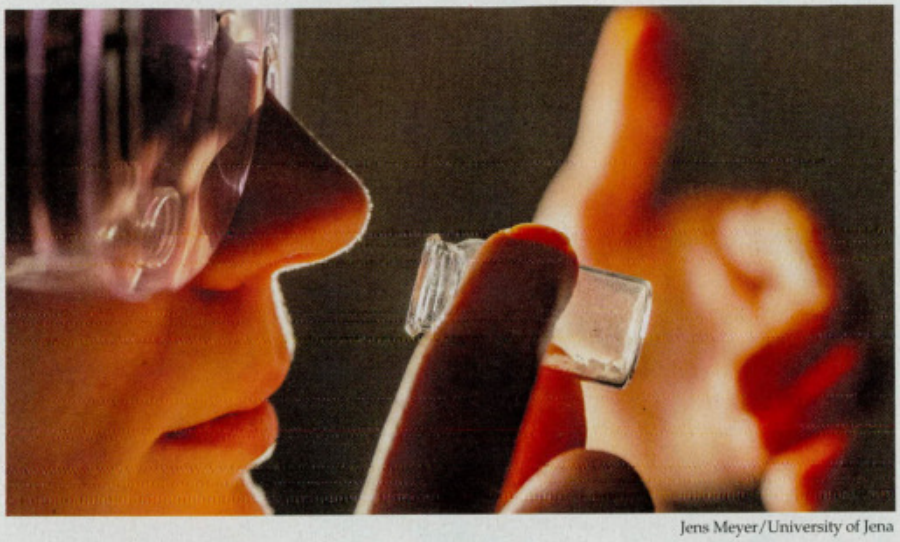
This unsettling lack of a one-to-one link between odor molecules and the associations and experiences they evoke in humans underlines how factors such as culture and experience affect what we smell—or even if we smell anything at all, as Bierling learned from a colleague: "We had one odor that, to our German fellows, just smelled like nothing," she said. "I gave it to our Chinese colleagues, and they said, 'Ugh, take it away!' For them, it smelled like a cheesy, milky, rancid odor."

Our tendency to react viscerally to some smells likely stems from the survival value of detecting unseen dangers. Unlike other senses, our olfactory sense determines immediately not only whether we recognize a smell, but how we feel about it. And unlike other senses, smell bypasses the thalamus—which usually processes sensory and motor information—and makes a beeline to brain areas governing emotion and memory, such as the amygdala. This emotional response fulfills an important aspect of each of smell's three chief functions: finding safe, nutritious food; avoiding environmental hazards; and aiding social functions such as mating.

Understanding how such an evocative yet elusive sense works requires researchers to overcome significant obstacles. Language ranks high on that list. After all, how do you study something when you lack a basic lexicon for asking questions, designing experiments, and interpreting results?

Perfumers rely on their training kits and fragrance wheels; sommeliers turn to their *nez du vin* boxes of vials and flash cards. Studies of odor have utilized terminology from both fields. But given the jolts of emotion and flares of memory fragrances can trigger, and considering people's remarkably variable reactions, Bierling and her colleagues wanted to devise something more universal and data rich. "If you think about a wine taster telling you about a good wine, of course they're not wrong," Bierling says." But if you ask 10 of your friends, if they're not wine experts, they'll probably have something different to say than that wine taster. It's a similar thing in olfaction." So the team created a test anyone could take—one that would capture not only responses to well-established descriptors in the research literature but also open-ended responses.

The design was deceptively simple: In Germany, 1,200 young adults each received a kit containing 10 small vials—eight holding different scents selected at random from a set of 74 odors commonly used in industry and research, and two containing "anchor odors" placed in every odor set. The latter were benzyl acetate and 4-decanolide, which emits a fruity peach or apricot fragrance. These two odors, which research shows are detectable even in people with a reduced sense of smell, provided a base-



Jens Meyer/University of Jena

Study participants each received 10 small vials to smell and comment on. Eight held randomly chosen aromas from a set of 74 single-molecule research scents, and two contained baseline "anchor odors" for comparing groups and guarding against potential systematic problems. The authors hope to establish a common glossary of smell based on established categories and open-ended responses, to support olfactory research and communication.

line for comparing groups and guarding against potential systematic problems, such as if one kit contained nothing but unpleasant odors. Bierling says testing all 74 odors on all participants would have taken an impractical amount of time and money. "But I still wanted to have something to compare, kind of a baseline," she says.

For consistency, the researchers balanced quantities against concentrations so that each smell would pack a similar punch. To simplify analysis, they chose *monomolecular* fragrances, which require only a single, isolated chemical compound to produce a scent. They also randomized the vials so people who received the same group of 10 did not sample them in the same order.

By the end, and following a few evaluations, at least 120 of the participants had sniffed each odorant. Around 70 percent performed the experiment at home, whereas 20 percent did so in the lab. Another 5 percent participated in a retest study involving six random odors one week later. For comparison, the team also recruited 120 people who had reduced olfactory performance.

Participants ranked the smells from "not at all" to "very" on eight provided terms such as "pleasant," "irritating," and "disgusting." To improve comparability with past research, the authors also asked subjects to choose "yes" or "no" from a list of 16 qualitative labels created by neuroscientists Andreas Keller and Leslie B. Vosshall of The Rockefeller University in New York City, in their 2016 study of nonexpert olfactory perception. These included terms such as "fruity," "musky," "fish," and "grassy."

First, though, participants were asked to describe the odors in their own words, which the researchers then standardized by isolating and grouping descriptors.

Unlike other senses, smell bypasses the thalamus and makes a beeline to brain areas governing emotion and memory.

They also retained more specific phrases ("old people perfume") and brand names ("Colgate toothpaste") as needed. Then came the challenge of translating the standardization from German into other languages. "This is not trivial," Bierling says. "In German, we have five or six terms that all kind of translate to 'pungent,' but with different qualities. We try to map them to 'stinging' or 'biting,' but it's hard. Sometimes it doesn't map one-on-one. You don't want to lose a degree of resolution."

After all, their study sought not to uncover some physiological mechanism but rather to sketch the rough outlines of an olfactory Rosetta Stone. Consequently, the paper's chief findings focused on ensuring the results were internally valid and consistent with prior research. For example, the authors found a strong resemblance between their findings and the patterns reported by Keller and Vosshall regarding how participants rated a set of shared smells in terms of pleasantness, familiarity, edibility, and intensity. However, respondents differed when rating substances for warmness—an inconsistency Bierling also saw among participants who took retests. "That makes sense," she says. "Most participants didn't really know what 'warmness' in an odor is. We tested it because it's a trigeminal perception—something that might be from the trigeminal nerve."

The trigeminal nerve contributes to *somatosensation*, an overlapping subsystem of our sensory nervous system that helps us relate to our environment. Whereas the olfactory nerve provides pure smell information, such as the scent of a flower, the trigeminal nerve detects the burning, cooling, or tingling sensations from chemical irritants such as ammonia or menthol (*see "Perfume or Noxious Fume," September–October 2024*).

The participants who retested the same smells a week or so apart were highly consistent when assigning terms such as pleasantness, edibility, and disgust; they were only moderately less consistent in rating warmness, coldness, and intensity. The two chemicals that saw people change their minds the most during the retest were the anchor scent 4-decanolide and allyl caproate, which puts off a fruity pineapple scent.

But to get to reliable digital olfaction—using sensors, signal processing, and machine learning to electronically mimic human olfaction—Bierling says her colleagues need to pay more attention to the wide variation of smell perception among humans instead of eliminating such variation as statistical noise. "This is actually the data we need. If we want electronic noses and digitization of olfaction at some point, then we need to know if 40 percent say this smells like banana and 60 percent say it smells like nail varnish remover, not what it smells like to a panel of 10 trained individuals who have a list of 20 categories we gave them in advance. That doesn't get us to a digitization of olfaction."—*Nicholas Gerbis*

Deepwater Hydrothermal Vents

In 1977, scientists studying an ocean ridge near the Galápagos Islands discovered fissures in the Earth's surface that emit geothermally heated fluid. Continued study has revealed that these hydrothermal vents are found worldwide in volcanically active areas where tectonic plates are spreading. The temperature of the vented fluid can exceed 400 degrees Celsius, but the deep ocean's extreme pressure prevents it from boiling. Ecosystems form around these vents despite the harsh conditions, which researchers had previously thought would prohibit life.

Hydrothermal vents form the base of the ocean food chain

hydrogen sulfide $6H_2S$ + water $6H_2O$ + carbon dioxide $6CO_2$ + oxygen $6O_2$ → glucose $C_6H_{12}O_6$ + sulfuric acid $6H_2SO_4$

chemosynthesis
(the microbial process of creating sugars from chemical reactions)

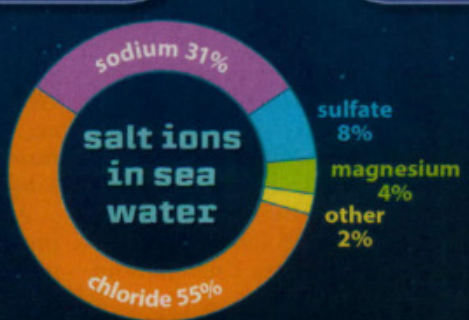
microbes

tube worms
consume the microbes

vent crabs
consume the tube worms

fish
consume the vent crabs

Mineral-laden water, heated by magma deep within the Earth, flows out of the sea floor from chimney-like structures called *black smokers*. Microbes convert the fluid into energy through chemosynthesis.



Smart Urbanization


Yale University

The world population continues to grow, and to migrate toward urban areas. To study how these trends affect land use changes and to forecast urban expansion, Karen C. Seto, the Frederick C. Hixon Professor of Geography and Urbanization Science at the School of the Environment at Yale University, integrates remote sensing, field interviews, and modeling methods. She is an expert in satellite remote sensing analysis and has pioneered methods to reconstruct historical land use. Seto's research has generated new insights about the interaction between urbanization and food systems, the effects of urban expansion on biodiversity and cropland loss, urban energy use and emissions, and urban mitigation of climate change. She was the coleader of the urban mitigation chapter for the Intergovernmental Panel on Climate Change (IPCC) 5th and 6th Assessment Reports. She is also the coauthor of City Unseen: New Visions of an Urban Planet *(Yale University Press, 2018). Seto is a 2025–2026 Sigma Xi Distinguished Lecturer, and she spoke with editor-in-chief Fenella Saunders about her work. (This interview has been edited for length and clarity.)*

What do you think are the overall goals of your research?

I'd say the big, overarching goal is to understand the process of urbanizing, not thinking about cities as places. How does urbanization affect the planet? Not in one place, but at the planetary scale. And are there ways in which urbanization could be better for the planet? I mean that very generally—everything from biodiversity to food production to energy and climate change.

Could urbanization concentrate human activity in a way that would be more efficient?

For me, the better question is: What are the pathways that are less harmful? So it's not necessarily efficiency, but does it do more good than bad? And here I'm very interested in multiple outcomes and trade-offs. For example, urbanization will require land. You need to put people on land, and we can put them in very dense settlements. But even if we talk about density, there are different layouts, different types of materials. Four-story buildings are pretty dense. Walkable cities are very dense because you don't have a lot of room for cars. Those layouts offer a lot of health benefits, and they offer a lot of environmental benefits because they save land for nature, they reduce the "sprawl" aspect of urban development. But at the same time, very high-density development could have trade-offs, for example, by creating urban heat islands or reducing pollution dissipation.

In terms of trade-offs, is there a point at which the density is the most beneficial in terms of the size of the buildings?

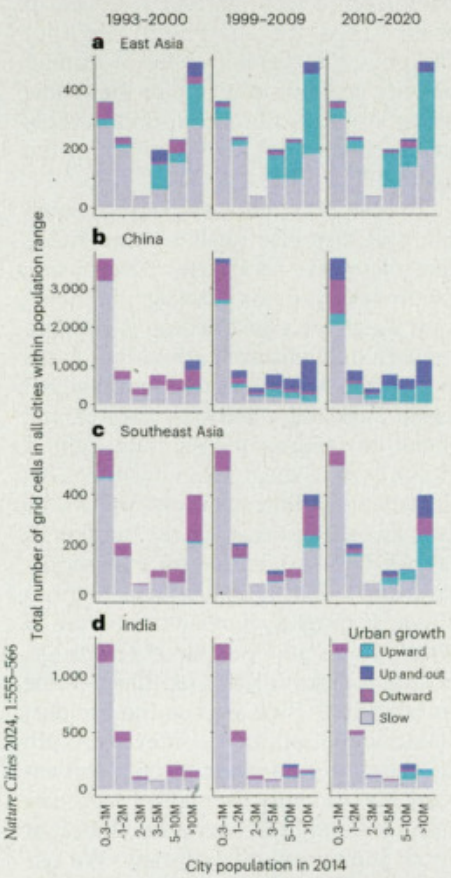
I draw on a lot of other research in this area—from design, from building engineering—and it depends on what your trade-offs are. I mentioned four-story buildings because they don't need to have an elevator. If you think about the material and energy requirements of a four-story building, you're still using human mobility, and it's better for our health. Four-story buildings can be smaller in size, so you've got a smaller footprint. The smaller footprint allows for shops, possibly on the ground floor. Think of Paris as a city with a lot of four-story buildings and people walking around. Tall buildings actually take a lot of energy. They cause pushback in different parts of the world where people don't want their city to look like that. I want to dispel the notion that dense has to be tall. Dense could actually be shorter—but not short.

Your 2024 *Nature Cities* paper found that building has increased in height faster than in outward spread. How did you use satellite data to find that?

The overarching idea behind using satellite data is to better characterize the process of urbanization in four dimensions. The first dimension is, of course, lateral growth, this outward dimension. Then there's vertical growth. There's more volumetric growth, so size and shape. And the fourth dimension is how that's changing over time. We use a variety of data. Some are more radar-type data that tells us something about the verticality and volume of structures. These structures are primarily buildings, but not always. We use nighttime light data to look at lights at night. That tells us a little bit about energy and energy availability. For instance, I just got back from a week in Sierra Leone in West Africa. It's a city with not a lot of lights, but certainly a lot of human activity, so lights don't tell us the whole story. We also use optical data, visible and near-infrared, to tell us about the vegetation in cities.

We use data from the Landsat satellite, and then also satellite-based radar, like microwave backscatter. It's an active microwave, it sends out a signal. The return signal for a tall building is going to be very different from a building that's very short. And so it's that return signal on the backscatter that tells us something about the volume, the general height. It doesn't tell us the number of stories. It's actually very difficult to compare and to give an exact estimate on the number of stories, because that varies by country, city, and building code. What we can say is, it gives us a relative measure of the volume and height of buildings. So the backscatter tells us that volume information. Then we use the Landsat data, which tell us the lateral growth by showing land cover, or land conversion. It's primarily the mid-infrared that tells us whether it's more vegetation or more human-made materials. We use all these different types of satellite data together to better characterize the structure of urbanization.

Is there also regionality to this growth?
What we're seeing with this time-series data is that Chinese cities that grew up primarily in the early 2000s are still continuing to build in an upward fashion. We think of Chinese cities as very tall: There's a lot of building structure, a lot of tall buildings. I think what was surprising for us was to see, for example, places like Southeast Asia and also in India, where there's not a lot of verticality in the development. Our economist friends tell us that verticality tells us a lot about land prices and about the kind of industries. You're not going to get manufacturing in buildings that are 30 or 40 stories tall. They primarily are services, financial sector, and residential. So it's quite a different economic mechanism happening on the ground, which we can actually see from space. What we're seeing here complements population estimates from the United Nations. The UN generates these population estimates for cities around the world, but it doesn't tell us how people are configured. That configuration, that structural, built environment aspect, is the value of using the remote sensing. Because a city of 5 million people with a low density and buildings that are disconnected and expansive is very different than a city of 5 million people in four-story buildings or 30-story buildings.



Satellite data show that urbanization over recent decades in China and Asia has grown upward while India has grown laterally.

How do all these data help you forecast urbanization?
We've developed a number of different types of models to predict urban growth in the future. The models we develop are at the global level. We're really trying to understand globally where we see different patterns, spatial patterns, temporal patterns of growth. We use historical trends that we can see from the satellite data to then predict into the future.

Your results particularly show an increase in urbanization in Africa?
Yes, which really corresponds with what the UN estimates suggest, that a lot of the new urban population growth will happen in Africa. What we're seeing in our models is that this population growth will come with built environment growth that is likely to be expansive, not a lot of tall buildings. But we're also seeing that cities in India in the coming decades are going to get taller, though not to the height that we see in Chinese cities. Part of what our models do is they estimate the probability that an area will become urban. And so there are a lot of places in the world where there's a positive probability that it's going to be urban, like 25 percent probability that it will be urban. But that is actually low-density or low-intensity urbanization, such as shorter buildings. Think of a land area where you would see both buildings and maybe some vegetation. This is where you see really expansive development as opposed to concentration of buildings.

How does your research show that increased rainfall could impact some of these urbanizing areas?
Many people know about urban heat islands, where urban areas are warmer than rural areas. There is an emerging and rapidly growing literature that shows that urban areas also create their own precipitation patterns primarily through convective rainfall. The mechanism is about the same around the world, but where the rainfall happens differs. In many parts of the world, the increase in rainfall happens south of the city. But cities are creating their own microclimates primarily through four mechanisms. One is the anthropogenic sources of heat—think air conditioning, cars, motorbikes. There's also the thermal mass of the built environment: All the buildings and concrete absorb heat during the day and release it at night. There's also the amount of vegetation and the change in evapotranspiration. That's a really big factor here, because if you have a city with little vegetation, there's no deep infiltration into groundwater, and a lot of the water runs off. Then the fourth factor is urban form—not only the materials, but the structure of the buildings. Think of very tall buildings creating microclimates in urban canyons. How many times have you walked on a street in a city and it's like a wind tunnel? It's because the wind hits those tall buildings and continues down to ground level. The built environment, through these four different components, shapes local climates.

Could increased levels of rainfall possibly increase flooding?
Absolutely. I think there are two different factors at play here. One, you've got global climate change, which is primarily driven by greenhouse gas emissions, and you've got warmer temperatures. Warmer atmospheres hold more water. Then you've got cities creating their own microclimates, and especially cities that have high levels of impervious surface. There's no place for the rain to go, so you see this extreme flooding.

Your research favors low-tech solutions, for which the barriers are more related to policy?
Policy and behavior, actually. It depends on what problem we're trying to address. Let's say we're trying to address the issues of transportation pollution and also urban greenhouse gas emissions. One of the biggest sources of urban greenhouse gas emissions is urban transportation. If cities were configured in a way where people could walk to work, or take transport other than your own private car, that would be better for your health and it would reduce urban greenhouse gas emissions from transportation. That's a low-tech solution. In many parts of the United States, it's difficult to bring commerce to where people live. Think of a more traditional single-family home, residential suburban community in the United States. It's very difficult to bring jobs to those areas, but you probably could. It doesn't have to be big jobs. It could be supermarkets. It could be banks. It doesn't have to be big foot-

Nature Cities 2024, 1:555–566

print stores. At the same time, we could bring housing closer to where there are a lot of jobs and commerce already. There are already downtowns, urban centers all across America, where there are the hardware stores, the supermarkets. You could build housing on top of it, reducing the need to drive.

Do you think it's possible to have United Nations–level global policy on urbanization?

The idea is not one urbanization policy that would be uniformly applied around the world. The idea is that urbanization is one of the biggest trends in the 21st century, and there is a discussion at the international level about how different types of urbanization lead to social and environmental outcomes. We know that urbanization has an effect on biodiversity, microclimates, the economy, social health. It clearly links to every single one of the UN Sustainable Development Goals. And yet there isn't a discussion at the highest level, at a global level, about what strategies have less negative effects, have more positive outcomes, and are more effective in different parts of the world. In Sierra Leone, for example, the policies that are going to be effective are very different from New Haven or San Francisco.

Do you have any insights about the development of better materials for constructing medium or taller buildings?

There's a lot of innovation in building science in the use of *mass timber*. There are many different kinds of mass timber. Some of them are laminated and developed in a way that is incredibly strong. You're not just using the raw timber, going to the lumber yard and getting a two-by-four and building a 30-story building out of that. These are special wood products, but it is a renewable resource and it doesn't have the carbon content or thermal mass of concrete. You're designing cities or buildings that don't absorb as much heat as concrete. My colleague Alan Organschi is one of the world leaders in this area. Another really interesting area is using biomass. My colleague Mae-ling Lokko is looking at how we can use coconut husks. In the Global South, they eat a lot of coconuts, leaving lots of coconut husks. How can we use the coconut husks to create building materials? Lots of exciting work here.

Another factor is that concrete requires sand, and there's a global sand shortage. We are seeing in places like in Africa that there's a big demand for concrete. There's a very strong cultural predisposition for concrete because it is "modern." There's therefore a huge demand for sand, and beaches are getting gutted out, eroded, because people are mining sand. And it's not only beaches, but rivers and other land. If we're going to accommodate another 2.5 billion people in urban areas globally, we need to rethink the materials that we use to build cities, and how we lay them out. It's very clear that we cannot build future cities the way that we've designed and built them in the past.

What would you like people to keep in mind about future urbanization?

Urbanization is a big trend. People are moving into cities, but not necessarily big cities. One of the questions I was asked a lot during the COVID-19 pandemic was: Is there detrending against urbanization? But people are not moving into rural areas. They are still moving into smaller-sized cities. I think the question is how we can urbanize in ways that are more beneficial to human health and to planetary health. ■

In this roundup, associate editor Nicholas Gerbis summarizes notable recent developments in scientific research, selected from reports compiled in the free electronic newsletter *Sigma Xi SmartBrief*: www.smartbrief.com/sigmaxi/

First Shark Sounds Heard

Scientists have documented the first case of a shark purposely making sounds. The event occurred during a hearing study of 10 New Zealand rig sharks (*Mustelus lenticulatus*). While being handled underwater, the sharks made loud clicks across a wide frequency range and reached

Paul Caiger

a peak that would be audible to many marine mammals. Elasmobranchs such as sharks, rays, and skates have long been considered silent, making noises only while eating, swimming, or colliding. That view began to change in 2022, when divers in Indonesia and Australia noted that two stingray species made clicking noises as they approached. Rig sharks are small predators that dwell in shallow coastal waters and feed on crustaceans and sea worms. Fish make sounds in a variety of ways, from using their swim bladders as drums to *stridulating*—rubbing together hard body parts such as pectoral spines. But rig sharks have no such mechanisms, so the team led by scientists at the University of Auckland in New Zealand proposed they make clicks by snapping their flat, platelike teeth together. More research is needed to determine if the sharks click only when stressed or if they also make sounds in more natural settings for defense, warning, or communication.

Nieder, C., E. Parmentier, A. G. Jeffs, and C. Radford. 2025. Evidence of active sound production by a shark. Royal Society Open Science *12:242212.*

Galactic Counter-Spin Bias

Viewed from our Milky Way, about 50 percent more galaxies rotate clockwise than counterclockwise, according to an analysis of James Webb Space Telescope (JWST) images by Lior Shamir of Kansas State University. The deep-field observations of a much-studied area near the galactic pole could raise questions about the standard cosmological model, which assumes *isotropy*—that the universe is essentially the same in all directions at large scales. Thus, galactic spin should be randomly and evenly distributed. But the farther back in time JWST peered with its three infrared bands, the more pronounced the rotational difference became, suggesting that the infant cosmos had a spin bias, perhaps due to some mechanisms or conditions governing the Big Bang or the early universe. Such *anisotropy* might comport better with more speculative models of the cosmos, such as the notion that our universe occupies a black hole, although some critics question whether the small sample of 263 galaxies is enough to support larger conclusions. Shamir says perspective factors and Doppler effects from galaxy rotation affected the results, but not enough to alter the interpretation. He adds that the spin difference, though curious, may require no radical hypotheses to explain—just the odd, tricky physics of galaxy rotation.

Shamir, L. 2025. The distribution of galaxy rotation in JWST Advanced Deep Extragalactic Survey. Monthly Notices of the Royal Astronomical Society *538:76–91.*

Wasp with a Flytrap Abdomen

Scientists have discovered a bizarre species of extinct parasitic wasps whose abdomens resembled Venus flytraps (*Dionaea muscipula*)—the first time such a structure has been observed on an insect. Dubbed *Sirenobethylus charybdis*, the wasp was an early evolutionary offshoot of Chrysidoidea (a superfamily of parasitic wasps). The unusual feature suggests the existence of a wide array of parasitic mechanisms 99 million years ago that no longer occur. The team, led by researchers from Capital Normal University in Beijing, found 16 adult females whose abdominal segments were specialized into flaps bordered by bristle-like hairs, or *setae*, that resemble the trigger hairs *D. muscipula* use to trap insects and arthropods. The flaps were preserved in amber in positions indicating they were likely used for grappling a host, into which the wasp would then have inserted its eggs. Unlike most modern Chrysidoidea, the wasps likely were *koinobiont parasitoids*, meaning their hosts could stay alive while the wasps' larvae developed and consumed them. The wasps were

Xiaoran Zuo

found in a Myanmar fossil site famed for preserving mid-Cretaceous insects in amber, sometimes even retaining soft tissues and capturing insects in the middle of characteristic behaviors.

Wu, Q., L. Vilhelmsen, X. Li, D. Zhuo, D. Ren, and T. Gao. 2025. A cretaceous fly trap? Remarkable abdominal modification in a fossil wasp. BMC Biology *23:81.*

Proof Gladiators Fought Animals

Researchers examining the remains of a late 3rd-century male exhumed from a Roman cemetery near York, England, have found the first physical evidence of human–animal gladiatorial combat. Until now, the belief that Roman elites pitted people against animals in events ranging from mythic reenactments to criminal executions stemmed mainly from ancient writings, artworks, and monuments. In addition to signs of repeated interpersonal violence, the 26- to 35-year-old male showed perimortem trauma (injury near the time of death) on both sides of his pelvis. When the team, led by a researcher at Maynooth University in Ireland, compared 3D scans of the pelvic gouges with bone lesions left by weapons or several candidate animals, they found that they most closely matched marks made in fresh carcasses by cheetahs, lions, tigers, and leopards in zoos. The findings lend context and credence to the existence of Roman spectacles called *venationes* ("beast hunts"), which reputedly included bears, large cats, and large herbivores (such as elephants, wild boars, stags, and bulls). They also suggest that Rome once devoted enormous resources to importing and maintaining wild animals.

Thompson, T. J. U., et al. 2025. Unique osteological evidence for human–animal gladiatorial combat in Roman Britain. PLOS One *20: e0319847.*

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Welcome to Jurassic Skye

Fossilized footprints show meat-eating and plant-eating dinosaurs coexisting.

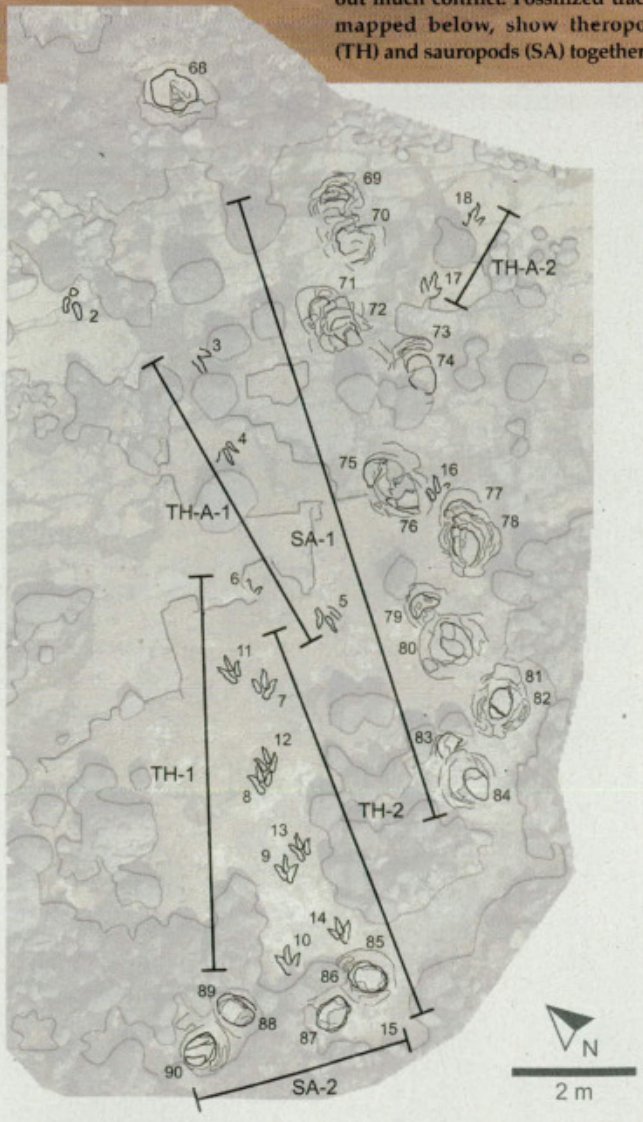
An illustration (*above*) shows a Jurassic Era landscape hosting both predator and prey dinosaurs without much conflict. Fossilized tracks, mapped below, show theropods (TH) and sauropods (SA) together.

Popular depictions of dinosaur interactions favor conflict, with plant-eating sauropods locked in desperate struggles for survival against fierce meat-eating theropods. Yet the quieter moments of coexistence were likely more common than the life-or-death battles. Indeed, prehistoric predator and prey likely drank together from freshwater lagoons, similar to how animals today congregate around watering holes, according to a recent discovery of 131 fossil footprints on Prince Charles's Point in Scotland's Isle of Skye. The discovery of the 167-million-year-old trackways at the remote shoreline, combined with advanced imaging techniques, has revealed an ancient hub of Jurassic dinosaur activity.

Although the footprints are out on the surface of the rocky beach, they weren't recognized until 2019. To image all of them, a research team from the University of Edinburgh flew a drone with a high-resolution camera across the site, which took 4,500 pictures at many angles. The overlapping images allowed the team, led by Tone Blakesley, to reconstruct the track site using a technique called *photogrammetry*.

Blakesley, a paleontology and geobiology PhD student, described the process as essentially merging the photos to create a view in three dimensions. As he explains, "The computer software which we import those images into is going to say 'Okay, so we've got this footprint that's located at this point in each set of images. Now that I know where it is in each image, I can cleverly reconstruct where it is in virtual space.'"

As Blakesley and his team reported in a recent issue of the journal *PLOS One*, they generated three different types of models. The first was a texture map, basically a single photograph of the area stitched together from all the pictures. The second type was a digital elevation model, or DEM, which represents the height of the region (*see facing page*). The third type was a contour map, which displays the elevation as well as the shape of the area using concentric rings.



PLOS One 20(4):e0319862

"The DEMs allowed us to accurately take measurements between specific points within our footprints, to be able to more accurately calculate things like a dinosaur's stride," Blakesley says. Fossilized footprints can also tell paleontologists about the behaviors and tendencies of dinosaurs within their environments, such as their preferred areas and whether they were in a hurry to get there.

The team's 3D models revealed fine-grained details of the footprints more clearly than field observations. The researchers were then able to draw track outlines to classify the footprints into shape-based groups called *morphotypes*, one for meat-eating theropods and one for long-necked plant-eating sauropods.

The sauropods, which were likely two to three times the size of an elephant, left behind large, flat, circular impressions on the beach. Their footprints are surrounded by what appear to be moon-shaped ridges, which further revealed what the Isle of Skye looked like around 167 million years ago. Skye was an island then, in the middle of the prehistoric Atlantic Ocean with a radically different climate. Steve Brusatte, a paleontologist and member of the team, says Jurassic Era Skye "was a subtropical, lush, verdant environment."

At that time, Blakesley says, "dinosaurs were walking across a thin layer of sand that was deposited over hardened mud. Whenever a sauropod walked through that sand, their feet pushed the sand horizontally across the mud and then upwards to form these wide mounds that surround each of these very flat footprints."

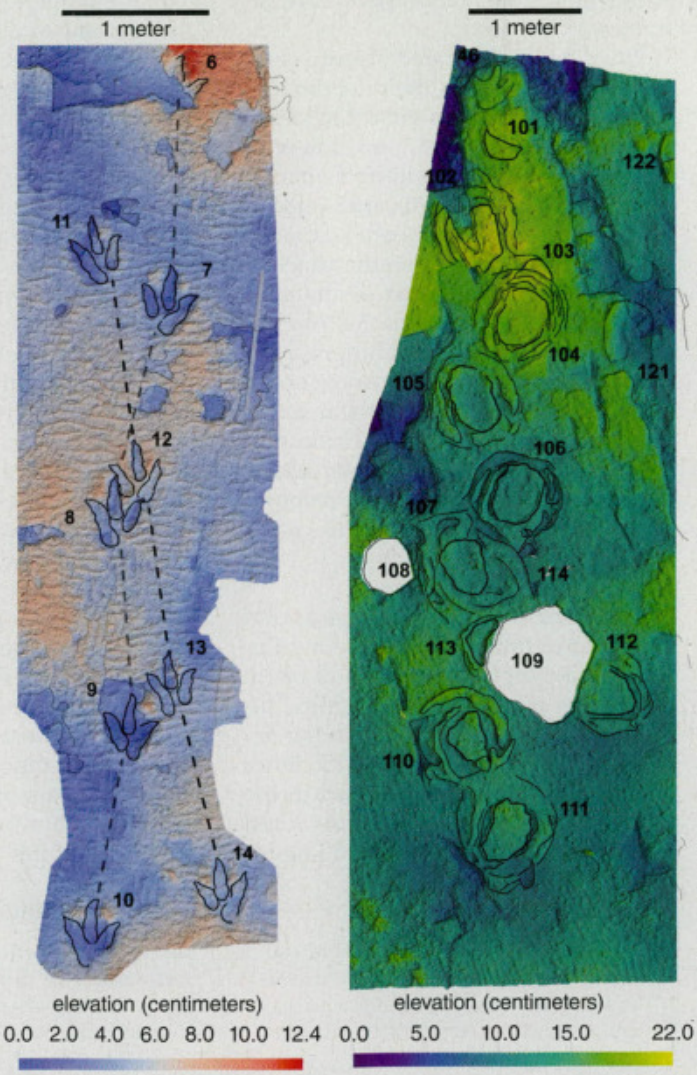
The team identified the other footprint morphotype as belonging to carnivorous megalosaurs, car-sized distant ancestors of *Tyrannosaurus rex*, of which there are scant fossils. But you wouldn't know that from looking at the tracks here. "These theropod footprints dominate these sauropods considerably," Blakesley says. "There are way more individuals represented at Prince Charles's Point than there are at any other lagoonal setting recorded on Skye." Blakesley and his team hypothesize that the large number of megalosaurs indicated their preference for freshwater lagoons, not a pack mentality.

Even though the megalosaurs outnumbered the sauropods, the modeled trackways showed no signs of dinosaur conflict. According to Blakesley's interpretation, "They were milling around. There are no chase scenes happening. There's no hunting in action. They were walking at about 8 and a half kilometers per hour, and they would have probably been in the same vicinity." As paleontologists seek to understand more about dinosaur behavior and how they interacted with one another, studies like this reveal how tracks were made and influenced by ancient environments.

The Jurassic was a period when dinosaur diversity was really taking off. By this time, dinosaurs had spread to more places around the world, growing and forming iconic physical traits such as long necks and spine plates. Brusatte emphasizes how this was a time when "so much of that underpinning of dinosaur evolution was happening in the Jurassic." Rock from the Jurassic is globally rare, making these footprints doubly valuable to the scientific community.

This remote bay is significant for another historical reason. On June 21, 1746, Scottish rebels Flora MacDonald and Charles Edward Stuart—known as Bonnie Prince Charlie—sought refuge on these shores. As Brusatte says, "Prince Charles's Point is a place where Scottish history and prehistory blend together. It's astounding to think that when Bonnie Prince Charlie was running for his life, he might have been sprinting in the footsteps of dinosaurs." —*Jameson Blount*

Three-toed footprints in the rocky beach on Scotland's Isle of Skye are about 167 million years old and were made by a Jurassic meat-eating megalosaur (*above*). They are part of a collection of 131 theropod and sauropod fossil footprints analyzed by *photogrammetry* to produce digital elevation models (*below*), representing the height of the regions, overlaid here with hand-drawn outlines. The digital elevation models were used to calculate dinosaur stride length, whereas the outlines help to classify the type of dinosaur footprints.



Tone Blakesley and Scott Reid

PLOS One 20(4):e0319862 (all 3 images)

Retraction Reactions

Scientists' responses to published errors provide case studies of practices to avoid or embrace when engaging with the research community.

Ivan Oransky and Adam Marcus

Retracted papers are uncommon in research, but as they have increased, more than 20 Nobel laureates—some 2 percent of the 1,000-plus people and organizations who have won the prize—have retracted scientific papers. Altogether, those 22 winners have retracted 41 articles.

How these celebrated scientists respond to the loss of their work from the literature reveals a great deal about the ways researchers should—and should not—handle public setbacks. Some embrace their mistakes and attempt to rectify them, others ignore the problem, and a few go on the attack in an attempt to defend their reputations.

As the founders of *Retraction Watch*, a website devoted to covering problems in scientific publishing, we know errors are an unavoidable part of the research endeavor. The responses of Nobel laureates to their retractions offer useful case studies in how best to respond when research comes under fire.

The Stigma of Retraction

In broad strokes, retractions are a solution (and definitely not the only solution) to a problem: What to do with unreliable articles in the scientific literature. The oldest example in the *Retraction Watch* database is a 1756 letter by Benjamin Wilson published in the *Philosophical Transactions of the Royal Society*. In the letter, Wilson, an English experimental philosopher, retracts a portion of his previously published treatises on electricity that critiqued the work of one Benjamin Franklin.

Despite their long history, however, retractions were extremely uncommon until relatively recently. In 2002, journals retracted about 40 papers, or roughly 0.002 percent of all published articles. A decade ago, that figure was closer to 0.02 percent, and today it sits at about 0.2 percent. Based on our experiences at *Retraction Watch* and on work by others, that percentage still does not reflect the true rate of errors in published papers and should be at least 10-fold greater.

Careful analysis by researchers going back more than a decade—including by microbiologists Ferric Fang of the University of Washington and Arturo Casadevall of Johns Hopkins University, as well as reporting by the news team at the journal *Science*—has found approximately two-thirds of retractions result from misconduct, including plagiarism, image manipulation, and the fabrication or falsification of data. The remaining third are due to honest errors, such as publishers' mistakes, legal issues, and other edge cases unrelated to the behavior of the researchers.

In other words, when journals retract papers, the odds are strong that the reason for the move is because one or more players have behaved badly. And given those odds, scientists are entirely rational when they worry about the damage to their reputation a retraction can cause.

Just as scientists fear tarnishing their reputations by publicly admitting mistakes, journal editors tend to avoid retractions as well. Some may fear that retracting more papers than other publications in their specialty might cause readers to question their editorial judgement, peer review processes, and other elements of quality control. They may feel legal pressure to opt for a lengthy correction over a retraction, for example, or to say they do not have the resources to conduct broad investigations. There is some good news: The growing number of retractions in part reflects moves by some journals to hire research integrity teams. But it also reflects the willingness of publishers to endorse—some might say cynically—a "victims of paper mills" narrative that absolves them of responsibility.

The calculus would be much different if retractions more commonly occurred for cases of honest error. Retractions might then lose a bit of their stigma and instead become part of the normal publishing process. But for the moment, at least, many publishers and scientists view retraction chiefly as a kind of "nuclear option" for sins of commission.

Responding to Criticism

Most of the 22 Nobel laureates who had papers retracted lost only a single

QUICK TAKE

Errors in research are inevitable and occur at every level of science, from students to Nobel laureates. Paper retractions are one important way to correct those mistakes.

Because most retractions are caused by misconduct, the practice has developed a stigma. Researchers and publishers are wary of issuing retractions, even for honest errors.

How researchers respond to errors and retractions in their work can affect their professional reputations. Transparency is key to overcoming the stigma of retractions.

Davide Bonazzi

Paper retraction is a rare but necessary part of research because it is the primary mechanism for correcting published errors. Whether researchers respond to retractions by trying to ignore their errors, attacking their critics and colleagues, or engaging openly with the scientific community can influence their reputation as scholars and that of their work.

article, but one Nobelist has lost 13 articles, a dozen of them since late 2022. Gregg Semenza, who shared the 2019 prize in Physiology or Medicine for "discoveries of how cells sense and adapt to oxygen availability," is a researcher at Johns Hopkins University. The retracted papers were published as far back as 2009, and all were challenged for reasons related to the duplication of data or images—reusing material to bolster a claim that might not otherwise pass muster.

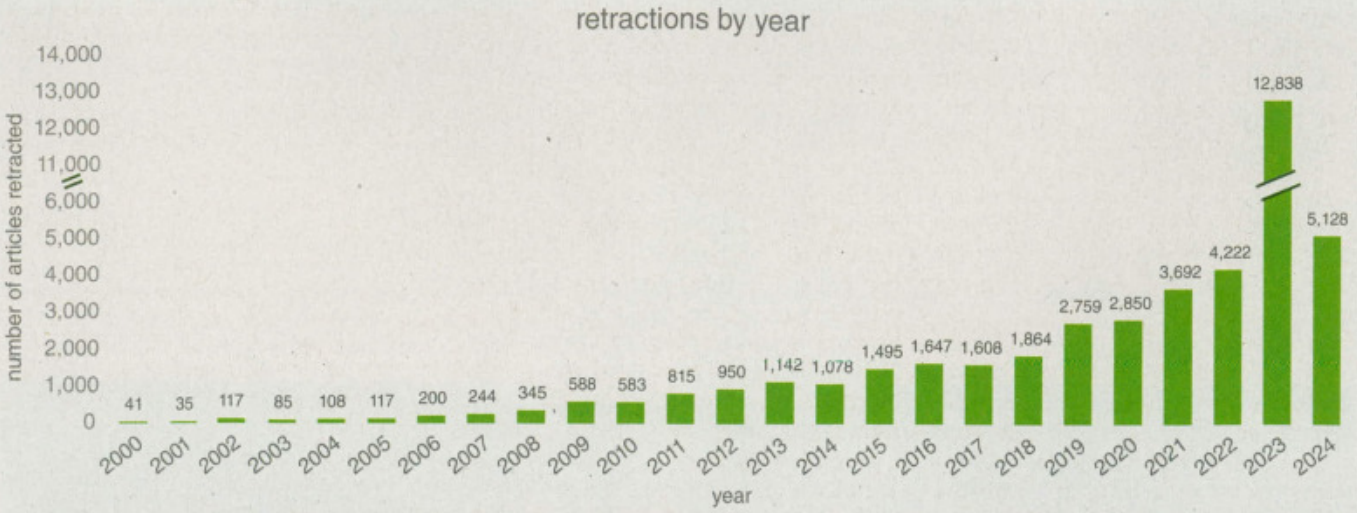
Thirteen retractions is not a record, although the vast majority of researchers have never had one paper retracted, let alone more than a dozen. And the Nobel Assembly at the Karolinska Institute, which bestows the prize, has never revoked an award. In fact, there would not seem to be a mechanism for doing so. Still, Semenza has not commented publicly on the retractions, even when asked to do so by news organizations such as *Nature*.

Semenza's lack of engagement and transparency contrasts with the behavior of another Nobel Prize winner with recent retractions. Thomas Südhof, of Stanford University, shared the 2013 prize in Physiology or Medicine with two others "for their discoveries of machinery regulating vesicle traffic, a major transport system in our cells." He has retracted two papers since early 2024, both for data aberrations related to figures.

Unlike Semenza, Südhof has engaged vigorously with critics and the media, even if not always in ways we at *Retraction Watch* would describe as constructive. In a frequently updated section of his lab website, Südhof responds directly and specifically to comments about nearly 50 papers critiqued on PubPeer, a site launched in 2012 that allows postings, including anonymous comments, about published research. About one in five retractions begin as concerns raised on PubPeer, an impact that earned the site the prestigious Einstein Award in 2024. (One of us [Oransky] is a volunteer member of the PubPeer Foundation's board of directors.)

On his site, Südhof acknowledges some errors but seems to deflect blame, saying "more than 30 students and postdocs in my lab over 20 years acknowledged copy-paste mistakes in their papers" and "many accusations against my lab actually identified copy-paste errors in collaborating labs." Südhof's responses also question the motivations of his critics and include descriptions of what he calls the "dark side to scientific fraud detection efforts." He claims on his website that "many PubPeer commenters maintain commercial websites communicating their discoveries and have a conflict of interest," a statement that is difficult to prove, because most users of the site post anonymously, and is misleading at best.

Südhof also claims, "PubPeer posts frequently exhibit a fundamentalist attitude that insists that even an accidental duplication of a control image, undetectable to the naked eye, is



Retraction Watch Database/Crossref/Stacey Lutkoski

Retractions have become more common over the past 25 years, and today about 0.2 percent of papers are retracted. The authors, however, argue that this rate still does not reflect the true number of published errors meeting the criteria for retraction, and that the rate should be closer to 2 percent. (In 2023, the publisher Hindawi—a London-based subsidiary of Wiley—retracted more than 8,000 articles, resulting in that year's outlier data.)

a major issue, demanding that science should be absolutely pure." In his second retraction, Südhof made a point of thanking image sleuth Matthew Schrag, a neurologist at Vanderbilt University who figured prominently in the story of how a major pillar of Alzheimer's disease research collapsed, but he did not thank those who had commented earlier on PubPeer about the same paper. While proclaiming the virtues of transparency, Südhof nonetheless feels the need to denigrate his critics. Still, compared with Semenza, Südhof's willingness to address his detractors publicly is refreshing.

If neither of these two heralded men should be considered paragons of transparency, another Nobelist offers a better model of how to handle mistakes in their work: Frances Arnold of the California Institute of Technology. In early 2020, Arnold, who shared the 2018 Nobel Prize in Chemistry "for the directed evolution of enzymes," announced the retraction of one of her papers even before the notice had been published by *Science*. "For my first work-related tweet of 2020, I am totally bummed to announce that we have retracted last year's paper on enzymatic synthesis of beta-lactams," she tweeted. "The work has not been reproducible." Arnold, who earned praise for being forthright, told us at the time, "I was in the middle of all the Nobel Prize hoopla and did not pay enough attention to this submission, so it is my fault."

So, what can we learn from Nobel Prize winners who have retracted papers, both about the role of retractions in the scientific enterprise and about how to respond to critics?

Embracing Mistakes

We think the defensive reflex, although understandable, is misguided. The data support our inclination. Scholars of retractions, including Susan Feng Lu of the University of Toronto and her colleagues, have found some evidence that scientists who take back their own work for honest mistakes enjoy something of a citation bump for their future publications. Other studies of the phenomenon—such as one from 2017 by Pierre Azoulay at the Massachusetts Institute of Technology and his colleagues—have shown that authors who retract papers due to fraud are, in fact, linked to decreases in their overall citation rate, but those who retract papers due to honest errors are not.

Authors who retract papers due to fraud are, in fact, linked to decreases in their overall citation rate, but those who retract papers due to honest errors are not.

Misconduct might not pay, but doing the right thing appears to. Such behavior is very much in keeping with dozens of cases that we've written about over the years on *Retraction Watch* and that we categorize as "doing the right thing." These posts tell the stories of researchers with the courage to go public about their mistakes even at professional risk. Perhaps they've ordered the wrong mice, or used the wrong reagent—real examples, by the way. Or they've just made a mistake. Despite the terror they might feel at "fessing up," they do it anyway. We should cheer.

What does this all mean for scientists whose work comes under scrutiny, particularly at a time when all of science is under the microscope by powerful forces? Earlier this year, *Science* published a thoughtful and useful guide for its authors about how to engage with the media, should the integrity of their work be questioned. Such coaching is necessary, according to the journal, given how in the current "age of growing, intense attacks on science, silence can be detrimental to both public trust and the careers of scientists who are under scrutiny."

Among the tips are a couple with which we strongly agree, particularly the admonition to "respond on substance" and not "attack the motives or standing of the people who question your work." We also like the call to avoid blaming junior colleagues. After all, as the guide notes, "all authors, and especially the corresponding authors, are all responsible for the data, interpretations, and conclusions presented in the paper."

And as journalists, we're fully behind the suggestion to talk directly with reporters "with humility"—an approach Arnold appears to endorse.

In other words, circling the wagons is the wrong tactic, for both individual scientists and their fields, particularly when scandal is involved. In these cases, aggressive transparency is far better than building walls to keep out prying eyes.

Consider the case of Jonathan Pruitt, formerly of McMaster University in Canada, a "rock star" in the field of behavioral ecology whose prolific—but in retrospect, highly questionable—fieldwork was incorporated into the work of scores of other researchers. As *Retraction Watch* and other publications reported, rather than suppress or ignore the scandal, many of the scientists scorched by Pruitt's unreliable data openly and honestly rallied together to purge his research from their own, even as he denied, deflected, and menaced his critics with threats of legal action against them.

And it wasn't only leaders in the field who had the courage to be fully transparent and retract their work. There were also relative newcomers, such as Kate Laskowski, who had recently landed a tenure-track position at the University of California, Davis, largely on the strength of several papers built around data on spiders Pruitt had provided her. "When I realized that I could no longer trust the data that I had reported in some of my papers, I did what I think is the only correct course of action," Laskowski wrote on her lab's blog in a 2020 post that became something of a landmark in scientific transparency. "I retracted them."

In other words, be more like Frances Arnold, a bit less like Thomas Südhof, and see Gregg Semenza's behavior as what not to do.

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Unrepresentative Meteorites

Carbon-containing asteroids are common in the Solar System, but they rarely reach Earth because the harsh journey can destroy fragile chemical components.

Patrick M. Shober

Much of what scientists know about the early Solar System comes from meteorites—ancient rocks that travel through space and survive the fiery plunge through Earth's atmosphere. Among meteorites, one type—called *carbonaceous chondrites*—stands out as the most primitive and provides a unique glimpse into the Solar System's infancy.

Carbonaceous chondrites are rich in water, carbon, and organic compounds. They're *hydrated*, which means they contain water bound within minerals in the rock. The components of the water are locked into crystal structures. Many researchers believe these ancient rocks played a crucial role in delivering water to early Earth.

Before hitting Earth, rocks traveling through space are generally referred to as asteroids, meteoroids, or comets, depending on their size and composition. If a piece of one of these objects makes it all the way to Earth, it becomes a meteorite.

From observing asteroids with telescopes, scientists know that most asteroids have water-rich, carbonaceous compositions. Models predict that most meteorites should also be carbonaceous. But less than 4 percent of all the meteorites found on Earth are carbonaceous. In a study we published this year in *Nature Astronomy*, my planetary scientist colleagues and I tried to answer an age-old question in our field: Where are all the carbonaceous chondrites?

Collecting Unaltered Samples

Scientists' desire to study these ancient rocks has driven recent sample-return space missions. NASA's OSIRIS-REx and the Japan Aerospace Exploration Agency's Hayabusa2 missions have transformed what researchers know about primitive, carbon-rich asteroids.

Meteorites found sitting on the ground are exposed to rain, snow, and plants, which can significantly change their composition and make analysis more difficult. So, the OSIRIS-REx mission ventured to the asteroid Bennu to retrieve an unaltered sample. Retrieving this sample allowed scientists to examine the asteroid's composition in detail. Similarly, Hayabusa2's journey to the asteroid Ryugu provided pristine samples of another, similarly water-rich asteroid.

Models predict that most meteorites should also be carbonaceous. But less than 4 percent of all the meteorites found on Earth are carbonaceous.

Together, these missions have allowed planetary scientists like me to study pristine, fragile, carbonaceous material from asteroids. These asteroids are a direct window into the building blocks of our Solar System and the origins of life.

For a long time, scientists assumed that Earth's atmosphere filtered out carbonaceous debris. When an object hits Earth's atmosphere, it has to survive significant pressures and high temperatures. Carbonaceous chondrites tend to be weaker and more crumbly than other meteorites, so these objects just don't stand as much of a chance.

Meteorites usually start their journey when two asteroids collide, creating a bunch of centimeter- to meter-sized rock fragments. These cosmic crumbs streak through the Solar System and can, eventually, fall to Earth. When they're smaller than a meter, scientists call them *meteoroids*.

Meteoroids are far too small for researchers to see with a telescope, unless they're about to hit the Earth and astronomers get lucky. But there is another way scientists can study this population, and, in turn, understand why meteorites have such different compositions.

Meteor Observation Networks

Most of the meteoroids that reach Earth are tiny, sand-sized particles, but occasionally, bodies up to a couple of meters in diameter hit. Researchers estimate that about 5,000 metric tons of micrometeorites land on Earth annually. And, each year, between 4,000 and 10,000 large meteorites—golf ball-sized or larger—land on Earth. That's more than 20 each day.

Today, digital cameras have rendered round-the-clock observations of the night sky both practical and affordable. Low-cost, high-sensitivity sensors and automated detection software allow researchers to monitor large sections of the night sky for bright flashes, which signal a meteoroid hitting the atmosphere. Research teams can sift through these real-time observations

Jeff Dai/Science Source

The Geminids meteor shower, shown here in a 2017 time-exposure image taken in Heilongjiang, China, is one of the most reliable annual meteor showers. Every December, debris from the asteroid 3200 Phaethon (possibly an extinct comet) collides with Earth's atmosphere, resulting in as many as 120 shooting stars per hour. Small rocks such as the debris from 3200 Phaethon are usually destroyed before they can reach Earth's surface. Because only large and hardy meteorites survive the journey to Earth, their mineral content is not representative of most asteroids' compositions.

using automated analysis techniques—or a very dedicated PhD student—to find invaluable information.

Our team manages two global systems: the Fireball Recovery and InterPlanetary Observation Network (FRIPON), a French-led network with stations in 15 countries; and the Global Fireball Observatory, a collaboration started by the team behind the Desert Fireball Network in Australia. Together with other open-access datasets, my colleagues and I used the trajectories of nearly 8,000 impacts observed by 19 observation networks spread across 39 countries.

By comparing all meteoroid impacts recorded in Earth's atmosphere with those that successfully reach the surface as meteorites, we can pinpoint which asteroids produce fragments that are strong enough to survive the journey. Or, conversely, we can pinpoint which asteroids produce weak materials that do not show up as often on Earth as meteorites.

Sunbaked Rocks

Surprisingly, we found that many asteroid pieces are destroyed even before they reach Earth's atmosphere. Something starts removing the weak stuff while the fragment is still in space. The carbonaceous material, which isn't very durable, likely gets broken down through heat stress when its orbit takes it close to the Sun.

As carbonaceous chondrites orbit close to and then away from the Sun, the temperature swings form cracks in their material. This process effectively fragments and removes weak, hydrated boulders from the population of objects near the Earth. Anything left over after this thermal cracking then has to survive the atmosphere.

Only 30 to 50 percent of the remaining objects survive the atmospheric passage and become meteorites. The debris pieces with orbits that bring them closer to the Sun tend to be significantly more durable than those that keep their distance. Consequently, the sunbaked objects are far more likely to survive the difficult passage through Earth's atmosphere. Because hardier meteorites make it to Earth, where they are found and studied by scientists, they are subject to *sample bias*: the mistaken interpretation of the surviving samples as being representative of all rocky objects in space.

For decades, scientists have presumed that Earth's atmosphere alone explains the scarcity of carbonaceous meteorites, but our work indicates that much of the removal occurs beforehand in space.

NASA/Erika Blumenfeld and Joseph Aebersold

In September 2023, NASA's OSIRIS-REx spacecraft returned samples that it had collected from the asteroid Bennu three years earlier. The sample contained amino acids and evaporative minerals that are rarely found in meteorites.

Going forward, new scientific advances can help confirm these findings and better identify meteoroid compositions. Scientists need to get better at using telescopes to detect objects right before they hit the Earth. More detailed modeling of how these objects break up in the atmosphere can also help researchers study them. Lastly, future researchers can develop better methods to identify what these fireballs are made of using the colors of the meteors.

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The Call of Engineering

The engineer's ethos is symbolized in rings of cold-worked metal.

Robert T. Pennock

On April 25, 1925, the first Calling of an Engineer ceremony was performed in Montreal, Canada. Six engineers pledged themselves to uphold the ethical standards and kindred spirit of their vocation. Historical documentation of the ceremony states that the Obligation, as it was called, was taken over "ancient landmarks" of the engineering profession: a machinist's hammer, a blacksmith's anvil, and a chain, all of "honorable working record," tried and tested in service. Rings made of iron, which had been cold-worked by convalescing World War I veterans, to be worn on the little finger of the working hand, would serve as a reminder of the serious responsibilities that engineers take on. A week later, 107 more engineers took the Obligation in Toronto. Thereafter, the ceremony spread across Canada.

American engineers are now invited to a similar ceremony to accept the Obligation of the Engineer. These ceremonies are held under the auspices of the American organization called the Order of the Engineer, founded in 1970. Local sections of this group are called "links," referencing the symbolic image of rings united to form a strong chain. The Order has no meetings or dues. It signifies no academic credential. Like the Canadian group upon which it was modeled, its sole purpose is to create a unifying spirit of pride and responsibility in the engineering profession and a commitment to using its expertise to contribute positively to humanity. More than 300,000 engineers have taken the pledge.

This centenary of the international establishment of the Obligation ritual is an opportune moment to reflect on the nature of engineering and the values that constitute its ethos.

The Origin of Engineering

Necessity may be the mother of invention, but no readily identifiable point marks the origin of engineering. The ancient builder Imhotep, who designed and constructed the Step Pyramid of Pharaoh Djoser at Saqqara in Egypt around 2630–2611 BCE, is often considered the first known engineer, but the simple machines—levers, ramps, and pulleys—that made such an edifice possible were invented long before. Military engineering is commonly taken to have been the first engineering profession, and it too has a deep history. The term "engines of war," referring to military devices and inventions, especially siege weapons, appears several times in the Christian Bible. The second book of Chronicles, for instance, refers to such engines "invented by cunning men" to shoot "arrows and great stones" from and at tower bulwarks. We now associate catapults and trebuchets with medieval warfare, which saw their highest development, but trebuchets were invented in the 4th century BCE in China.

Of course, technology for knocking down walls presumes the prior existence of walls, so perhaps civil engineering actually came first. The biblical story in the book of Genesis of the Tower of Babel may be thought of as an ambitious civil engineering project; human engineering prowess threatened the gods themselves, who responded by confusing human language to limit their power. Engineering was an arms race from the start. Engineers designed castle fortifications for defense as well as offense. The U.S. Army Corps of Engineers, which this year celebrates its 250th anniversary, still uses an image of an imposing stone castle with arrowslits and battlements as a symbol, with the motto "Building Strong."

The Corps began as part of George Washington's Continental Army in the American War of Independence when Congress appointed a chief engineer and two assistants. Washington quickly realized the need for more trained engineers, but there were few in America, so Congress turned to France, which had a well-established history of military engineering. Congress authorized three companies of sappers and miners to be trained by French engineers. The term *sapper* comes from the French word meaning "to dig." Sappers had to know how to build and how to undermine fortifications, sapping the strength of their foundations so walls could be breached. Their engineering expertise was also needed for laying and clearing mines. Such duties soon expanded to include building and repairing roads and bridges, and to other technical operational tasks that today would be classified as civil engineering.

Engineering and Science

As specialization has increased, the two basic categories of civil and military

QUICK TAKE

The history of engineering dates back to ancient China, ancient Egypt, and earlier, but the first known ceremony pledging engineers to their profession was in 1925.

Science and engineering go hand in hand as research helps determine the constraints and affordances that make technology possible, which further drives new discoveries.

The obligation of the engineer includes the promise to be meticulous in practice, to persevere in design challenges, and to hold the line against failure as best as humanly possible.

Wikimedia Commons/University of Edinburgh Library

An early 14th-century depiction shows the 1003 siege of a fortress in what is now northwestern Afghanistan. The fortifications are being attacked by a trebuchet, one of many "engines of war" that defined the early era of the profession of engineering. The field has developed over the millennia into a diverse array of specialties to solve design challenges.

engineering have become too limiting. Today, there is a veritable alphabet of engineering fields and subfields—aeronautical, biological, chemical, electrical, material, mechanical, and so on. I am most familiar with computer engineering, but I know only narrow areas of software engineering and little about hardware. I must rely on others to design and build the computer chips I use. Engineers develop the knowledge and methods relevant to their specialized domain, but they share a mindset in that basic engineering principles apply across the board, from the mortarboard to the motherboard.

All engineering involves the generation of technical designs to solve field-specific engineering problems. Leonardo da Vinci's innovative contraptions were based on understanding the application of mechanics, hydraulics, and other physical principles. Engineering in the modern sense began together with modern science in that it involves an understanding of scientific principles and how they may be used to manipulate materials creatively for very different purposes. Although both the Step Pyramid and the system on a chip (SoC) integrated circuit may be said to be made of sand, it takes a long chain of technical know-how to identify and engineer the component materials of various sands for those two very different purposes.

Engineering takes the laws of nature as given and seeks to use them for its own ends. The job of making something work requires understanding one's materials and the clever use of physical cause–effect relationships, which is no easy task. Johny Srouji, recipient of the 2025 Imec Innovation Award for leading Apple's extraordinary silicon development team, has been quoted explaining that basic element of the engineering challenge this way: "When people say, 'This is hard,' my rule of thumb is, if it's not gated by physics, that means it's hard but doable."

The second law of thermodynamics states that entropy—a measure associated with disorder—in a closed system cannot decrease with time. However, by marshaling other natural laws in local open systems, engineers have the chance to bring about desired order. They need science to understand the constraints and the affordances that make technology possible. Scientists then use technology to help make new discoveries. Thus, the two vocations rely on one another, but they are not identical. There are various ways to articulate the difference. Science is what we can come to know; engineering is about what we can come to build. Scientists seek answers to empirical questions; engineers seek solutions to design problems. Scientists use the scientific method; engineers use the design process. The outputs of the scientific process are discoveries; the outputs of engineering are innovations. Scientists discover the world as it is; engineers build the world as we want it to be.

The Purpose of Engineering

The root of both the words *engineer* and *engine* is found in the Sanskrit *jan*, which means begetting, being born, and being produced, from which derives the Latin and Greek root *gen*, which means both birth and origin. From these derive the French *s'ingénier*—to engineer—a mental trait that Émile Littre's late-1800s French dictionary elegantly defines as "to seek in one's genius, in one's mind, some means of success." This etymology reveals the core concept underlying the profession: Engineering is a special kind of mindset that seeks to produce practical solutions—means of success—to given problems. The ancient Greek philosophers usefully distinguished *epistemé*, which involves knowledge and understanding, from *techné*, which involves making and doing. It is from the latter term that we get the engineering notion of technology—machines and processes that can achieve desired ends repeatedly and reliably.

These conceptual roots help point us to the simplest way to state the central, guiding purpose of engineering: to solve technical design problems. The engineer's goal is to design, build, and maintain technical structures that will reliably achieve a specified purpose.

The notion of "technical structures" includes machines and other artifacts,

Kenneth Garrett; Apple

Representing the range of engineering, from ancient to modern, are the Step Pyramid at the site of Saqqara in Egypt, dating back 4,600 years (*left*), and the Apple M1 computer chip, released in 2020, with advanced system on a chip technology (*right*). Engineering continues to push the boundaries of what is scientifically possible, while maintaining the rigor that prevents failure.

but also more abstract processes and procedures. Because these structures have built-in techné, they have a degree of autonomy, which is to say that they can operate to some extent without constant direct intervention. Bakers make donuts. Engineers build donut-making machines. Think of the elaborate apparatus that is worth a special stop to watch when the "Hot Now" sign is on at a Krispy Kreme.

The notion of "specified purpose" is essential to the engineering task. The technical structure and its degree of success from an engineering point of view is the extent that it is functional, a relational notion that is judged relative to some end. Engineers may or may not set design goals. They usually work to solve design problems given to them by others. Their expertise lies in figuring out how best to achieve the purposes laid out in a specification sheet while maintaining or advancing other basic values. For example, the storied German engineering firm Siemens, which adopted the slogan "ingenuity for life" for the 200th anniversary of its founder's birth in 2016, applies that virtue in all its projects. It has proudly highlighted the technical details of how its engineers cleverly retrofitted their advanced drive and control technology into existing Krispy Kreme donut machines, contributing not only to increased uptime and mean time between failure, but also to improved safety for in-store operators.

In a much-loved story in the 1943 children's book *Homer Price* by Robert McCloskey (who was not only a Caldecott Medal winner but also a talented deviser of mechanical contraptions), a malfunctioning donut machine provides the hook for a humorous tale of unstoppable donut production. But operating complex machinery in real life is no joke, and engineers take possible dangers seriously. Reliability cannot be severed from safety. The specter of failure haunts the engineer and lies behind the founding of the Calling of an Engineer ceremony.

The Kipling Connection

The original idea for a ceremony to pledge oneself to standards of integrity requisite to the calling of an engineer was motivated by an engineering tragedy. In 1907, at least 76 people died in the collapse of the Quebec Bridge during its construction. The bridge was to have been an engineering marvel but failed due to design flaws and inadequate oversight—the fault not of faulty materials but of faulty engineers. The tragedy moved Herbert Haultain, a Canadian mining engineer and educator, to propose a meaningful way for engineers to hold themselves to the highest standards of excellence and integrity.

The original ceremony was sometimes called the Kipling Ritual, after Rudyard Kipling, the Bombay-born British writer and the first English-language winner of the Nobel Prize in Literature, who Haultain approached to help craft an appropriate ceremony. Haultain was likely inspired by Kipling's writings on the life and duties of daily workers whose labors make the world run. For example, Kipling's notable 1893 short story "The Bridge Builders" drew from his observations of the construction of several bridges in India that he had reported on as a newspaper correspondent.

The story is about builders who have nearly completed a bridge across the River Ganges (also known as Ganga or Gunga in India), only to see it threatened by a storm flood. Kipling's prose is evocative as he describes the thoughts of the engineer as he reviews the technical points of its construction, worrying whether his design can withstand Mother Gunga's seething currents. In a key section of the story, the Hindu gods argue among themselves whether to destroy the bridge; is it a threat to them? In the end, Krishna, the incarnation of the preserver god Vishnu who maintains the order of the universe, decides to let the bridge stand. Vishnu notes that Brahm, the original creator of that order, continues to sleep and dream without concern, suggesting that it is Brahm's creative passion that stirs humans to build but that, in the end, the universe itself will outlast any human constructions.

Kipling won his Nobel Prize in 1907, the same year as the Quebec Bridge collapse. He readily agreed to Haultain's request.

Breaking Strain

Kipling not only wrote the pledge but also created the ceremony and suggested the cold-worked metal ring, rough-hewn to symbolize to young engineers their yet unrefined character. It rubs the drafting board (or the computer keyboard) during the design process to remind engineers of challenges they face and the duties and growth that are required of them.

Kipling also wrote a poem to be read as the ceremony's homily titled "Hymn of Breaking Strain." The engineering concept of *breaking strain* refers to the amount of force that will cause the fracture or collapse of some component of a built structure. The first

stanza of the poem references the import of that technical concept:

The careful text-books measure
(Let all who build beware!)
The load, the shock, the pressure
Material can bear.
So, when the faulty girder
Lets down the grinding span,
The blame of loss, or murder,
Is laid upon the man.
Not on the Stuff—the Man!

The gods, the poem goes on to note, seem to have no feeling of justice regarding our own breaking strain, and they provide no textbook with measures of the loads we cannot bear. Then the poem expresses what initially seems to be a lament of the engineer's predicament.

We only, of Creation
(Ah luckier bridge and rail!)
Abide the twin-damnation—
To fail and know we fail.

Kipling's poem links the importance of understanding the technical concept of failure under stress to the character of the engineer and the need to develop the virtues of humility and resilience. This recognition and ethical commitment are reprised in the final portion of the Obligation, which begs pardon "for my assured failures and derelictions" to "my betters and my equals in my Calling here assembled," and prays that "in the hour of my temptations, weakness and weariness, the memory of this my Obligation and the company before whom it was entered into, may return to me to aid, comfort, and restrain." Like the ring, the pledge is a reminder to hold fast to the ethos of the vocation.

The Division of Moral Labor

Virtue ethics is about moral character. It asks us to consider what character virtues we ought to cultivate to be more capable of achieving our proper ends. Aristotle analyzed the virtues we should seek as human beings, but my focus here is on the narrower notion of vocational virtues—those that constitute one's normative identity in a disciplined practice. Aristotle uses the example of a martial virtue: Sailors and soldiers must exhibit courage, and their experience gives them reason to do so. I think of this concept as the division of moral labor; we are limited in what we can achieve alone, so let us split up the tasks and each work to contribute some special ethical expertise to the common goal of human flourishing.

PCStuff/Wikimedia Commons

Engineers who take an oath of obligation to their profession receive a rough-hewn ring to wear on their working hand's fifth finger.

The characteristic virtues to be cultivated by engineers are those that serve engineering's central, guiding purpose. Ingenuity and creativity are core virtues, and these are supported by others, such as humility and resilience. The reference in Kipling's poem to paying careful attention to precise measures of load, shock, and pressure point to further virtues of meticulousness and prudence.

Engineers typically do not need to embody military courage, but sappers do because their dual role as soldier-engineers requires both engineering and martial virtues. There is no better example of this combination than Rama Raghoba Rane, of the Bombay Sappers Regiment of the Indian Army's Corps of Engineers. In the 1947–1948 war with Pakistan in the state of Jammu and Kashmir, Rane led a heroic mine-clearing effort that required both courage and technical expertise. Over the course of four days, under heavy fire that killed two sappers and injured five, including himself, Rane led his company to clear a path through a series of dense minefields and roadblocks that his battalion could not pass. For this valiant, successful effort in overcoming the engines of war, Rane was awarded the Param Vir Chakra, India's highest military decoration, the first living recipient to be so honored.

The characteristic virtues that constitute the ethos of engineering similarly may need to be married to those of other vocations in driving the engines of peace. I interviewed Rane's son Pratap, an engineer himself, who runs his own engineering firm that designs and builds specialized factory machinery. His reflections on the ethos of engineering are like those of engineers I have known around the world. He emphasizes the central importance of being innovative and how that trait is supported by being observant (both of nature and in manufacturing) and meticulous. As he expresses it, an engineer's immediate purpose may be to improve efficiency or to optimize the use of materials, but the ultimate goal is to make things "that safely serve humanity and at the same time preserve Mother Earth."

Rise and Build Anew

So, what does it mean to obligate oneself to the call of engineering? It is to innovate and create order in the service of human purposes. It is to be meticulous in one's practice and to persevere in what is hard but doable. It is to accept the responsibility to hold the line as best as humanly possible against the inevitability of failure.

The sands of time will wear down all human constructions. Today's fastest silicon chip is soon rendered obsolete. The Step Pyramid still remains, but it too will eventually collapse to sand. Kipling's poem acknowledges breaking strain as a fact of engineering life, but does not see it as an unalloyed evil. Rather the poem finds a silver lining to the storm cloud that threatens the engineer's work; the poem is a *hymn* to breaking strain. It is not "in spite of being broken" but rather "because of being broken" that engineers know what their vocational ethos requires of them and can call up the power within to "rise and build anew."

Engineering is the drive to humbly but courageously battle the inexorable downward pull of entropy, if only for a time, and to build always upward. If you feel it, heed the call that ends the poem: Stand up and build anew!

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Policy

"Why Are We Funding This?"

Long-standing myths about "silly science" have contributed to the reckless slashing of government-supported research.

David Shiffman

For the first time since the modern federal research system was established after World War II, scientific funding in the United States is facing harsh cuts. These cuts undermine the core of American public health, safety, and environmental protection, but so far they have provoked only limited backlash beyond the scientific community. One likely reason much of the public seems to be shrugging off this act of self-sabotage is that the cuts have been misrepresented as a fix for waste and fraud, playing off a false but remarkably durable criticism: "A lot of the research we're funding sounds silly! Why are we funding it? Who cares about this stuff?"

Scientists hate this line of attack, for many reasons. At a personal level, no one likes to have work that they are passionate about be misunderstood and mocked. More importantly, scientists know how much thought and careful consideration goes into every funded research project. It requires tremendous time and effort simply to write a grant application, and only a tiny fraction of applications (those that get the highest ratings from independent expert peers) are selected for funding. Long before a public dollar goes to a research project, a whole team of experts in this kind of work must pass judgment and decide that it is important and worth funding. "Silly" science reliably springs from a serious motivation, with serious goals.

Still, the value of scientific research is not always evident to people outside of the relevant field. Some of the criticisms of science funding are certainly made in bad faith, but often the wider public is genuinely confused about what they are funding, and why. There's value in scientists sharing clear and compelling answers to this question, now more than ever.

Silly-sounding science is what happens when researchers do exactly what they are supposed to do, which is thinking freely and exploring new ideas with wide-open curiosity. Enabling dedicated experts to study everything and to push the boundaries of human knowledge in every direction is how vital, and unexpected, discoveries are made. The more we learn, the more we know.

Why should taxpayers in particular pay for that kind of research? Because nobody else has the capacity to fund these studies, and because such basic science has traditionally led to countless transformative discoveries that benefit us all. The attacks on "silly research" are nothing less than an attack on the academic freedom and innovative thinking that turned the United States into the world's leader in science and technology. It is imperative for those of us in the scientific community to defend that leadership.

You Never Know What We'll Discover

One major point that scientists need to communicate more effectively is that we can never anticipate what the future benefits of knowledge will be. It therefore benefits us to learn as much as we can about as many things as we can.

People often wrongly believe that scientific progress is made by a few "great geniuses" working on a few "big questions," and that those geniuses have some sense in advance of what the answers are going to be. In reality, knowledge is advanced by many independent teams of people working on chipping away at the boundaries of knowledge a little bit at a time. Sometimes doing so leads to a world-changing discovery. Other times it just tells us one more thing that doesn't work, a vital step toward eventually learning what does work.

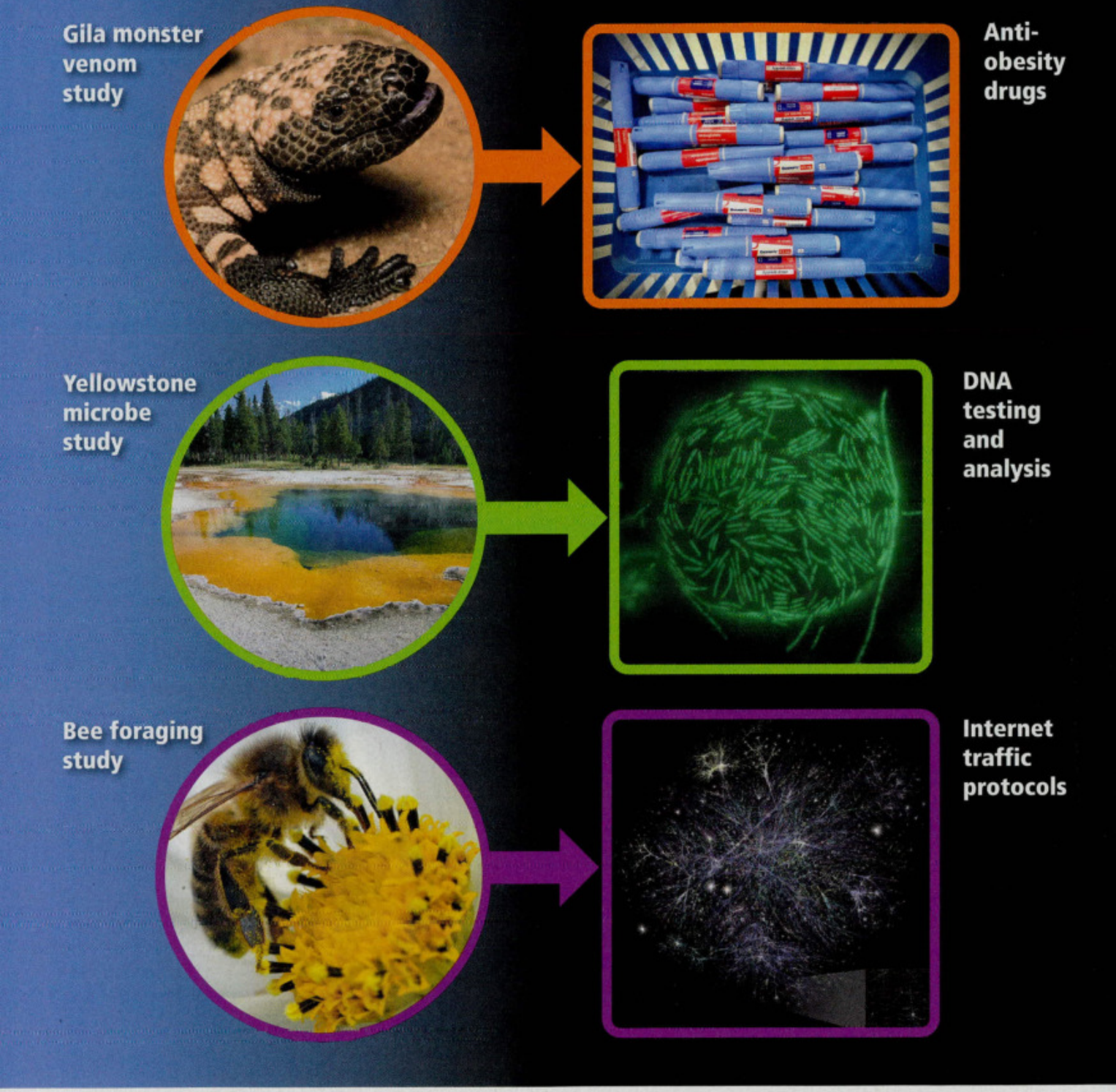
A lot of the time, those world-changing discoveries are utterly unexpected. If someone had said, "Who cares how desert lizard venom works? Let's not fund that research," we never would have discovered semaglutide, a key component of drugs such as Wegovy and Ozempic, which have helped millions of Americans lose weight. If we had decided not to study how bees optimize nectar foraging and distribution among a colony because it sounds silly, we never would have developed an algorithm that allocates internet traffic among computer servers—a technology that powers the $50 billion web-hosting industry. If we hadn't funded research into how bizarre microorganisms thrive in boiling

QUICK TAKE

Public funding of science in the United States has long been criticized for supporting studies that seem "silly" or irrelevant to the public good. Such critiques are especially intense now.

Wide-ranging, curiosity-driven research has led to enormous theoretical and practical benefits over the decades, ranging from anti-obesity drugs to the internet.

Scientists need to speak out on the value of government-supported basic research, so the public understands how much damage will result if we continue the current funding cuts.

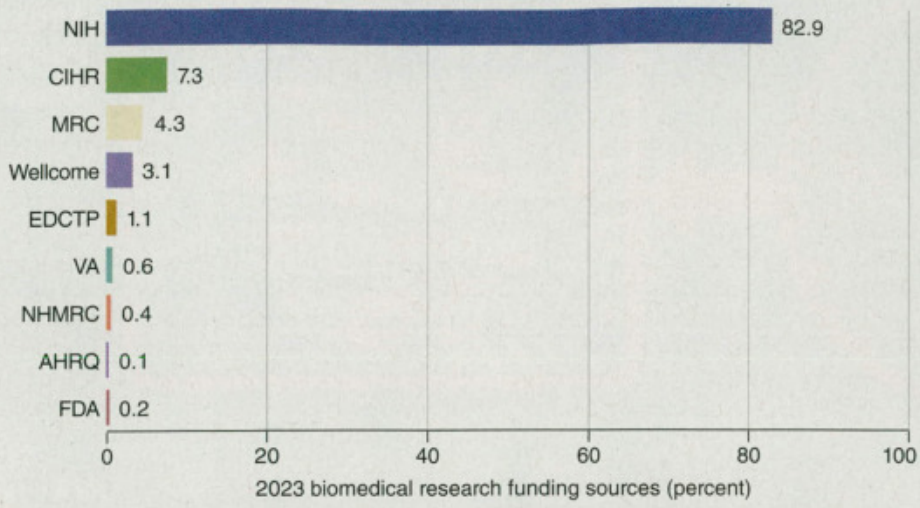


Seemingly obscure research often leads to important results, in unpredictable ways. Research on Gila monster venom led to the development of GLP-1 drugs for diabetes and obesity (*top row*). While studying the *Thermus aquaticus* bacterium, scientists discovered the Taq polymerase enzyme widely used in genetic analysis (*middle row*). Investigations of honeybee foraging patterns inspired one of the computer algorithms used to route data efficiently on the internet (*bottom row*).

Yellowstone geysers, we never would have discovered the bacterium *Thermus aquaticus*, whose Taq polymerase enzymes now enable medical tests for countless genetic diseases.

The American Association for the Advancement of Science (AAAS) honored several of these discoveries with the Golden Goose Award. "The Golden Goose Award honors federally funded research that had an unexpected impact on society, and the idea came from a former member of Congress who had seen narratives about wasteful government spending and wanted to showcase why investing in research is the opposite of that, by highlighting life-changing scientific discoveries," says Erin Heath, the director of federal relations for AAAS. "Our lives are better because of government support of scientific research, which helps the economy, drives discoveries, and creates jobs."

The Golden Goose Award was devised in response to the Golden Fleece Award, created by former senator Wil-



NIH–National Institutes of Health; **CIHR**–Canadian Institutes of Health Research; **MRC**–Medical Research Council; Wellcome; **EDCTP**–European and Developing Countries Clinical Trials Partnership; **VA**–Department of Veterans Affairs; **NHMRC**–National Health and Medical Research Council; **AHRQ**–Agency for Healthcare Research and Quality; **FDA**–Food and Drug Administration

World RePORT/Barbara Aulicino

Public funding is crucial for sustaining a vigorous science ecosystem that leads to intellectual leaps and major new applications. Private industry and philanthropies will not, and cannot, fill the gap if we slash public support. In biomedical research the U.S. National Institutes of Health dominates overall public funding for the entire world—at least, it does so for now.

liam Proxmire in the 1970s to mock what he saw as useless science being funded by taxpayer dollars. He focused on studies with odd or obscure-sounding titles, paying little regard to their actual purpose. Proxmire's highly publicized campaign seriously damaged the public perception of federally funded scientific research and fostered the myth that researchers often get paid to engage in frivolous work for their own amusement.

What is striking about the numerous Golden Goose examples listed on the AAAS website (along with countless more that were considered) is that nobody knew at the time of funding which of the research projects were going to change the world and improve our lives. Undoubtedly there were many funded projects that didn't lead to these breakthroughs. That is the nature of problem-solving: Some possible approaches work, some do not. We therefore need to attack problems from many different angles, knowing that some approaches will fail, and some will sound silly when presented out of context.

Research Benefits Local Economies

Another important point that does not receive enough emphasis is that research grants are economic powerhouses for the communities surrounding universities. Federal research grants are vital economic pipelines, paying the salaries of people who then spend money in the region. Every $1 spent by grants from the National Institutes of Health (NIH) generates nearly $2 in economic activity, for example. Every $1 spent by the National Oceanic and Atmospheric Administration (NOAA) generates at least $2.40 in economic activity, while creating thousands of jobs in rural coastal communities. At the same time, these investments also keep our food supplies safe and guard us from major storms. If you had the opportunity to invest with a guarantee that you'd double your investment, wouldn't you take it?

Silly-sounding science is what happens when researchers do exactly what they are supposed to do: think freely and explore new ideas.

It's important to remember that not all universities are in big cities; many major research universities are in very rural areas, and in many counties a university is the largest employer. Academic research supports surrounding small businesses—many a sandwich shop is kept in business by lunchtime foot traffic from a NOAA lab, not to mention grocery stores and housing.

And scientific research grants are not just great investments in terms of creating jobs. They are great investments in terms of producing concrete benefits for the public. The "silly" grants are a crucial part of the process of creative inquiry that has helped generate lifesaving medical treatments, led to cleaner water and air, safeguarded our food, bolstered our national defenses, and enhanced our understanding of the beauty and majesty of nature.

Research Trains the Next Generation

Research grants that cover a wide range of ideas also pay for the training of graduate students, the scientists of the future. Although undergraduate students pay tuition, often graduate students in the sciences get paid for their work (not much, but something)—which is vital, because they are essentially full-time employees of their university and lab with little time for a side job. The main source of these research assistantship funds is research grants, which means that cutting those grants will lead to fewer future scientists in training.

"It's smart to leverage as much brainpower in our citizenry as we can, because that's a really efficient way to increase productivity and innovation," says Brandon Jones, the president of the American Geophysical Union. "One of the best ways you can do that is for science to train as many students across as many broad demographics as possible, because then you increase the future yield in new ideas."

A large, intellectually diverse, well-trained scientific workforce will lead to countless future innovations. We may never know what won't be discovered because of the current, short-sighted budget cuts. It's important to stress that we aren't just training graduate students on how to use a microscope or a centrifuge. We are training them how to think like a scientist, which means supporting wide-ranging scientific curiosity—exactly the kind of free thinking and problem-solving that often gets dismissed as "silly science" by those who are not themselves contributing to any solutions.

"Now is the time to build, not to retreat," Heath says. "Other nations are stepping up their games when it comes to investment in scientific discovery and innovation."

Research Is a Public Good

We can't rely on private industry and charities to take over the funding of creative, basic research, because they cannot or will not fill the gap. They don't have the resources, and they fund different types of work.

The Wellcome Trust, the largest charitable funder of biomedical research, spent about $1.3 billion on research grants in 2022, whereas the NIH spent nearly $33 billion. A 2023 study that examined all of the new pharmaceuticals approved by the U.S. Food and Drug Administration (FDA) in the 2010s found that the research that led to 99.4 percent of them was funded by NIH grants. The National Science Foundation (NSF) spent $7.2 billion on nonmedical science research in 2024. "All of the philanthropy in the United States is just a drop in the bucket compared to the total federal research budget, so you just have a scale issue," says Brenda Mallory, a former head of the White House Office of Science and Technology Policy.

It's also important to note that private industry funds different kinds of research: mostly applied questions with precise goals, rather than open-ended basic foundational science with many possible future uses. "How do you fund things that might not have any kind of immediate profit?" Mallory asks. "Maybe it's not quite clear what the market incentive is, but it's still very important for basic knowledge that supports other research, and maybe even future commercialization. NIH and NSF grants support the research and support the ecosystem that keeps knowledge and information flowing freely."

Applied science has value, too, but it usually involves optimizing an application of something we already know about rather than making new discoveries. Research into basic principles, even if it sometimes sounds "silly," is fundamental to future conceptual breakthroughs, applications, and commercial payoffs. It rarely produces immediate applications, though, which is why it almost never receives investment from private industry.

A further obstacle is that private industry keeps much of its research private as trade secrets, rather than publishing it where anyone anywhere can use it. It's a very different model, one that simply is not sufficient for us to rely entirely on it. A world with research funded wholly by private industry is a world with dramatically fewer innovations.

This idea that private industry could replace the wide-ranging research supported by government funding is not just an idle theory. Elon Musk, representing the Department of Government Efficiency, has stated that he wants to put that idea into action. It's worth noting that the system proposed by opponents of federally funded research—which they term "running the government like a business"—has never worked for science, ever, anywhere in the world. Every single country with a strong research community relies very heavily on government-funded grants.

We may never know what won't be discovered because of the current, short-sighted budget cuts.

How to Make the Case

Scientists understand the value of publicly funded research, but their arguments always run the risk of seeming self-serving. So how do we convince the public that they should support a healthy science ecosystem, even if it includes some silly-sounding research?

Some people who personally oppose government institutions, or who reject the very concept of scientific authority, are probably never going to change their minds. But there are a lot of persuadable people out there, many of whom have little or no idea what researchers actually do, and may have only heard criticisms about wasteful research without ever having heard from a scientist. Convincing those people to support and protect science funding, even if it seems "silly" when presented out of context, requires scientists to get better at explaining to the public not only what we do, but why.

The field of science communication, and the skill set of persuasive narrative argument, have much to offer here. "Finding out where people are and meeting them there with arguments about scientific innovation, societal benefit, and economics, and having discussions at those levels is good," Jones says. "It would benefit scientists to be able to collaborate with folks in other disciplines who know about marketing and can repackage our stories, because speaking technically is not enough."

It's also important to act like a person—not like a walking, talking textbook—in your interactions with the public. In my career as a public science educator focusing on marine biology and conservation, I've persuaded people as much through *how* I present myself as through the lists of facts I present. For instance, in a recent op-ed about the removal of protections from a marine protected area, I stressed not just the science of ocean conservation, but my personal experience as a SCUBA diver who loves seeing healthy coral reefs.

"For those of us who are researchers, science is more than a job," Mallory says. "It gives you meaning. There are other jobs that we might do to make more money, but there's a sense of purpose associated with discovery work."

"Think about how to describe your work at the dinner table so it's understandable," Heath adds. "And remember why you care about the work you do, and let your passion for it come out when you talk about it. Passion for your work is infectious and lets other people know why it's important and why they should care."

Scientific research is in danger. Scientists need to be vocal, visible, and direct in its defense. It is easy to get overwhelmed by the magnitude of the funding changes happening. Finding places to speak to a wider audience, holding open discussion sessions with your community, and sharing the purpose behind your work can help protect research and all the good that comes from it.

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The Ecoacoustics of Forests

Sound can be a hugely important source of data about ecosystems—but first it has to be reliably recorded.

Becky E. Heath

I was crouching silently in the tall elephant grass with Syamin Zulkifli, one of our project's research assistants, with thick tension between us. We were in a tropical rainforest in Malaysian Borneo, and we could hear the looming footsteps of a herd of Bornean pygmy elephants as they approached us calmly but forcefully. The name "pygmy elephants" makes them seem like they should be sweet and small; however, they're anything but that. At about 3 meters tall and weighing from 3,000 to 5,000 kilograms, most of the time these animals are gentle giants that graze peacefully. But if they are spooked, they will charge at anything that frightens them, which can make them just about the scariest creature to run into alone in the forest. Syamin and I were acutely aware of this fact, but we had stumbled across the herd while putting out a batch of our acoustic recorders. We had attempted to disappear up the side of a bank and into the grass to wait for the elephants to pass, but we had unwittingly put ourselves exactly where the herd wanted to go.

As we waited quietly, we could hear the sounds of the elephants' teeth grinding grasses and see their huge heads looming over the top of the field. I looked at Syamin, who was on her phone frantically searching the internet for "what to do if you see a wild elephant." The search results gave us an assault of contradictory advice: both "play dead" and "shout loudly," both "get to high ground" and "get into the undergrowth," both "run away as fast as you can" and "don't ever try to outrun an elephant." But overwhelmingly, the overall consensus of the advice was just *do not be in this situation*. Fantastic. Syamin met my eyes, we looked around for an escape, and the only route was off the cut trail and deeper into jungle. "Just run," Syamin said, and we bolted as fast as we could into the forest.

Tearing down vines and getting torn to shreds by rattan, we ran for as long as we could in the sweltering 30-degree Celsius heat and nearly 100 percent humidity of the tropics. We regrouped in a clearing—now covered in scratches and mud and way off-trail—laughing hysterically from the panic and trying to calm down. As we looked around, there were no signs of elephants, and we breathed a sigh of relief. Syamin checked our GPS device: Two dots were on it, one for us (now in the middle of nowhere) and a little dot showing the meeting point for our research truck, on one of the old logging roads that are common in this area.

We each took out our *parang*—a Malayan machete—and we slashed through thick undergrowth for about an hour, avoiding spiderwebs and thorns and keeping an eye out for deadly pit vipers, trying to get back to something that felt like safety. I remember collapsing onto the ground when we reached the truck pickup point. Syamin got through to a driver at our project's basecamp, and someone was blissfully only an hour away. We laid in the heat of the jungle sun, drinking warm water from our crumpled plastic bottles, imagining we were instead at a tropical beach club sipping ice-chilled watermelon juice. We were surrounded by *Mimosa pigra*, or "shy plant," a magical little legume that collapses dramatically when you touch it—a strategy likely developed to deter hungry herbivores, though I felt like I could particularly empathize with its behavior after our harrowing elephant encounter!

Syamin and I were in the jungle not to get up close to wildlife but to study it without human disruption, using sound. We were putting up recorders to collect the ecoacoustics of this intricately diverse and fascinating corner of the world. *Ecoacoustics*, the method of using sound to understand environments, is a relatively new tool that is gaining interest and uptake from ecologists and beyond. It might not be immediately obvious, but sound recordings contain an absolute tapestry of information that can be tied to specific places and points in time. Anyone lucky enough to live in a region of the world with a lot of wildlife will be familiar with the cycles that the acoustic environment goes through over the course of a day: At the break of dawn, the trilling, tuneful calls of songbirds abound, perhaps speckled with caws from cockerels; as the day heats up, the birds become quieter and the consistent beats or tones of insects come to dominate the soundscape; then crawling into dusk, birds re-enter the soundscape as they fly home to roost, alongside insects and frogs that continue into the night, accompanied by the hoots of owls and squeaks of nocturnal mammals.

Acoustic Data

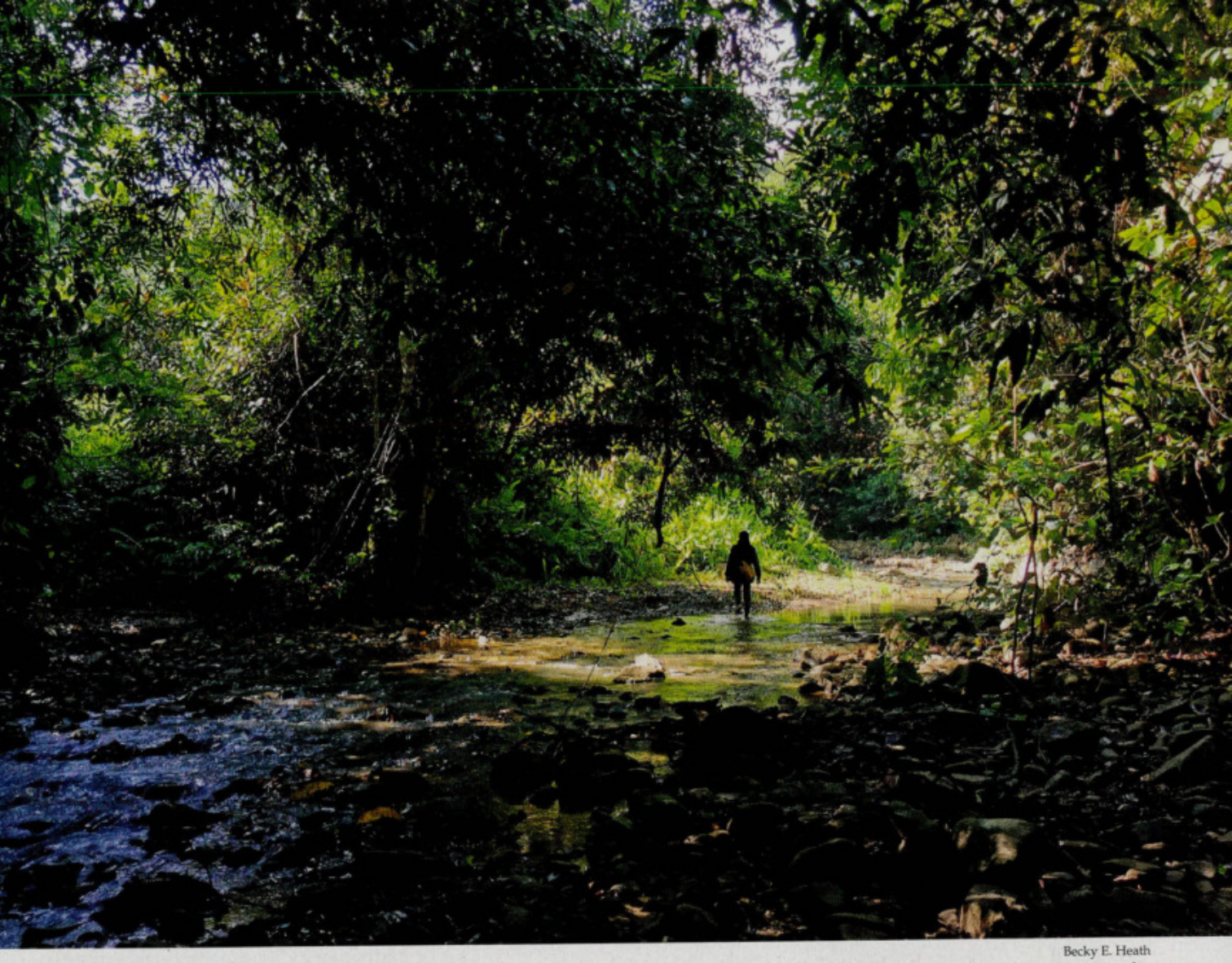
Wherever you are, just a minute of recorded audio contains an extraordinarily large amount of information that scientists and conservationists can use

QUICK TAKE

Acoustics can provide an immense amount of data about ecosystem inhabitants, including what part of the habitat each species uses at different times of day.

Sound must be reliably recorded from multiple directions in order to be useful in this analysis, and different ways of storing audio data can affect quality and information content.

Acoustical data can then be analyzed using deep learning algorithms developed specifically for identifying sound, to create broad soundscape characterizations of ecosystems.



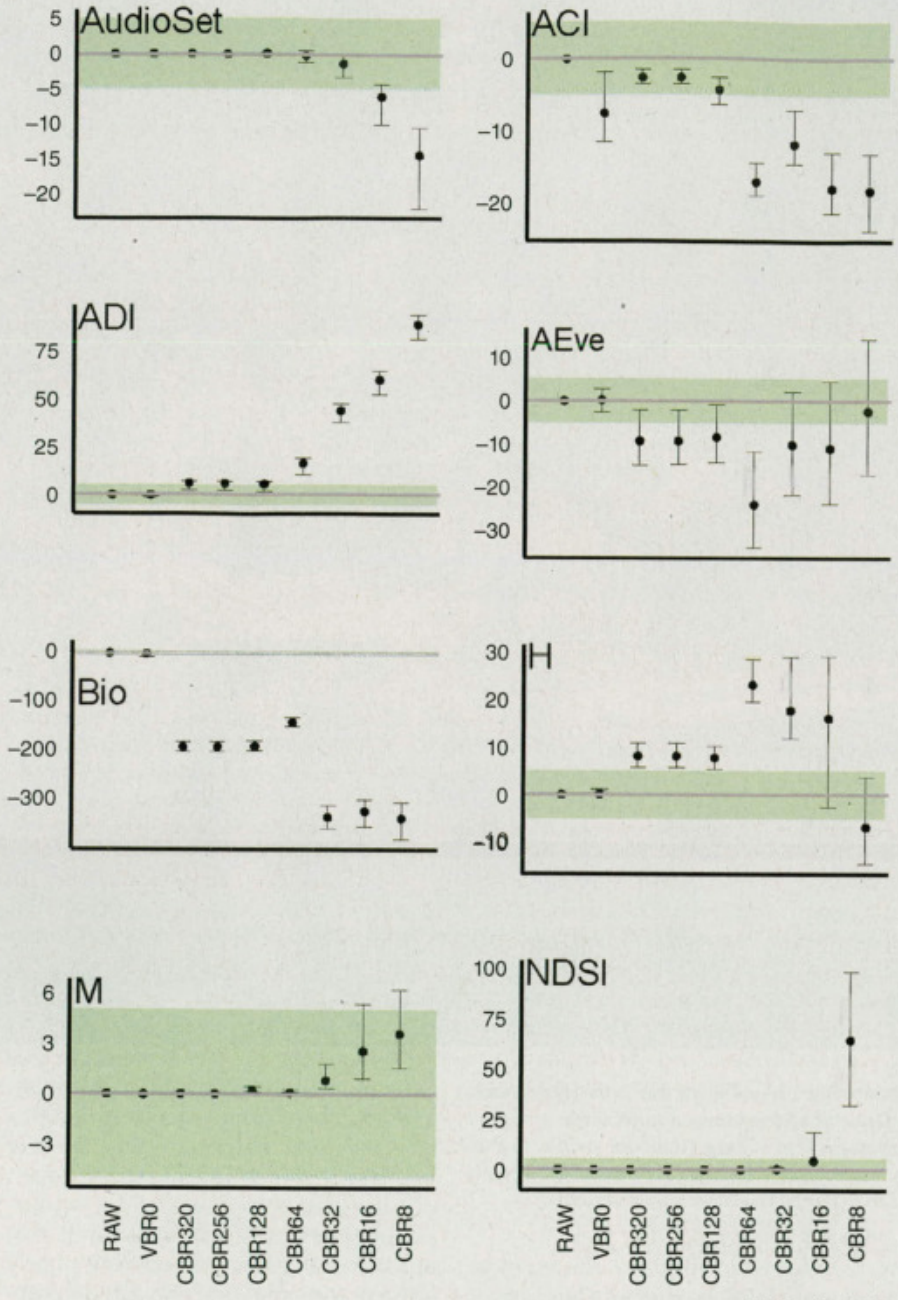
Becky E. Heath

Tropical rainforests, such as this one in Borneo (showing a member of the author's research team in the distance), are teeming with an abundance of species linked together in complex ecological relationships. These species are also often good at hiding; none are visible in this photograph. But even if they can't be seen, they often can be heard. Ecoacoustical research aims to use the immense data provided by sound to better characterize environments.

to work out what's where, and when. And because sound is so data-rich, even a single recorder can be useful. But the first task I had was to dig into the nuts and bolts of recording protocols and the corresponding analysis methods, to try to unpick potential drivers of unrepresentative data. In ecoacoustics, broadly there are two roads you can go down with analysis. The first is to attempt to isolate individual calls from each recording, so that after analyzing your recordings either manually or with "machine listening" (machine learning algorithms trained for sound), you end up with a list of each species detected in the recording at each specific time. This approach is sometimes called *bioacoustics* and it is very useful for targeted biodiversity monitoring. For example, if you want to see which British birds are most commonly found in different land-cover types in Europe, this approach would probably be the way to go.

Sound recordings contain an absolute tapestry of information that can be tied to specific places and points in time.

The problem with this bioacoustics approach comes up when you're trying to analyze very complicated or noisy recordings, or trying to survey areas where the key noisemaking animals (usually insects, frogs, mammals, and birds) are poorly documented. It's impossible to determine what you're hearing if the sound has never been documented before—and there's a surprising amount of wildlife sounds that are still undocumented or very poorly known. Instead, what you can do is appraise the soundscape as a whole entity. Rather than getting a list of species at the end of your analysis, you end up with metrics that can suggest attributes about the sonic diversity of that recording. Typically, these are measures of activity in the recordings, such as



B. E. Heath et al, 2021.

Five-minute audio samples recorded in different formats were compressed and measured using different indices of audio quality. The audio derived from a machine learning algorithm, labeled AudioSet, was more robust in maintaining functionality in lower quality audio than any of the other indices (green regions show the five percent error range). Large audio files must be stored and transmitted without reducing quality to be useful in ecoacoustics analyses.

the spread of amplitude across different frequencies, how much the spread of frequencies changes over time, or the loudness of bioactive frequency bands.

As in most fields of research, advances in machine learning have also started to change the game in ecoacoustics, and there are now deep learning algorithms that can be used to appraise whole soundscapes in very powerful but abstract ways. I tend to think of this type of analysis as being like a fingerprint or a barcode, in that more similar fingerprints (or barcodes) can indicate more similar soundscapes. Therefore, we can use these methods to look for broad commonalities in soundscapes across time and space, and—particularly usefully—we can use them to start determining when the acoustics of an area are changing, for better or for worse.

There are advantages to using ecoacoustics for ecosystem monitoring, but as a new field, there are still major questions that are lacking answers. Which is why Syamin and I were running away from elephants in Borneo: We were there to explore some basic methodological questions such as, "Will this data work if the audio is compressed?"

Despite the elephants, our initial recorders worked, so we had high-quality recordings to experiment with. The next challenge was to simulate different recording and post-processing protocols. Specifically, we looked at the use of compression in MP3 format, shorter versus longer individual recordings, and the time of day when recordings were made. We edited copies of the raw recordings along all these parameters, then ran them through an analysis pipeline that extracted the acoustic indices (such as loudness, frequency spread, and many more), as well as through the machine learning ecoacoustics analyzers. We found that the deep learning algorithms produced a consistently better descriptor of the soundscapes than the analytical indices, and that the deep learning approach was also more robust to the effects of compression and shorter time periods. Overall, we found that compression actually had a rather minor effect on how well soundscapes were described, and any effect could usually be mitigated by simply recording for a longer time. Honestly, I had been hoping to conclude that compression *is* bad so I could advocate for the highest quality recording possible—which I do still think is important—but at least we know now that compressed audio is very useful.

Spatial Recordings

During that (admittedly eventful) field season, the commercial recorders we used were *omnidirectional*, with just a single microphone, or channel, to record from every direction. The next step was to develop recorders that had multiple channels and could capture *spatial soundscapes*, which would allow us to better isolate different acoustic sources.

Sound, for the most part, is just oscillating waves of pressure traveling through a material (such as air) over time. Sound waves are comparatively slow, chugging along at around 343 meters per second, as opposed to light's speed of 299,792,458 meters per second. We make use of this trait in our daily lives—even on the scale of a person's head, there's a detectable difference in the speed of sound as it reaches one ear before the other. Our brains then in-

stantaneously compare this difference to guess the direction the sound came from; it's how, for example, a blindfolded person in a game of Marco Polo can determine where the other players are. This principle was the basis for the goal of my next block of research: to develop a completely autonomous spatial recorder that we could chuck in the rainforest for a year at a time—easy.

Of course, it ended up being anything but easy. Spatial recording generates a huge amount of data very quickly that requires all sorts of tricky management, and all microphones need to be recording sound at exactly the same time. Any delays would artificially add distance in the data and limit how well the recorded sound could map to what was actually happening in the environment. But it's not just a case of kicking all the microphones off at the same time and hoping for the best, because of a troublesome feature in sound recording known as *clock drift*.

All digital microphones have an internal clock that drives exactly when air pressure is sampled, which is what allows for sound to be recorded. For most high-quality recordings, this sampling happens around 44,100 times per second, quite an impressive feat. But the clocks themselves can lose accuracy gradually, on the order of 0.01 seconds per day. That loss is pretty minor and doesn't usually cause problems for single-channel recording, but it becomes real trouble when you need to do fine-scale comparisons, as in spatial recording. Clock drift unhelpfully doesn't happen in a linear or predictable way, and it also is confounded with temperature because the clocks run faster when it's hotter and slower when it's cold. All that to say, for our purposes, individual microphones were out. In recording studios, this problem can be handled with very powerful electronic audio interfaces that are big and expensive and not at all built to withstand tropical storms and pigtailed macaques. We needed something simple, robust, cheap, and easy.

Becky E. Heath (*left*); James Skinner (*right*)

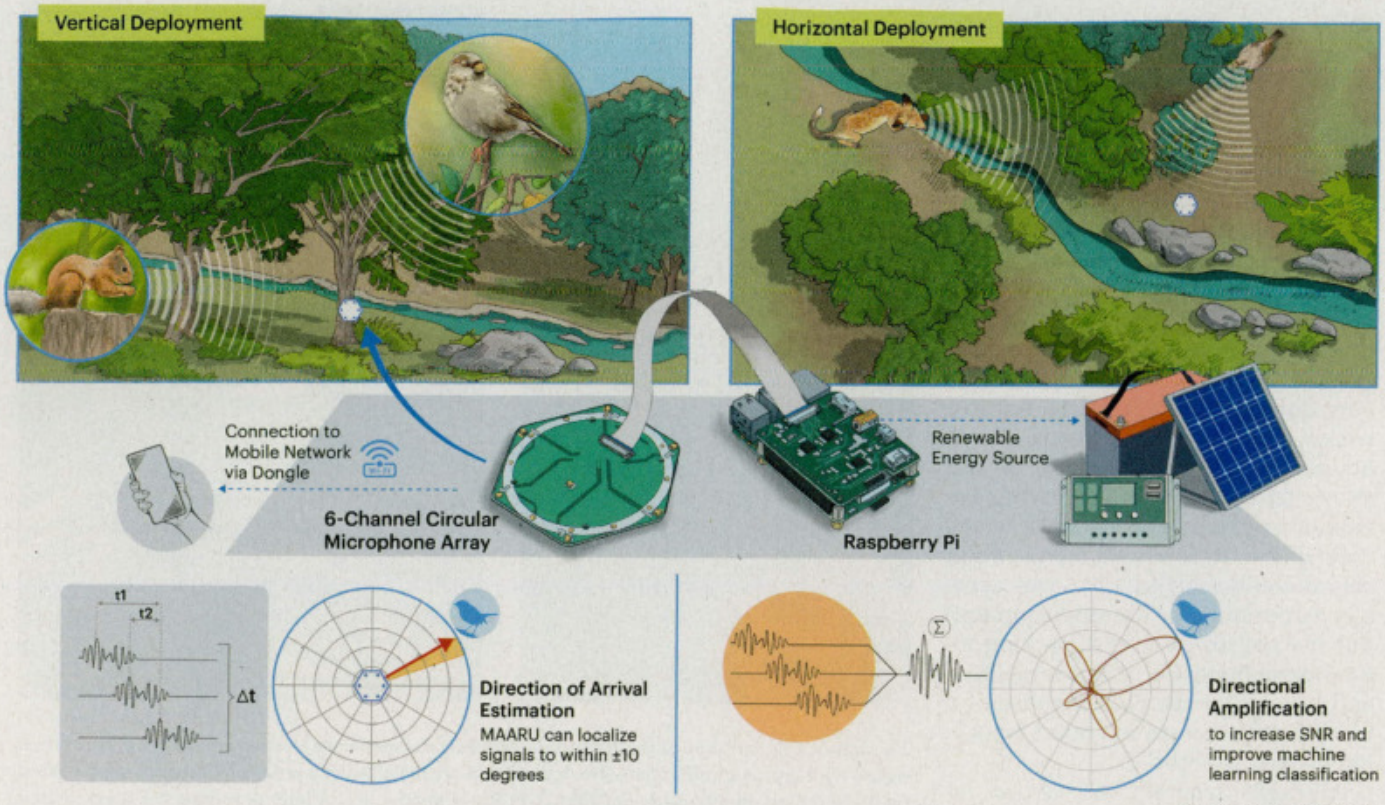
The author's first prototype multichannel recording devices were weatherproofed in plastic boxes sealed with tape and caulk (*left*). These devices were installed in a proof-of-concept experiment in the United Kingdom because of COVID-19 travel restrictions. A later prototype the team created used a 3D-printed case sealed with resin (*right*). These devices were successfully deployed for up to a month in the Amazon rainforest, and are now being used to collect data in Borneo.

The do-it-yourself trend came to our assistance here, particularly in the area of devices that are internet-enabled, linked in what is called the Internet of Things. After some extensive searching, we came across some small microphone arrays produced by Seeed Studio, which were designed for people creating their own home digital assistants, essentially like an Alexa. Crucially, all of the microphones in this array are moderated by the same internal clock. Along with some other customized hardware and soundcards, and some extensive problem-solving, eventually I was able to integrate these components into a prior system developed by my colleague Sarab Sethi. Sarab had developed an autonomous, solar-powered, and mobile-networked single-channel sound recorder that had been recording across the Bornean rainforest for months. I worked with a group of colleagues at Imperial College London—Sarab, Lorenzo Picinali, Neel Le Penru, James Skinner, and Robert Ewers—and after some detailed tinkering, we completed development of a device we called MAARU (for Multichannel Acoustic Autonomous Recording Unit), a completely autonomous multichannel sound recorder. But then we needed to see if it worked.

It's impossible to determine what you're hearing if the sound has never been documented before—and there's a surprising amount of wildlife sounds that are still very poorly known.

Out in the Trees

To develop a proof of concept for MAARU, we worked with Reiji Suzuki from Nagoya University. Reiji had been working on a portable ecological app called HARKBird, which is based on open-source robot audition software called HARK (short for Honda Research Institute Japan Audition for Robots with Kyoto University). HARK uses an algorithm called MUSIC (for Multiple Signal Classification), which essentially cross-correlates recordings



Courtesy of Becky E. Heath

The device that allows autonomous recording from multiple directions simultaneously, called MAARU (for Multichannel Acoustic Autonomous Recording Unit), connects an array of six microphone channels all controlled by one clock to a small, single-board computer called a Raspberry Pi. The device is connected to a mobile network and to a power source. It can be deployed vertically for height monitoring perpendicular to the ground (*top left*), or horizontally to localize sounds parallel to the ground (*top right*). The device uses the time delay in signal reception to localize the direction of sound sources. MAARU can also amplify the sound received in a specific direction to increase the signal-to-noise ratio (SNR), which can improve classification by machine learning.

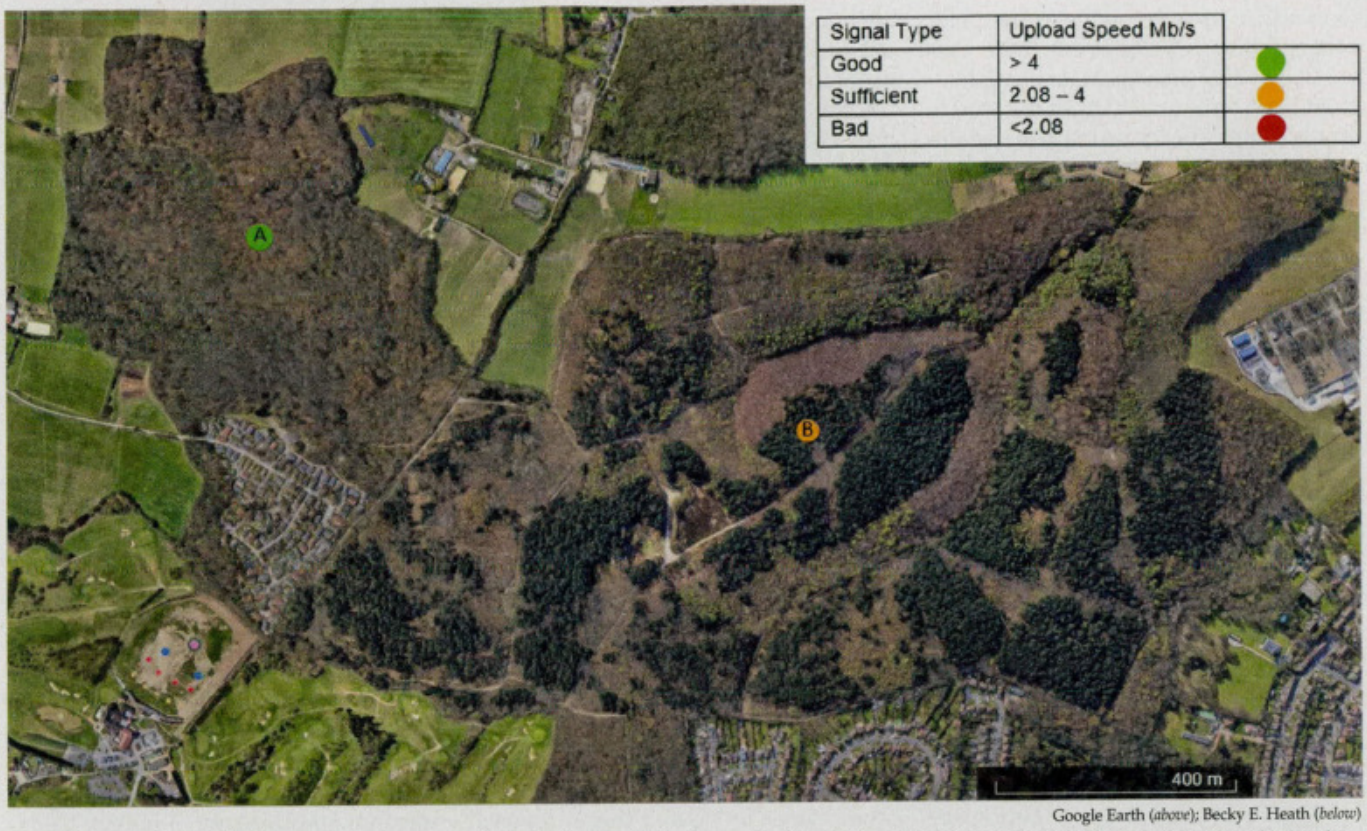
across all microphones with artificial delays that mimic sound coming from any number of possible directions. For each time point, you end up with a likelihood that sound in that time window came from each possible direction, from which you would take the most likely one or two, depending on how many sound sources you're expecting. Reiji worked with us to develop a configuration algorithm for MAARU specifically, and we were able to start testing in the lab and in short field deployments. We found that the setup we'd developed worked quite well, getting high rates of detection and localization accuracy to within 10 degrees in any direction.

Those results were a relief, but the next task was getting the recorder ready for long-term field deployments. My hope from the start was to create something completely open-source and easy to set up, so that other people in the field could take up the device and improve upon it. So, I hope that goal excuses the first iteration of waterproofing MAARUs, which was a sandwich box with holes drilled in it, covered in grip tape and bathroom sealant. The original plan was to take this device back to Borneo to test it across the rainforest, but at the time we had this version of MAARU finished, it was the tail end of the COVID-19 lockdowns, and it was impossible to get everything out to Malaysia and deployed on a schedule that made sense with our funding deadlines.

Recording studio electronic audio interfaces are big and expensive and not at all built to withstand tropical storms and pigtailed macaques.

In the end, we opted to deploy four MAARU recorders in the equally glamorous woods around the corner from my mom's house on the outskirts of South East London. However, for me, there was something sweet about that: I'd grown up on this public land and had spent so much time there tearing about on bikes, taking the dog on walks, playing in World War II bomb craters (the woodland is on a flight path to mainland Europe, so any bombs that weren't spent over central London were instead dropped there), and during an embarrassing teenage phase, recording music videos with my friends. Maybe it wasn't Borneo, but it was nice to be working at home for a change.

Although this deployment was mostly a proof of concept, I wanted to see whether we could use MAARU to detect any patterns in the use of vertical strata in the woods: which birds are most often in the canopy, which are in the undergrowth, and does this usage change

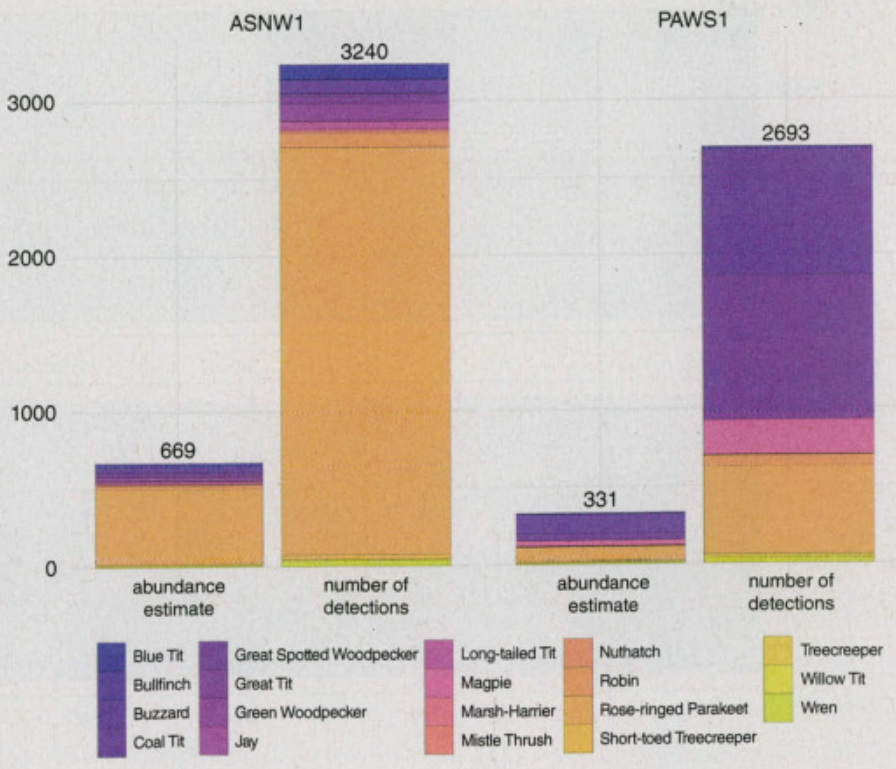


Google Earth (*above*); Becky E. Heath (*below*)

in different places? The woods themselves are quite handily segmented into two main forest cover types. The first is called a "plantation on ancient woodland site" (PAWS); this particular one was an area of former conifer plantation that was felled for timber until 1993, at which point the U.K. Woodland Trust gained ownership and has been gradually felling the site to return it to the natural land cover of the area. Despite 30 years of felling, this part of the woodland is still characterized primarily by rows of non-native Corsican pine, which create a dense, closed canopy providing little opportunity for undergrowth beyond ferns and a couple of holly bushes. The other area is labeled as an "ancient semi-natural woodland" (ASNW), and this one is an area of many mature broadleaf species including sweet chestnut, oak, sycamore, and ash. This area of ASNW likely has been there for more than 200 years, and the canopy is more open, which facilitates a more diverse undergrowth and variety of habitat.

A team of hired tree climbers helped me place four MAARU recorders 10 to 15 meters up in what is considered the mid-canopy, with two in the ancient woodland and two in the conifer plantation. I enjoyed working with the tree climbers, who were very enthusiastic about the project and contributed a lot of great ideas for device setup. And it

A proof-of-concept deployment of multichannel autonomous recorders in the United Kingdom took place in two different types of woodlands—one that had been logged for decades (*B above, PAWS1 below*) and one that has had established forest for centuries (*A above, ASNW1 below*)—that were in close geographical proximity. The recorders were able to transmit recordings, and analysis was able to determine where in the canopy birds were located, as well as differences in species between the two forest areas (*below*). A deep learning algorithm predicted the species present at different time points, from which the author's algorithm clustered the number of species per recording related to the range of call directions. The number of clusters was taken as a proxy for the number of calling individuals, which was further extrapolated to estimate species abundance.



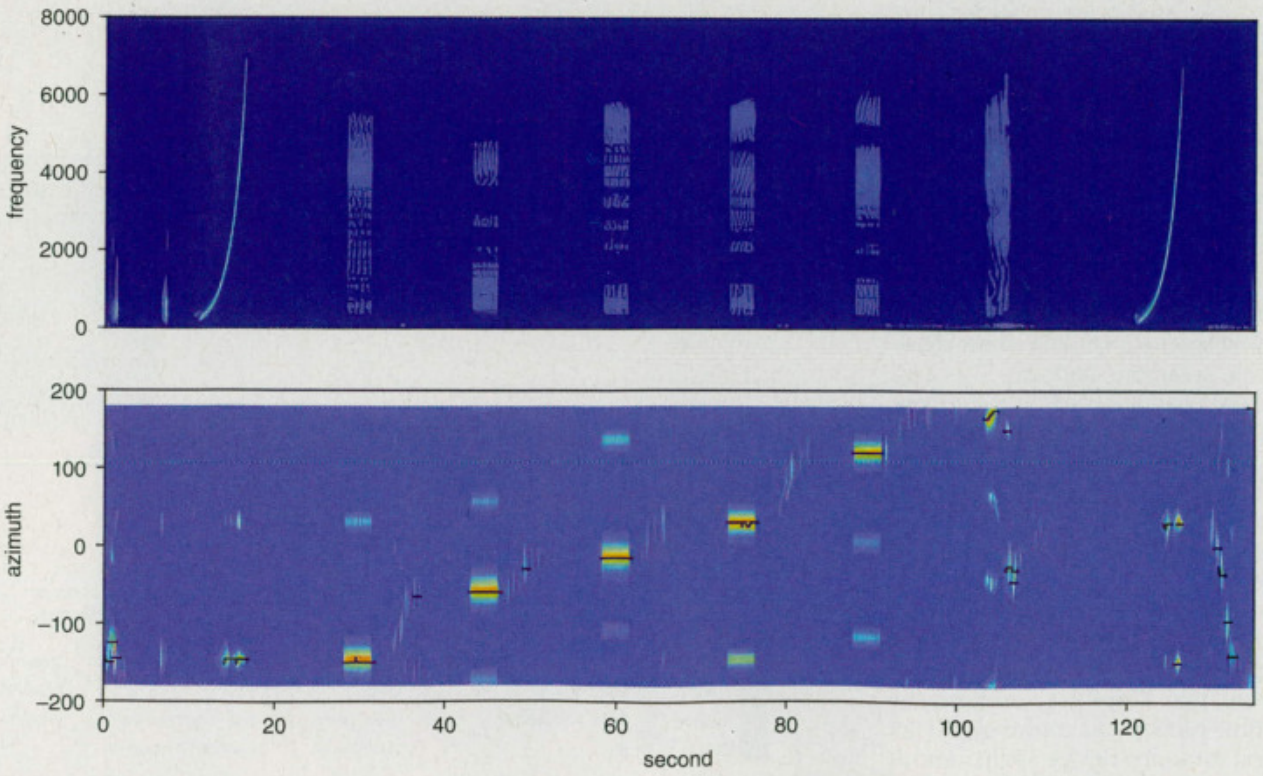
worked! After a few days in the field, I logged into the data hosting site, and we had spatial acoustic data being live-streamed continuously from the woods around the corner. Two of the recorders survived the full six-month recording period. One casualty was early on; I believe that a branch to which a solar panel was attached broke in a storm, resulting in a loss of power to the device. The second casualty was more dramatic and related to an unfortunate common gray squirrel mistaking a power cable for lunch. Both incidents were, however, important for helping us improve the durability of the device prototype.

Once again, I used HARKBird to analyze the data, but this time I combined the HARKBird-predicted sound directions with known bird call detections. For the latter, we used a program developed at Cornell University called BirdNET, a deep learning algorithm trained specifically for bird call identification from environmental recording. At the time of our analysis, the BirdNET algorithm had been trained on 226,078 labeled three-second spectrograms of environmental recordings of bird calls. The algorithm can pick up patterns in these visual representations of sound with impressive accuracy and unbeatable speed. By using both these programs for our acoustic data analysis, we could therefore get both a species prediction and an estimated bearing.

Now we could map not only what was in the woodland, but where in the vertical strata it was calling from. We were then able to compare the vertical stratification of different bird species in the two types of woodland, showing that there were fewer birds in the former plantation, and that the vast majority of birds in this area were calling from the mid- to upper canopy. In the ancient woodland, the calls were spread across the vertical strata. Although these results were expected, the study was likely the first instance of these parameters being picked up autonomously with a device like ours. This proof of concept showed that the device could be applied reliably to unknown research questions.

Since that first deployment, we've learned a lot of lessons, such as the use of armored cable and different modes of solar panel attachment, as well as other ways to power these devices. MAARU's development has been ongoing, and a master's student on the research team, James Skinner, created a sleek resin-coated 3D-printed case for the device, a big step up in looks from the first prototype. Our team deployed these devices for up to a month in the Amazon rainforest, and they worked great. MAARU's development was then taken over by Neel Le Penru, who in 2024 took MAARU devices to where they were first intended to go, in the beautiful lowland rainforest of Danum Valley in Malaysian Borneo. Neel's data are still being collected and analyzed. Back in the United Kingdom, in the next few months we expect another installation in collaboration with Ed Baker and John Tweddle at the Natural History Museum in London. Ed invited us to establish a network of MAARU sensors within the museum's gardens for long-term spatial acoustic monitoring of this area. We continue to expect insightful data about ecosystems across the world from MAARU devices.

Test sounds were used to determine the frequency response and accuracy of the recorder's sound localization. Spectrograms visualize these sounds (*below, top row*) used in a test sweep, six beeps of broad-spectrum sound called *pink noise*, and a final test sweep across frequencies. The bottom row shows the algorithm's determination of the likelihood of a location of each sound as it was played at different directions (or *azimuths*) around the six-microphone array.



Becky E. Heath/HARKBird

Agriculture and Ecosystems

In my current research, I am exploring ways to apply ecoacoustics to broader research questions about human development and ecology. For a few years, I have been working with Ed Turner at the University of Cambridge's Museum of Zoology on monitoring and assessing agricultural landscapes in the tropics. We're hoping to work out which methods of farm management will be most mutually beneficial for ecosystems and

growers. Specifically, I am now looking at different ways of establishing restoration areas within oil palm plantations. Although oil palm has a bad reputation because of its association with deforestation, the situation is more nuanced, and we have to think about challenges and opportunities in the whole system.

Oil palm is a crop native to the tropics that grows best in tropical environments, so it is true that it is in direct competition with tropical rainforests. However, this competition is true of all tropical crops, including coffee, cocoa, and rice. Negative attention likely has fallen specifically on oil palm because it was an introduced crop to Southeast Asia, and because there are reasonable alternatives. Oil palm has been grown in West Africa for thousands of years, and it is much more entwined with culture and tradition there than in other parts of the world. In the 1980s, industrial oil palm production started to explode in Southeast Asia, particularly in Malaysia and Indonesia. This explosion saw huge swaths of primary and secondary forest cut down to make way for oil palm plantations, and this deforestation caught both conservationist and media attention. One of the public service announcements that resulted showed orangutans walking across bare ground where forest used to be.

In response to this outcry, environmental groups advocated boycotts. Other vegetable oils have similar tastes and properties, so in theory, big companies could just switch. But oil palm is enormously efficient, producing up to seven times the oil per square meter than the next most productive oil crop, and it produces continuously in plantations that last 25 to 30 years before replanting. Messaging against oil palm plantations tends to show only that replanting event. The rest of the time, oil palm plantations grow to support relatively complex communities of plants and animals, even some charismatic fauna—including macaques and leopard cats. To replace oil palm, plantations would need seven times the amount of land for a crop that is cut to ground annually, without any major degree of carbon storage, succession, or canopy. All of these factors need to be taken into account when considering the nuanced choices of one crop versus another.

Properly maintained conservation areas and restored natural landscapes are absolutely vital. But if we assume that existing oil palm is here to stay, the question then becomes whether there's anything we can do to make it better. That is where Ed Turner's research comes in, with the Riparian Ecosystem Restoration in Tropical Agriculture (RERTA) Project, which I joined in 2023. RERTA is a large-scale landscape experiment set up as a collaboration lasting more than decade between the University of Cambridge, the University of Nottingham, IPB (Bogor Agricultural University) in Indonesia, and SMART Research Institute in Indonesia. Ed, Sarah Luke from the University of Nottingham, Agung Aryawan from SMART Research Institute, and their team began restoring forest around river systems in oil plantation areas using different restoration strategies. Every year since 2018, Agung and his team have gathered an enormous amount of data from these areas using more than 30 different collection protocols, including yield, insect biodiversity, ecosystem function, temperature, water nutrient quality, erosion, camera traps, predation rate, soil decomposition—and, of course, acoustical recordings. With these recordings, we're starting to combine high-confidence species detections of ecologically important pest control agents (such as owls, eagles, frogs, and aptly named assassin bugs) and overall soundscape metrics. This analysis gives us a great opportunity to explore how to tie state-of-the-art technology in ecosystem assessment to real-world land management decisions.

Ecology is undergoing a technological revolution as researchers begin to employ a wide range of new tools and analysis methodologies.

High-Tech Ecology

We're at an exciting point in both ecology and applied ecology. I feel as though the field is currently undergoing a technological revolution, as researchers begin to employ a wide range of new tools and analysis methodologies, including ecoacoustics, that could change how we understand our world, both for its protection and to increase our fundamental understanding of our planet. And our planet is vastly complex: For example, it has been noted that, gram for gram, even soil is more intricate, complicated, and diverse than the human mind. Scaling that complexity up to a garden, let alone a tropical rainforest, represents a fundamental challenge in ecology. It might be an impossible task to ever study, catalog, and understand our entire planet. But perhaps, if we can use the immense amount of data provided by sound as one additional tool, we stand a better chance.

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Herders from the Green Sahara

Modern genetic data from Fulani populations illuminate ancient migrations, adaptations, and interconnections shaping Africa's drylands.

Cesar A. Fortes-Lima, Viktor Černý, and Carina M. Schlebusch

The young Fulani man opens his mouth, patiently granting me the 30–60 seconds I need to collect cells from his inner cheek onto my swab. He is one of hundreds of Fulani across sub-Saharan Africa who, following consultation with their chiefs, have volunteered and consented to provide the DNA samples we need to better understand their origins. The Fulani are the largest group of pastoralists (nomadic or seminomadic livestock herders) in Africa. They are a group marked by distinct cultural practices, useful survival adaptations such as lactose tolerance and malaria resistance, and a prehistory reaching back 10 millennia to when the Sahara was green and wet.

Understanding the origins of cultural groups in Africa requires combining comprehensive genetic evidence with knowledge of how lifestyles, ecological conditions, and climate change have affected both ancient and modern populations. Sometimes, genetic evidence is abundant and well-preserved in fossilized remains, but too often the environmental conditions of the Sahara Desert and the semiarid Sahel belt leave little for scientists to analyze. Consequently, to address longstanding debates concerning the ancestors of the Fulani people, one's best bet often lies with a population-genomics approach.

It's an exciting opportunity for us, a chance to collaborate with Fulani communities to better understand ancient migrations and their relationships to modern cultural and genetic patterns, and to gather further evidence that could support our earlier hypothesis of a bidirectional migration corridor across the Sahel/savanna belt. To learn about the genetic structure and ancestry of this widespread population—around 25 million people in groups scattered across sub-Saharan Africa from the Atlantic Ocean to Lake Chad—we collected genome-wide genotype data from 460 Fulani who made up 18 local populations, as well as comparative data from both modern and ancient Africans and non-Africans. Our research shows that Fulani genomic information preserves a fascinating history of cultural continuity, a resilience to challenging environments, and a shared ancestry that reaches back 5,000 to 12,000 years. These data also reveal that some Fulani ancestors contacted populations from Europe and North Africa, and that gene flow from these sources contributed to Fulani survival by enabling them to consume milk.

Pastoralists and Farmers of the Sahel

The term *Fulani* is from the West African language Hausa and is merely the most widely used of many names for this ethnolinguistic group. These traditional nomadic pastoralists, whose seasonal routes can span hundreds of kilometers, dwell in the Sahel and African savanna alongside sedentary farmers and agropastoralists, who live near their fields and rely on regular cycles of sowing and harvesting, feeding crop residues to their animals. What unites pastoralists is the practice of *transhumance*—seasonal movements of herds along a north–south axis, following the summer monsoon rains and the growth of nutritious grasses.

Historically, the Fulani were nomads who raised mainly cattle, as well as goats, sheep, and sometimes camels. Individuals from other local ethnic groups have, in some cases, assimilated into Fulani communities, a fact researchers must consider when collecting and evaluating genetic samples. Some Fulani groups are more insular, however. Communities in Niger, Cameroon, and Chad, who call themselves Woɗaaɓe, usually live in small, dispersed groups across the Sahel but gather once a year for the Guérewol celebration, in which young men compete for the attention of marriageable young women. These events reduce *endogamy* (the cultural practice of marrying within a specific social group) by encouraging marriage beyond close relatives. However, they also limit interethnic unions with neighboring non-Fulani communities, because only Fulani can participate in Guérewol; thus, they reinforce endogamous marriage traditions between Fulani communities.

Over recent generations, many Fulani families have adopted a sedentary lifestyle, although they remain deeply connected to cattle herding. Their pastoralist counterparts still establish mobile camps along their routes that may host single families or extended kin groups primarily linked through paternal lines. This nomadic way of life presents a challenge for archaeologists, because the temporary camps leave behind virtually no traces, which complicates efforts to reconstruct the human past in this region.

The Green Sahara Period

Just 10,000 years ago, the Sahara region (today the largest hot desert in the world) was a green savanna teeming

QUICK TAKE

The Fulani are the largest pastoralist group in Africa, spanning 25 million people in populations scattered across sub-Saharan regions from the Atlantic Ocean to Lake Chad.

Cultural and genetic factors, including genes for milk digestion, have made this ethnolinguistic group resilient, resistant to pathogens, and adaptable to changing conditions.

Recent genomic findings trace a 10,000-year ancestry shared by the Fulani and the North African Amazigh, highlighting large migrations prior to the formation of the Sahara Desert.

Jordi Zaragozà Anglès

The Guérewol celebration assembles hundreds to thousands of members of different lineages of Woɗaaɓe, a Fulani subgroup. Young men vying for the attention of marriageable young women wear face paint and specific clothing, and make various facial expressions while singing and dancing. Unique physical and cultural traits have long sparked curiosity about Fulani origins.

with vegetation and wildlife. It was home to hunter-gatherers and, later, to herders of cattle, sheep, and goats. Around the same time, key African cereals such as sorghum and pearl millet were domesticated in the Sahara. However, with the onset of a drier climate around 5,500 years ago, nomadic groups (likely Fulani ancestors) were forced to move southward to what are now the semiarid hinterlands of the Sahel belt, which today crosses Senegal, Mauritania, Mali, Burkina Faso, Niger, Nigeria, Chad, Sudan, South Sudan, and Eritrea, and which touches The Gambia, Guinea-Bissau, Guinea, Ivory Coast, Cameroon, and Ethiopia (*see map on page 236*).

Today, the Sahara Desert is the world's largest open-air museum. Beyond its vast sand dunes and rocky plateaus, visitors can explore breathtaking rock formations etched with engravings and paintings that document the now-vanished world of its prehistoric inhabitants. Thanks to its once rainy past, the Sahara still harbors significant underground water reserves, which occasionally reach the surface. In some places, one can even encounter isolated populations of aquatic animals such as crocodiles—relicts from the time when rainfall was more abundant. The freshwater fish found in the Lakes of Ounianga in northern Chad also point to ancient hydrological connections with Lake Chad more than 1,000 kilometers away, suggesting the former existence of a vast body of water known as the Mega-Chad Lake during the African Humid Period between 5,500 and 14,800 years ago.

Farther south lies the Sahel and the more southern, greener savanna, a transitional zone between the arid Sahara Desert and the tropical rainforests of sub-Saharan Africa. It is a dynamic dryland ecosystem, a mosaic of grasses, shrubs, and scattered trees well-suited to the coexistence of pastoralists and farmers. Here, not just the amount but also the spatial distribution of rainfall brought by the summer monsoon, which is strongest in West Africa, starkly influence both ecosystems and human societies. When rains fail in an area for several consecutive years, the fragile vegetation can quickly disappear, turning the land into desert.

Despite the harsh and erratic conditions, many geographers argue that the Sahel's ecosystem shows strong regenerative abilities and remarkable resilience—evidenced, for example, by the regreening of parts of the Sahel following the severe droughts of the 1970s and 1980s. Some studies even suggest that pastoralists such as the Fulani have helped slow the process of desertification by rotating grazing areas and periodically allowing lands to lie fallow.

New Genetic Insights

Historians, archaeologists, and anthropologists once thought the Fulani were directly descended from ancient Saharan herders because of a combination of physical characteristics, female decorative practices (tattoos, scarifications, and other adornments), and a moral code (called *pulaaku*) that differs from

Viktor Černý

African pastoralists such as the Fulani are widely dispersed in the Sahel, so researchers often must travel far to find them. The authors collected Fulani DNA samples near volunteers' tents using buccal cheek swabs (*pictured here*) or saliva. These are painless methods that pose no risk and provide invaluable data for uncovering the population history of this ancient ethnolinguistic group.

that of surrounding communities. Others argued for origins in Southwest Asia (where cattle were domesticated), the Nile Valley, or the highlands of southern Algeria. But recent findings, including our study published in the *American Journal of Human Genetics*, add nuance and doubt to these interpretations.

Our team of anthropologists, archaeogeneticists, and evolutionary biologists gathered anthropological surveys and more than two million genetic markers from 460 participants belonging to 18 local Fulani populations across nine African countries (approximately from west to east: The Gambia, Senegal, Guinea, Mauritania, Mali, Burkina Faso, Niger, Cameroon, and Chad). After removing samples that did not pass our quality control or that came from people who were too closely related, we analyzed Fulani individuals using a special DNA chip created to capture the vast genetic diversity and small DNA blocks found in African populations. DNA blocks consist of groups of heritable genetic markers called *single nucleotide polymorphisms* (SNPs), which are places where a single DNA letter, or nucleotide, differs.

We compared participants' genomic data with that of both modern and ancient populations from Africa, Europe, and the Middle East from previous studies. To uncover underlying similarities and differences—and to tease out how lifestyles and geographical factors might affect genetic patterns—we first used a statistical method called *principal component analysis* (PCA) to boil down the highly complex data to a few key factors. We combined this approach with other statistical methods to make PCA results more obvious and fine-grained by retaining small genetic differences. We also mixed in variance and regression tests, tools for measuring geographic and genetic distances, and a clustering program called ADMIXTURE that uses SNPs to assess the percentage of DNA that comes from various ancestral groups.

Through these methods, we identified an ancestral genetic component likely linked to early pastoralists but different

Ethical Frameworks for Genomic Research

To respect the autonomy, cultural heritage, dignity, and human rights of Indigenous peoples in Africa and elsewhere, and to avoid some highly objectionable practices of much past research, scientists today follow strict ethical frameworks when conducting research involving these populations. These guidelines, set forth in international standards and enforced by bodies such as institutional review boards, go beyond obtaining informed consent from the subjects to include respectfully engaging with involved communities, considering cultural values, doing the least possible harm for the greatest benefit, and sharing the data, results, and benefits of the research.

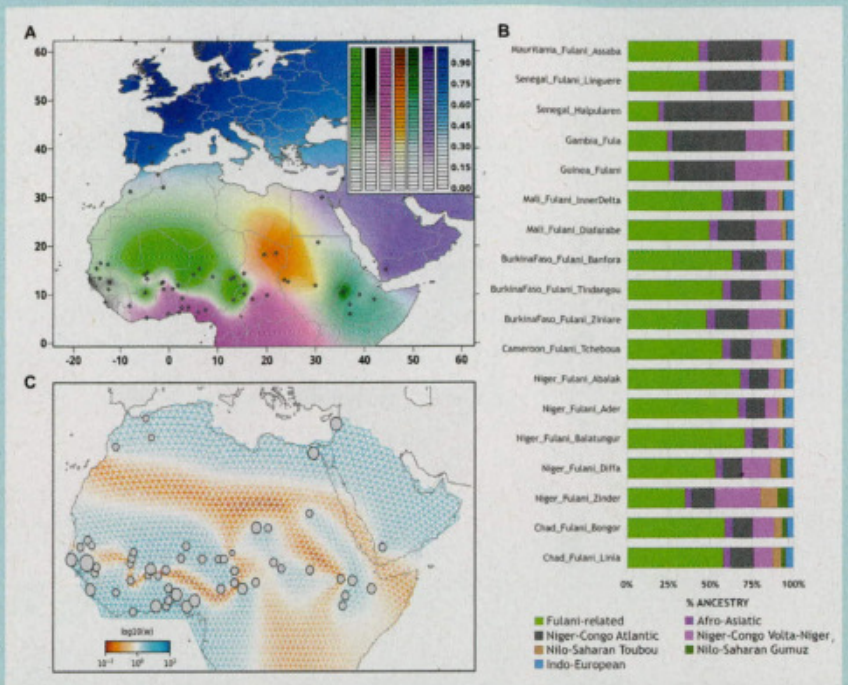
The study described here was conducted by researchers employed in the Czech Republic, Sweden, and the United States, and it involved taking biological samples (cheek swabs and saliva samples) from people in seven African countries with longstanding Fulani communities: Senegal, Mauritania, Mali, Burkina Faso, Niger, Cameroon, and Chad. In each country, we collaborated with local Fulani representatives to contact and organize each community. Once we described the project and its goals to them, these envoys discussed the information with local chiefs, who then invited unrelated people to a meeting, where we described the project in detail and answered all questions. Fulani representatives translated our words into their native language (Fulfulde). We also stressed that participating in the project was fully voluntary and would involve neither compulsion nor compensation. We still maintain regular contact with each community's representatives and provide comprehensive information to local communities regarding all the research papers we publish.

The study was approved by the Ethics Commission of Charles University in Prague and the Swedish Ethical Review Authority. Because ethics committees were not established in the countries where we collected samples when we conducted our fieldwork, we acquired the needed permits from applicable state institutions before we began our research. The population genetics intention of our research was explicitly spelled out in these permit applications. We also obtained informed consent from all Fulani participants prior to collecting samples, ensuring that our research methods met the standards outlined in the Declaration of Helsinki. (This methodology has been paraphrased from Fortes-Lima, C.A., et al. 2025. *The American Journal of Human Genetics* 112:261–275.)

from the genetic variation observed in other present-day African populations. We also found a gradual change in the genetic makeup of Fulani across the Sahel belt from west to east, which suggests regional differences between western and eastern Fulani. PCA revealed significant genetic differences between the Fulani communities of Burkina Faso and those of Eastern Niger, Chad, and Cameroon. Moreover, western and central Fulani (Senegal, The Gambia, Mauritania, Guinea, and Western Niger) are more mixed than eastern Fulani (Chad), consistent with the west-to-east gradient.

Our geographic analysis confirmed that the Sahara Desert and Lake Chad posed barriers to migration between sub-Saharan Africa and North Africa, and between central and eastern groups, respectively. Moreover, we found strong links between subsistence style and genetic differences: Fulani farmers in Senegal, The Gambia, and Guinea are significantly genetically different from Fulani pastoralists elsewhere.

Beyond this west–east genetic variation, we found evidence for the geographic separation and subsequent cultural shifts among Fulani groups in studies of the Fulani language (called Pulaar or Fulfulde), which belongs to the Atlantic branch of the Niger–Congo family of West Africa (spoken in Senegal, The Gambia, Guinea, and Sierra Leone). These findings highlight differences between Fulani dialects from the western Sahel belt, where most Fulani live today, as compared with the central or eastern regions. However, we also found variations (*see bar plots in figure at right*) corresponding to the Niger–Congo Volta–Niger language family of southern West Africa (Ghana, Togo, Benin, and parts of Nigeria); the Nilo-Saharan family of Central and East Africa (Chad, Sudan, South Sudan, Uganda, and Kenya), and the Afroasiatic language groups of North Africa, the Horn, and the Arabic regions of the Middle East.



Fortes-Lima, C. A., et al. 2025.

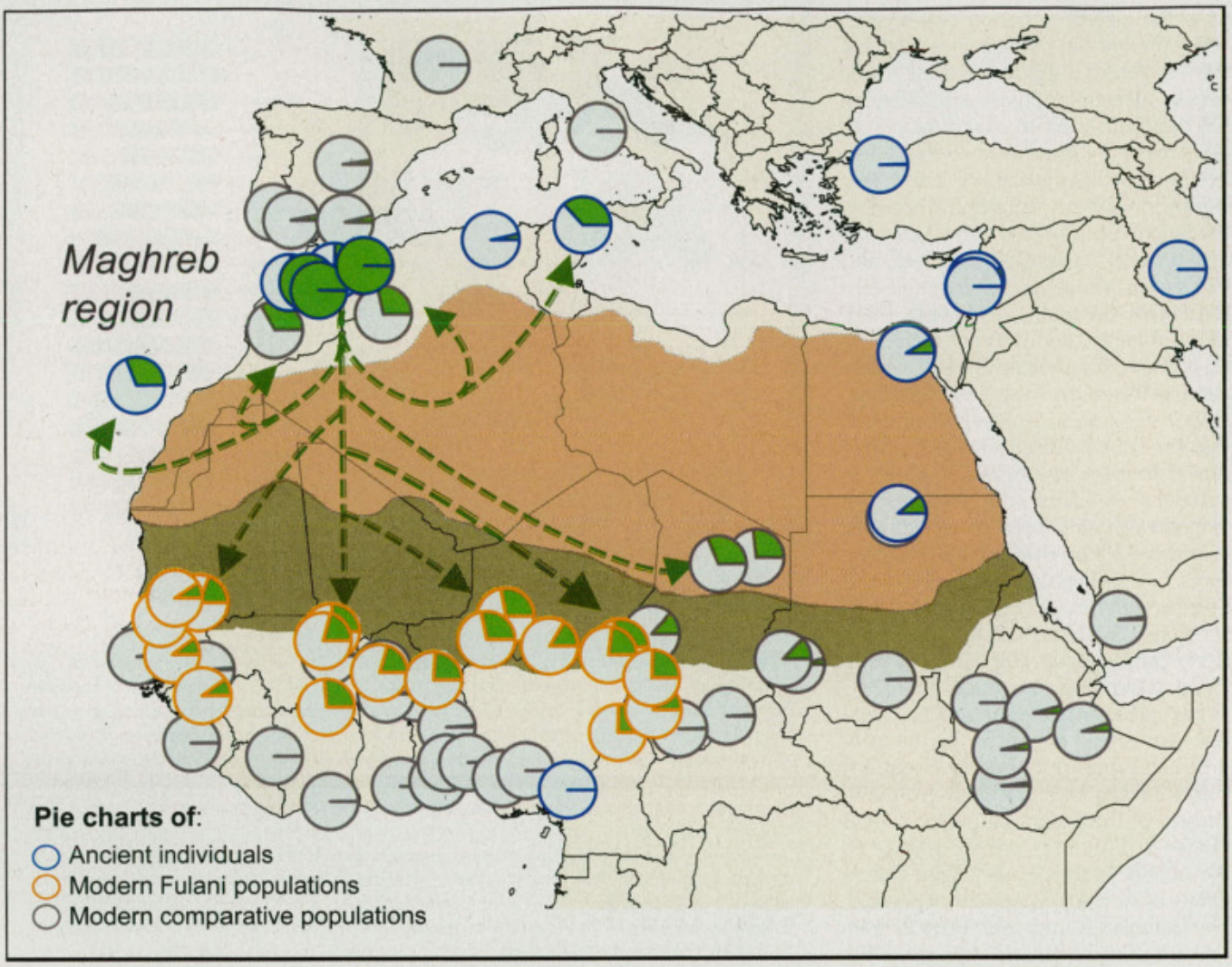
Genomic analysis reveals the proportions of estimated ancestries in modern Fulani and allows mapping of Fulani migrations across Africa. The ADMIXTURE program (*A*) analyzes heritable genetic markers (called *single nucleotide polymorphisms*) based on an assumed number of putative ancestral groups (seven) in each population. A statistically smoothed grid maps the distribution of the highest values of the estimated ancestral groups (*each color*) and the sampling locations (*black diamonds*) of each population. Bar plots (*B*) show the percentage of each ancestral group found in each of the 18 Fulani populations sampled. The highest values were observed for the Fulani-related component (*light green*). The genetic makeup of Fulani populations changes gradually across the Sahel belt from west to east (suggesting population structure), whereas western and central Fulani are more mixed than eastern Fulani (suggesting different interactions with other local populations). Effective migration rates based on the falloff of genetic similarity over distance are shown logarithmically (*C*) to visualize higher (*blue*) and lower (*brown*) migration rates. Today, the Sahara Desert represents a crucial geographical barrier for human migration in North Africa. Also, cultural factors could be a genetic barrier between linguistic groups across the Sahel belt.

Archaeogenetics and Past Migrations

The preservation of biomolecules such as proteins and DNA in archaeological remains such as bones depends heavily on environmental stability. Successful extractions and analyses of the oldest DNA have come from cold regions of Eurasia, particularly caves, in which low and stable temperatures helped preserve genetic material. By contrast, much of Africa, especially sub-Saharan regions, presents a challenging environment for DNA preservation: Heat and humidity can promote the growth of microbes, which can consume DNA or produce enzymes that degrade it.

Fulani experience fewer symptomatic malaria cases, lower infection rates, and reduced parasite densities compared with neighboring ethnic groups.

The oldest successfully recovered DNA in Africa comes from Morocco, where skeletons associated with the Iberomaurusian culture were found—again, mostly in caves. These ancient hunter-gatherers lived between 10,000 and 20,000 years ago in the Maghreb region in the western part of North Africa and have shown biological ties with non-African populations, such as the Middle Eastern hunter-gatherers known as Natufians, who predate the domestication of plants and animals. However, similarly ancient genetic evidence is absent from regions adjacent to the southern parts of the Sahara Desert, which makes



Cesar A. Fortes-Lima

Ancestry associated with the Iberomaurusian culture (a misnomer coined by archaeologists who thought this Upper Paleolithic group reached Africa from the Iberian Peninsula of Spain and Portugal), shows up in ancient human remains and in living people. These pie charts show the proportions of this ancestry (*green slices*) estimated to exist in ancient remains (*blue*), modern Fulani (*orange*), and modern comparative populations (*gray*). Green arrows over the Sahara Desert (*tan*) and the Sahel belt (*olive*) indicate the likely routes of spread of Iberomaurusian ancestry.

piecing together the prehistory of the Fulani that much more difficult.

To understand relationships between modern Fulani and ancient populations, and to try to determine which peoples intermixed, we merged our full dataset (Fulani and non-Fulani) with DNA taken from the remains of 91 ancient individuals. This work required special treatment, because genetic data from such remains are often damaged or incomplete. We then used PCA, ADMIXTURE, and other tools to build a *phylogenetic diagram*—a kind of family tree depicting evolutionary relationships. Understanding the timing of these gene flows was more involved and relied on modeling how the SNPs break apart and are shuffled over ensuing generations—the more scrambled they are, the longer ago the mixing with other groups must have taken place. Other genetic tests allowed us to estimate changes in Fulani populations over the past 50 generations, as well as instances of new Fulani communities splitting off.

Considering this potential for smaller groups to break from larger ones, as well as the endogamous influence of practices such as Guérewol, we also looked for evidence of endogamy by analyzing *runs of homozygosity* (ROH), long sections of DNA in which a child inherits the same set of SNPs from both parents. Homozygosity grows more likely the more closely related the parents are. Population dynamics inferred from genetic diversity losses show that the Fulani underwent major population drops around 800 and 400 years ago—perhaps because of conflict, disease, famine, or environmental factors, although such potential causes are only speculation. ROH indicators of endogamy fell between those typical of Eurasians and Africans, further suggesting gene flow from non-sub-Saharan sources such as North Africa and Eurasia. Western Fulani had less endogamy and genetic isolation than eastern Fulani. Some areas of high endogamy were descended from small offshoot communities.

Strikingly, all Fulani groups also carry a detectable genetic signature related to Iberomaurusians, the ancient Maghreb hunter-gatherers mentioned earlier. Previous studies have also found this ancestry in other ancient North African individuals and modern Amazigh populations (historically known as "Berbers"). Amazigh are the closest living group to modern Fulani in terms of their mix of ancestry, which is about 18 percent the same. This overlap highlights deep historical connections between North and sub-Saharan African

groups at least 10,000 years ago, likely because of migration and intermixing. Indeed, the presence of this ancestry in the Fulani suggests that gene flow between groups from different African regions occurred, likely during the Green Sahara period 12,000 to 5,000 years ago, contributing to the complex genetic mosaic of today's Sahelian populations.

Although physical remains are desirable for establishing migration and population patterns, we believe these analyses demonstrate the value of tools such as archaeogenetics. As the American biochemist Vincent Sarich is quoted as saying, "I know my molecules have ancestors; you must prove your fossils had descendants."

A prior ancient DNA study illustrated this challenge when skeletons from a rock shelter at Shum Laka in Cameroon, dated between 3,000 and 8,000 years ago, were found not to be related to modern Bantu-speaking cultures, despite being from the region traditionally considered the Bantu homeland. About one-third of the DNA of the Shum Laka individuals came from ancestors who were more closely related to present-day hunter-gatherers in western-central Africa. The other two-thirds came from an ancient source in West Africa, representing an unsampled population of modern humans that we didn't know about before. This finding suggests either that the putative Bantu ancestors had a different origin or that the Shum Laka individuals belonged to a population that lived alongside the ancestors of Bantu speakers but did not contribute significantly to their genetic ancestry.

Our analyses suggest a connection between the Shum Laka people and modern Fulani. Genetically, PCA plots place the Fulani between ancient and modern sub-Saharan Africans, North Africans, and Eurasians. They also draw a clear distinction between West and Central African Fulani, with Fulani from Cameroon and Niger showing closer genetic ties to the Shum Laka people. Establishing these connections is another way that we are making notable progress in understanding African population history, unraveling patterns that were hard to discern until now.

New Clues from Archaeogenetics

In the early 2000s, when the field of archaeogenetics was still in its infancy and DNA data were scarce, our understanding of population history came primarily from studying genetic diversity in present-day populations, particularly data from mitochondrial DNA (mtDNA). This part of our genome, inherited maternally and changing through new mutations, serves as a kind of genetic thread running through generations. Even then, we observed that about 10 percent of Fulani pastoralists from Burkina Faso, Cameroon, and Chad carried mtDNA variations of West Eurasian origin. These variations are present in the Fulani because of admixture with North African or Eurasian groups.

Viktor Černý

The Fulani of the subgroup called the Woɗaaƀe are fully nomadic and must carry all of their equipment with them during *transhumance* (seasonal movement of livestock). For this purpose, they usually use donkeys, which the preponderance of evidence indicates were domesticated in Africa. Men typically lead the herds while women carry household items.

Subsequent research has shown that Fulani mtDNA and nuclear DNA both carry variations indicative of West Eurasian ancestry. Indeed, a previous whole-genome study suggested that the Eurasian component within the Fulani population might be quite ancient, perhaps reaching back to the Green Sahara period when the first cattle pastoralists appeared in North Africa. To understand such *genetic enrichment* (genes or genetic features found more often in one group than in others) of Fulani African ancestry, we used *haplotype*-based methods, which look at groups of heritable genes that are more prevalent in individuals of a particular ancestry—in this case, African. These enrichment regions can be used to understand the genetic basis of traits and diseases, as well as to identify potential genetic markers for personalized medicine in admixed populations. For instance, in Arabs and Nubians a gene region related to cellular signaling, called the Duffy antigen receptor for chemokines (*DARC*), shows enrichment for African ancestry, whereas in the Fulani the taste 2 receptor (*TAS2R*) gene cluster for expressing bitter taste receptors and apolipoprotein L1 (*APOL1*) are enriched for non-African variants.

This nomadic way of life presents a challenge for archaeologists, because the temporary camps leave behind virtually no traces.

Viktor Černý

The Fulani comprise around 25 million people in groups scattered across sub-Saharan Africa. Although some have put down roots, most are nomadic pastoralists whose seasonal routes can span hundreds of kilometers.

Milk and Medical Implications

The Fulani's genetic heritage extends beyond ancestry, encompassing adaptations to the Sahel environment with potentially significant biological and medical implications. One prominent adaptation is the high prevalence of the lactase persistence (LP) allele, which enables the digestion of milk into adulthood (particularly the milk sugar lactose). This trait is advantageous for pastoralist societies reliant on dairy products. Interestingly, the LP allele observed in the Fulani is often associated with European and North African populations, suggesting gene flow from these groups into the Fulani gene pool. This *introgression* or adaptive admixture likely conferred a selective advantage, facilitating the adoption and maintenance of pastoralist practices.

Most strikingly, the European variant associated with lactase persistence was likely introduced into ancestors of analyzed Fulani populations from Ziniaré, Burkina Faso, through cultural contact and genetic admixture with groups from North Africa. Eurasians likely brought the gene to the region during late Stone Age and Bronze Age migrations across the Strait of Gibraltar, around the Levant, or across the Mediterranean. The LP allele has since been strongly favored by natural selection. This conclusion aligns with the fact that the Fulani consume large quantities of fresh cow's milk; it is not difficult to see how the ability to digest milk as a substitute for water might offer a significant evolutionary advantage in populations living in semiarid environments.

One prominent adaptation is the high prevalence of the lactase persistence allele, which enables the digestion of milk into adulthood.

Notably, although the LP variant found in the Fulani is of West Eurasian origin, the larger surrounding regions on chromosome 2, where the variant allele occurs, appear to be of North African origin because of admixture between Western African populations and North African populations carrying the European LP variant. Because this genetic signature is also shared by other nomadic populations such as the Moors and Tuareg, we suggest that the ability to digest milk into adulthood may have affected the spread of pastoralist groups across the western Sahel and savanna belt. But the Sahel belt crosses all of North Africa; in the east, it reaches the doorstep of the Arabian Peninsula. It is perhaps not surprising then that, in the eastern part of this region, we find Arabic-speaking populations such as the Baggara and Shuwa whose ancestors brought with them a different genetic variant for lactase persistence from Arabia.

In addition, the Fulani exhibit unique immunological characteristics. Studies have documented a lower susceptibility to *Plasmodium falciparum*, the parasite responsible for the most severe form of malaria. Researchers have observed that the Fulani experience fewer symptomatic malaria cases, lower infection rates, and reduced parasite densities compared with neighboring ethnic groups. The underlying mechanisms for this resistance are not entirely understood, but they may involve distinct immune response profiles and genetic factors unique to the Fulani. These findings highlight the evolutionary interplay between human populations and pathogenic pressures, and open new potential avenues for medical research and public health interventions in Africa.

Migration Corridors

Our genomic research highlights how interconnected Sahelian populations are in their population histories. Although there are exceptions—such as the Arab Rashaayda, whose ancestors arrived in Eastern Africa from Saudi Arabia only a few generations ago—most groups across the Sahel have experienced admixture at various points in history. The Sahel belt has been a zone of many demographic movements because of its pivotal position at the intersection of different geophysical, climatological, and cultural areas. These movements have brought genetic contributions from all surrounding regions, including the Middle East, Mediterranean Europe, North Africa, and sub-Saharan Africa.

Unfortunately, relations among Sahelian groups have become increasingly strained in recent decades. Climate

Viktor Černý

Lake Boukou in northern Chad's Ounianga region is fed fresh, high-quality water from the Nubian Sandstone Aquifer. Such reliable oases are vital sources of water and respite for herders such as the Fulani in regions where rain is rare and a few dry years can turn vegetated land to desert.

change has reduced rainfall, and agricultural expansion has encroached on grazing lands. Tensions over land and water access frequently escalate into conflicts between and within countries. Although pastoralists are frequently marginalized and stigmatized, there is no doubt that the prosperity of Sahelian societies depends on harmony and cooperation between herders and farmers.

Besides the observed population structure among Sahelian populations, our hypothesis of a bidirectional migration corridor across the Sahel/savanna belt proposed in 2007 remains valid today. In the words of the renowned Cameroonian historian Eldridge Mohammadou, "None of the ethnic groups of this country can claim to have always been there: All of them, without exception, were at one time or another in the past, from a source outside the geopolitical triangle that constitutes Cameroon today." From an evolutionary perspective, human populations are not static; they are like a vast ocean, continuously shaped by the tides of climate and time.

An Evolving Picture

Although significant strides have been made in understanding the Fulani's genetic landscape, many questions remain. If possible, obtaining more ancient DNA from archaeological sites within the Sahel and Sahara regions would provide direct insights into the ancestral populations that contributed to the modern Fulani gene pool, offering a clearer picture of the migratory routes and admixture events that have shaped their history. Additionally, exploring the functional aspects of the Fulani's genetic adaptations could yield valuable information. Investigating how specific genetic variants confer advantages, such as malaria resistance or efficient lactose metabolism, can enhance our understanding of human adaptation and inform medical research.

These genetic insights into the Fulani not only illuminate their biological history but also enrich our understanding of their cultural and historical narratives. The admixture events and migratory patterns reflected in their DNA correspond with oral traditions and historical accounts of the Fulani's movements across Africa, many of which describe an eastern origin in Egypt, Syria, or North Africa, followed by a westward migration.

New genetic research methods are allowing us to combine current technology with Fulani traditional knowledge to better understand the origins of this diverse and widespread group. As scientists continue to delve into their past, the Fulani's legacy offers profound insights into the broader narrative of human evolution, migration, and health across the African continent.

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When the Body Turns on Itself

Molecular insights are revealing the hidden architecture of immune dysfunction—and how to stop autoimmune diseases before they begin.

Jane Buckner

In the mid-1990s, I was working as a rheumatology fellow at the University of Washington studying rheumatoid arthritis. One day, I was asked to help draw blood from a research participant, which usually happened when the blood draw was particularly difficult. When I walked into the exam room, I found a young girl with type 1 diabetes sitting with her mother, who was participating in the study to help with research on the genetics of her daughter's disease. The mother had severe rheumatoid arthritis, and she was in so much pain that she could not straighten her arms for the blood draw.

Both type 1 diabetes and rheumatoid arthritis are autoimmune diseases, in which the body attacks its own beta cells and joint tissues, respectively. There are many different types of autoimmune diseases, but there is no collective approach to all of them, even though these diseases run in families and share genes. My encounter with this mother and daughter was formative and galvanizing for me: I realized that if we could uncover the deep commonalities between autoimmune diseases, we could develop new treatments to help millions of suffering patients and alleviate the immense struggles of whole families. The lab I worked in was already studying the genes shared among autoimmune diseases, but seeing this mother and daughter together firsthand made the implications of our research clear and has inspired my work for the three decades since.

The stakes couldn't be higher for our immune system: Without it, we fall prey to infections or cancer, and we fail to heal. To protect our bodies, our immune systems—a complex biological web composed of cells, molecules, and intricate signals—orchestrate responses to stresses. These systems function seamlessly most of the time, but sometimes the immune system makes a mistake and tries to protect us from ourselves, attacking healthy tissue. The resulting disease depends on the immune system's target: skin, joints, nerves, muscles, thyroid, or blood. Anything is fair game, resulting in diseases such as psoriasis, rheumatoid arthritis, multiple sclerosis, Grave's disease, or anemia, to name some of the 140 known autoimmune diseases. Each disease is unique, but they share a fundamental cause: a mistake by the immune system. As I began my career, figuring out how such mistakes unfold was at the forefront of my field.

Autoimmune diseases affect between 25 and 50 million Americans, and many of these diagnoses, such as type 1 diabetes, have been increasing in incidence over the past 50 years. Despite major advances in the treatment of autoimmune diseases in recent decades, no autoimmune disease is curable, and many lead to disability and shortened life expectancy. Nevertheless, the mother and daughter who inspired my work on the commonalities among autoimmune diseases did indeed play a part in helping to improve treatments for people like them. Today, given modern medical advancements, their experiences would be entirely different: The mother's pain would likely be much better managed, and the daughter might never even develop type 1 dia-

If we could uncover the deep commonalities between autoimmune diseases, we could develop new treatments to help millions of suffering patients and alleviate the immense struggles of whole families.

QUICK TAKE

Autoimmune diseases seem disparate, but they share genetic underpinnings and exhibit similar immune system malfunctions. Triggers include lifestyle and environmental exposures.

Researchers are now uncovering how these early immune system misfires unfold—and how to catch them in time—using predictive biomarkers such as autoantibodies.

By screening for warning signs and targeting shared pathways with new therapeutics, researchers hope to be able to stop autoimmune conditions before symptoms begin.

Jason McAlexander

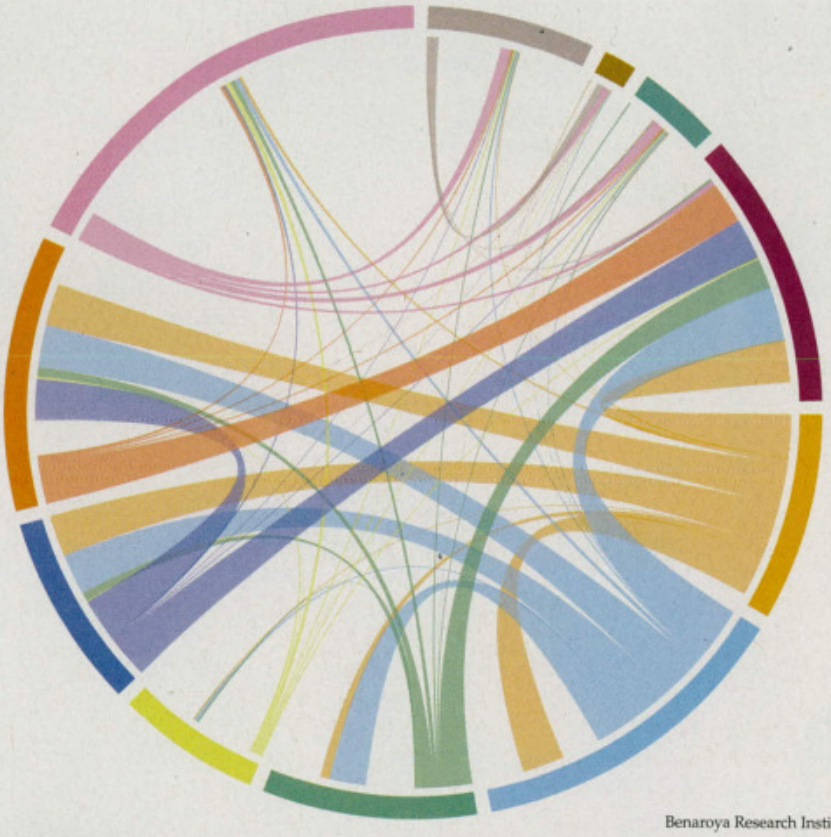
The classic facial butterfly rash of lupus, an autoimmune disease that attacks connective tissues, is illustrated above surrounded by the genes, autoantibodies, and environmental factors that may contribute to the development of the disease. Many of the same genes are implicated in different autoimmune diseases, suggesting shared processes of progression. Researching the genes that autoimmune diseases have in common has led to the discovery of shared immune pathways and new diagnostics and treatments.

betes. As researchers have uncovered many genes that autoimmune diseases share—which allowed me to begin studying how those bits of DNA affect the immune system—I have witnessed an explosion of treatments that lower the level of disability and lengthen patients' life expectancies.

Interrelated Genetics

When I first met the mother with rheumatoid arthritis in the 1990s, researchers knew of only a few genes that were involved in the development of autoimmune diseases. Within the next 10 years, technological advances had allowed geneticists to study the genes linked to autoimmunity in much greater depth. We hoped that these genetic studies would reveal the cause of autoimmunity. But the answer was not so simple: Up to 100 genes are involved in autoimmune disease development. Each disease involves different clusters of genes, but my colleagues and I were looking for significant commonalities. (*See figure on page 242.*) Importantly, many of these genes influence immune system functions, and multiple risk variants are shared between autoimmune diseases, giving us reason to believe that studying these shared genes could reveal how the immune system makes the mistakes that lead to autoimmune diseases. Even though that sounds simple enough, the interplay of genes, environment, and the immune system is incredibly complex.

In my lab, we wanted to understand how the genes that put people at risk for autoimmunity alter immune cell function. We had already noticed that when study subjects' immune systems were challenged, the cell signaling responses of healthy family members of patients with autoimmunity were more like those of people with disease than healthy individuals who did not have relatives with autoimmunity, a clear sign that genetics is involved. So, we began studying individuals who had the risk genes but who did not have autoimmune disease. In so doing, we identified the genetic fingerprint of autoimmunity risk.



Known gene associations among autoimmune diseases are shown using what's called a *chord diagram*, a visualization of the interconnected relationships between data in a matrix. The genes are arranged radially with the relationships between them connected with arcs. The more genetic associations between diseases, the thicker the arc lines.

Certain immune pathways are involved in autoimmunity across various diseases, and these pathways can go awry through a variety of triggers, including genetics or environmental exposures. Identifying these pathways gave my team and others in my field a much broader way to understand the mistakes that the immune system makes. My lab as well as many others began to explore how these immune pathways could be targeted therapeutically.

We need to know more about how the genetic and environmental factors that lead to autoimmune disease impact immune cells to be able to predict who will develop which disease.

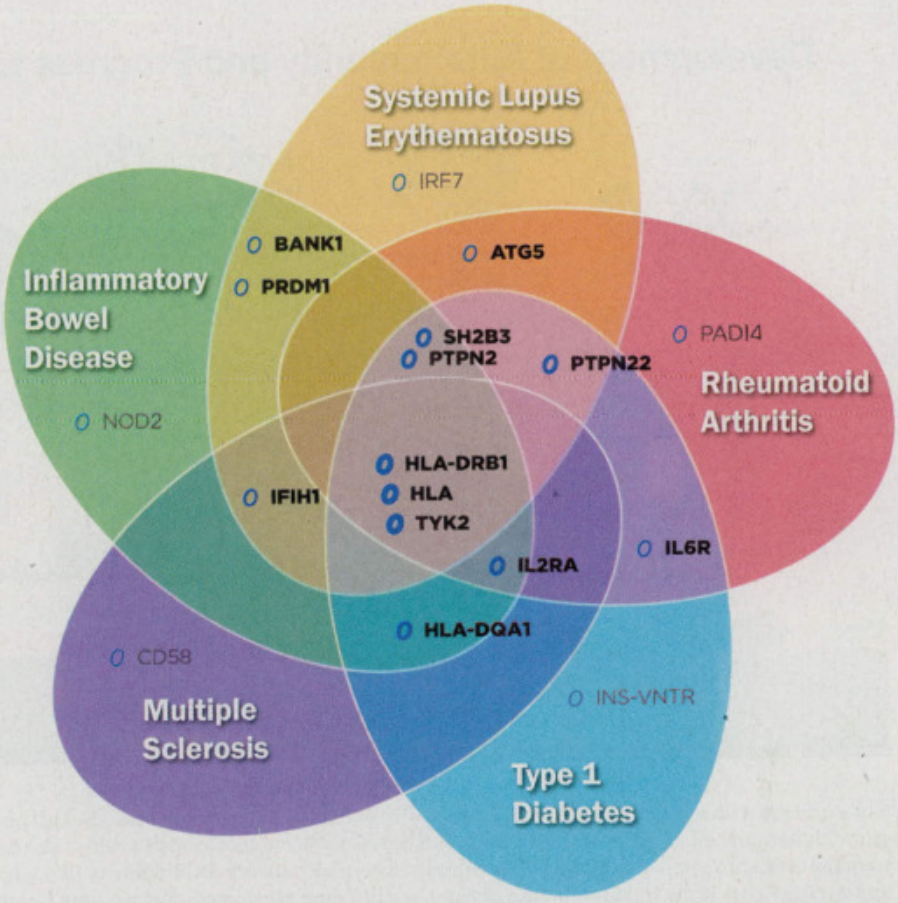
Twenty years ago, the experiments that we used to link the autoimmune genotype to phenotype were done one gene at a time and one immune cell type or immune pathway at a time. Today, technological advances have allowed us to look across the genetic and immune landscape, revealing important information about thousands of genes, proteins, and cells at a time, and accelerating the rate of discovery and the development of new treatments.

Despite these technological advances, there are limitations to such genetic studies of autoimmune diseases. To understand the impact of the genes, one needs to understand the workings of the immune system in detail, but there was surprisingly limited information at the time about what happens to autoimmune patients at the cellular level. Most significantly, not everyone who has the autoimmunity risk genes ends up being diagnosed with autoimmune disease, suggesting that we need to know more about how the genetic and environmental factors that lead to autoimmune disease impact immune cells to be able to predict who will develop which one. As demonstrated by the daughter with type 1 diabetes, who developed a different autoimmune disease than her mother, factors beyond genetics—our homes, jobs, exposures, diets, and lifestyles, unique to each of us—may influence the type or timing of an autoimmune disease. Although much had been learned from model systems about how the immune system works, I wanted to take the next step and study autoimmunity in people.

By the early 2000s, I was a practicing clinician in rheumatology and had started my first faculty position at Benaroya Research Institute (BRI), where I still work today. I spoke with my patients about the impact and symptoms of their diseases, and I recommended treatments (albeit limited at the time). But I also wanted to connect those experiences with what was happening in their immune systems at the cellular and molecular levels. To do so, I needed blood samples from patients, and because no two patients are exactly the same, I needed to know more about each patient beyond their diagnosis (such as age, sex, lifestyle, exposures, medications, and health history). So I teamed up with another faculty member, Carla Greenbaum, an expert in type 1 diabetes. We both were passionate about the importance of bringing

discoveries from the lab to the patient. Based on that goal, we developed the first comprehensive bank of blood and tissue samples from individuals with many different autoimmune diseases, along with their detailed histories, building what would become BRI's Biorepository.

As part of this work, it became clear that we needed to assemble a detailed catalog of healthy as well as compromised immune systems, so that we could study the differences in more detail. So we expanded our collection of samples to include participants who did not have autoimmune disease. This biorepository has grown to include 15,000 participants with more than 10 different autoimmune diseases and more than 2,000 healthy individuals. These samples are now used globally as a reference for studying autoimmune diseases. The repository has helped investigators at my institute and elsewhere understand the causes of autoimmune diseases and develop new ways to diagnose and treat them.



Benaroya Research Institute

Studying the specific genes shared by different autoimmune diseases led the author to discover shared immune pathways that could be used as therapeutic targets. The center of the diagram shows genes that are common between all of these autoimmune diseases.

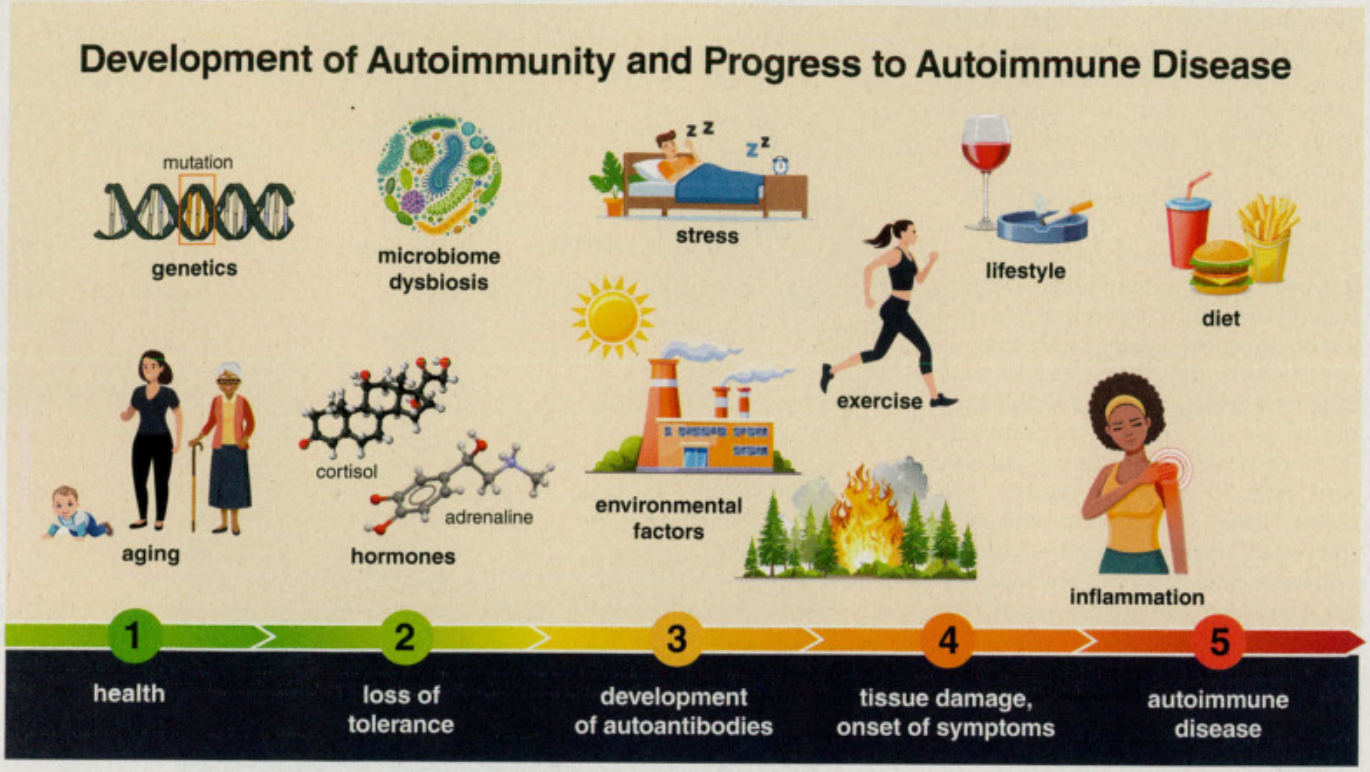
Learning to Predict Type 1 Diabetes

Even as my team and I were identifying the immune pathways that autoimmune diseases share, I could still see in my clinical practice that treating patients once they already had these diseases did not cure them. Therapeutics can target the immune pathways where a mistake is occurring and can help control symptoms and diminish disabilities. But as soon as a patient stops the immunomodulatory medication, the disease returns. Curing people once these immune mistakes arose and once tissues were damaged seemed impractical and maybe impossible. If we wanted to actually cure people, we needed to intervene early. If we could predict who would develop autoimmunity, I believed we could prevent it. Which genes confer autoimmunity risk, what pathways can be targeted to prevent disease, and what lifestyle and environmental factors are contributing have become active areas of research.

At the same time, studies on type 1 diabetes began to provide a solid approach for predicting who will be diagnosed with the autoimmune disease. The immune system of a person with type 1 diabetes attacks and destroys their pancreatic beta cells, which make insulin. People are typically diagnosed with type 1 diabetes when they have elevated blood glucose levels due to the lack of insulin. By that point, their immune system has destroyed so many beta cells that they will be reliant on insulin therapies for life. Researchers, including me, have worked for decades to better identify people at risk, with the goal of preventing their progression to disease.

In 1974, two groups of researchers at Middlesex Hospital Medical School in England and the Royal Infirmary in Scotland simultaneously identified immune system proteins called *autoantibodies* that target healthy tissue and that notably correlate with and precede disease diagnosis. They discovered the *islet cell antibody* (ICA), which targets the insulin-producing islet cells in the pancreas and became a key marker of type 1 diabetes. This leap forward sparked a flurry of research

In 2015, type 1 diabetes became the first autoimmune disease for which clinicians were able to screen individuals for autoantibody presence and predict who would progress to disease diagnosis.



Barbara Aulicino

Not everyone with a genetic risk for autoimmune disease goes on to develop one. They all begin with immune tolerance, a state of unresponsiveness to the molecules that could cause an immune attack on one's own tissues. The complex interplay between environment, lifestyle, and genetics that leads to autoimmune disease is still being elucidated. But we now know that the development of *autoantibodies*, the body's signals to attack its own tissues, precedes symptom onset by years and can be used to intervene early.

on how the immune system causes type 1 diabetes and on the identification of other autoantibodies associated with the disease. Five different targets have been identified to date.

In 2015—40 years later—type 1 diabetes became the first autoimmune disease for which clinicians were able to screen high-risk individuals for autoantibody presence and predict who would progress to disease diagnosis. A landmark consensus paper showed that relatives of people living with type 1 diabetes who had two or more autoantibodies approached 100-percent certainty that they would develop the disease in their lifetime.

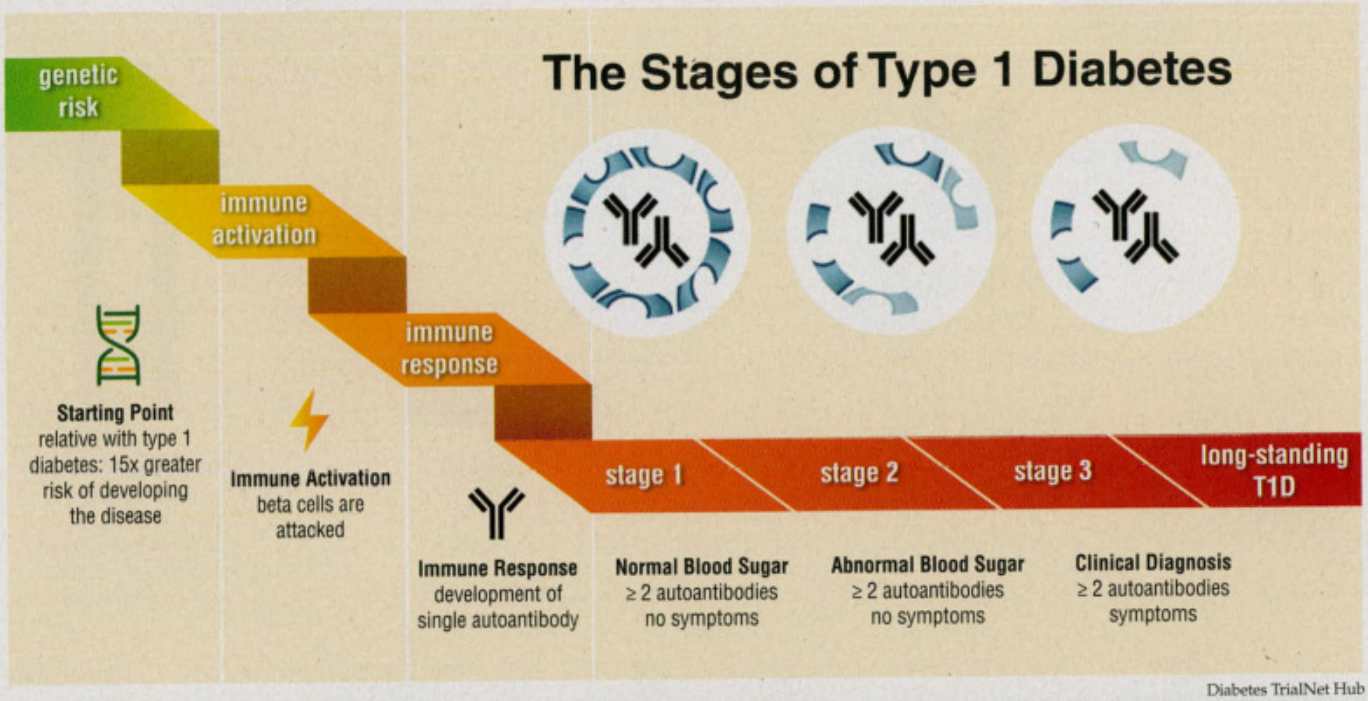
Based on this finding, I hoped, along with many others in my field, that autoantibody detection prior to disease diagnosis would be useful in other autoimmune diseases as well, including rheumatoid arthritis, lupus, and ulcerative colitis. Importantly, the presence of autoantibodies before disease onset, along with the specific genes associated with patient populations, suggests a pathway for screening patients for risk of type 1 diabetes and many other autoimmune diseases.

The presence of autoantibodies before disease onset, along with the specific genes associated with patient populations, suggests a pathway for screening for autoimmune disease risk.

Once predicting type 1 diabetes was possible, researchers could then test whether it could be prevented by performing clinical trials in individuals identified as being at-risk based on the presence of two or more autoantibodies. TrialNet—an international network of researchers and physicians (including those of us at BRI) put together in 2001—began conducting these trials, testing a variety of drugs that target the immune system.

In 2019, TrialNet researchers led by Kevan Herold of Yale University reported that teplizumab, a drug targeting T cells, could delay the onset of type 1 diabetes by a median of two years, and in some cases longer in at-risk individuals. For the first time, a therapy had successfully altered the course of development of an autoimmune disease and demonstrated that successful intervention is possible prior to disease diagnosis.

The U.S. Food and Drug Administration approved teplizumab (brand name Tzield) to delay the onset of type 1 diabetes on November 17, 2022. Patients who are in stage 2 in the disease's progression and who are at least eight years old can now be prescribed teplizumab (*see figure on page 246*). For



Diabetes TrialNet Hub

The progression of type 1 diabetes (T1D) begins with immune activation in a person with genetic risk for the disease. Traditionally, diagnosis of this type of diabetes was only possible once insulin-producing tissues had already been damaged, leading to lifelong dependence on insulin. To prevent the disease, one would need to intervene earlier. Now that the specific autoantibodies associated with type 1 diabetes are known, they can be detected before symptoms emerge. A new treatment, teplizumab, was approved in 2022 and can treat patients early, delaying disease onset. The three circles show the decline of insulin-producing beta cells in each stage.

type 1 diabetes patients and their families, a delay in the certain development of the disease can mean two or more years of a child running out to recess without having to check their blood sugar. Or this treatment might delay type 1 diabetes onset from childhood to teen years or from teen years to early adulthood. Even though a two-year delay may not seem like a big improvement, it also reduces lifelong damage: These patients can maintain insulin production for longer, which means in turn that they will have better blood glucose control, less hypoglycemia, and reduced rates of disease complications in the long term.

An Explosion of Early Interventions

Teplizumab provided a proof of principle: We can identify individuals at high risk of developing an autoimmune disease by testing for biomarkers such as genes and autoantibodies, and then improve their outcomes with early treatment. Next, we needed to find those biomarkers for other autoimmune diseases.

Combined with our knowledge in treating rheumatic diseases using immunotherapy, we are on the verge of treating patients with precision medicine based on the specifics of their genetics and immune systems. Using information about a patient's genes, immune cells, and molecules in circulation, we are even learning to predict which patients will respond to specific autoimmune treatments.

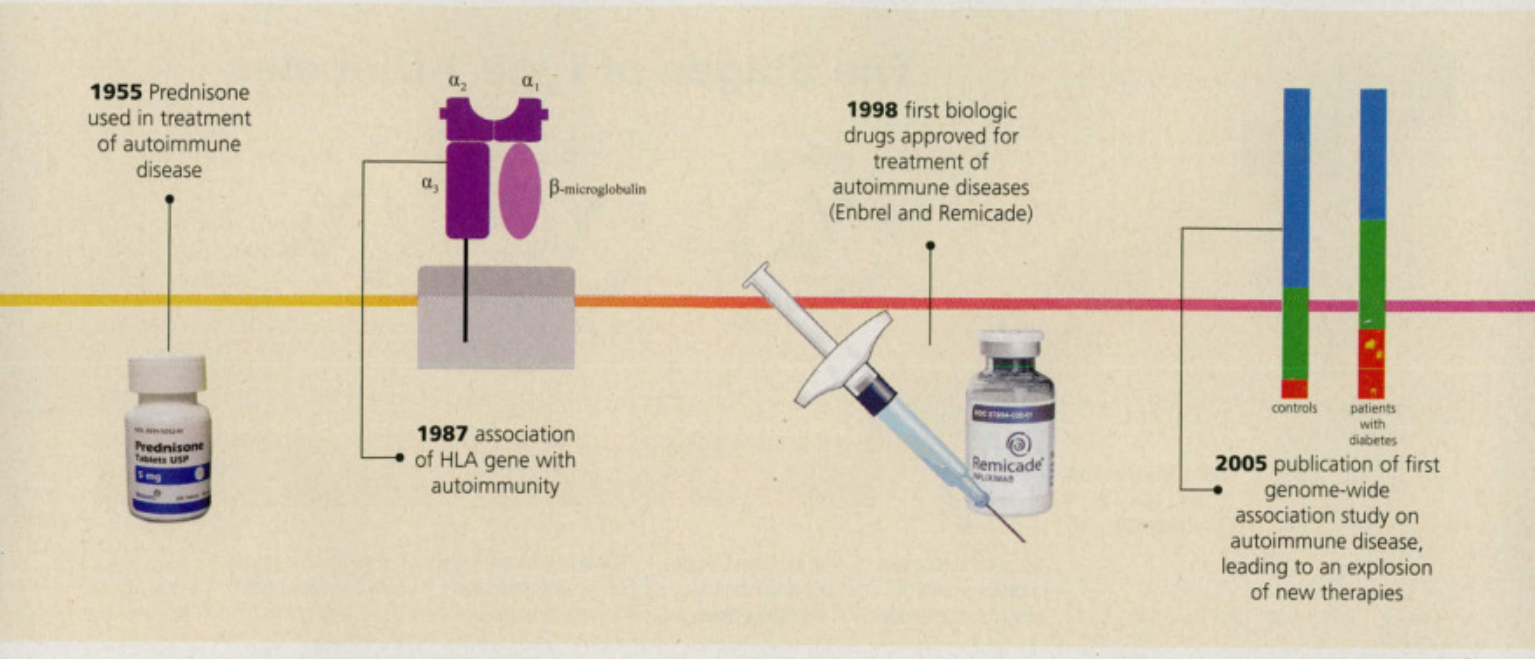
Figuring out implementation for early intervention remains an ongoing area of research: Should newborns be tested for the genes associated with type 1 diabetes, for example? Should kids with those genes be tested later in childhood for autoantibodies? In the meantime, those searching for this testing can look to TrialNet (trialnet.org).

Following individuals with genetic risk for autoimmunity and screening them for autoantibody development can ensure that diagnoses are made early, before severe medical complications arise. Trials of treatments to delay or prevent other autoimmune diseases are moving forward, too.

Early in my career, many of my patients were like the mother with rheumatoid arthritis: severely disabled, some even using mobility aids such as wheelchairs. Since the 1990s, my colleagues and I have witnessed an explosion of drugs to treat autoimmune disease. Today, it is rare to see a rheumatoid arthritis patient in so much pain or using a wheelchair.

For example, we can now identify and treat a patient with the potential for developing rheumatoid arthritis,

We can identify individuals at high risk of developing an autoimmune disease by testing for biomarkers such as genes and autoantibodies, and then improve their outcomes with early treatment.



Barbara Aulicino

Over the past half century, research on what leads to autoimmune diseases and how they can be treated has progressed by leaps and bounds. Over the course of the author's 30-year career studying rheumatoid arthritis and other autoimmune diseases, she has witnessed a massive improvement in the lives of her patients.

preventing such debilitation early in life. We now know that the autoantibodies used to diagnose rheumatoid arthritis actually precede its diagnosis by years and can be used to predict who will develop the disease. Studies led by Andrew Cope at King's College London explored treating high-risk individuals with immune modulatory drugs before they had developed rheumatoid arthritis and showed that the onset of rheumatoid arthritis can be delayed, opening the door to the next step: prevention. The early success of trials treating type 1 diabetes and rheumatoid arthritis have inspired investigators to explore the prediction and prevention of more diseases.

For example, one of my BRI colleagues, Adam Lacy-Hulbert, has been studying a molecule, anti-integrin αvβ6, for 25 years, and he has learned that an autoantibody to this protein is present in people with ulcerative colitis and can be found up to a decade before the disease is diagnosed. He was intrigued by that finding and quickly replicated these data from samples in BRI's biorepositories. He has already begun investigating whether these autoantibodies cause ulcerative colitis development and could indicate therapeutic targets, with the goal of delaying or preventing disease development.

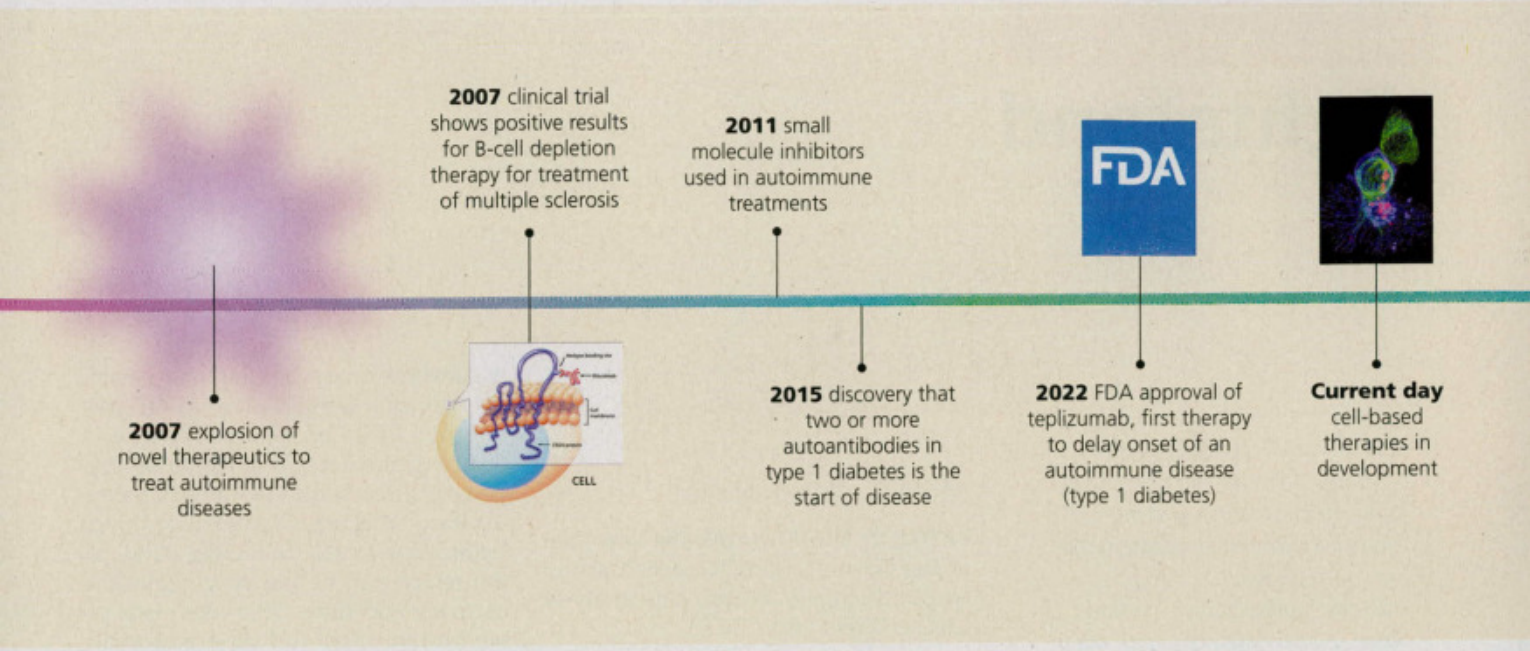
Following individuals with genetic risk for autoimmunity and screening them for autoantibody development can ensure that diagnoses are made early, before severe medical complications arise.

In the past year, I have partnered with Cate Speake and Sandra Lord, both colleagues of mine at BRI, to pilot new screening approaches for type 1 diabetes, rheumatoid arthritis, and celiac disease, with the ultimate goal of treating these conditions with targeted therapies before symptoms arise. As a clinician and researcher, I am acutely aware of the clinical challenges that screening for autoimmunity could bring. Routine screening in primary care clinics is already a time-consuming process, including assessing blood pressure, weight change, and heartbeat. Our pilot screening of more than 200 patients visiting their primary care provider for a blood draw demonstrated that this additional screening is possible and productive.

Early Intervention to Prevention

Although prediction, prevention, and ultimately cures for autoimmune diseases remain areas of open investigation, our progress in elucidating the complex pathways these diseases share suggests exciting possibilities for future treatments.

Today, things would likely look quite different for the mother and daughter I met so many years ago. The mother's rheumatoid arthritis could be identified earlier by testing for autoantibodies, and she would receive immunomodulatory therapy that targets the pathways that we know promote that disease—resulting in minimal joint damage. Her daughter could be screened for risk for type 1 diabetes, and if two autoantibodies were detected, she would be eligible for treatment



with teplizumab to delay or possibly prevent the disease's development.

Preventing a disease takes a long time to demonstrate. By looking for commonalities across autoimmune diseases and examining how disease develops or does not in at-risk individuals, my colleagues and I have been able to improve outcomes for many autoimmune diseases. Once we identify immune pathways important to autoimmunity development, many of the same or similar therapeutics can be used for a variety of autoimmune diseases. We now know that early interventions for many autoimmune diseases are within reach or already available, and we can keep pushing for earlier interventions and longer delays of disease onset. Prevention is a long-term goal, but we now know that it is an achievable one.

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SCIENTISTS' Nightstand

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ONLINE

On our *Science Culture* blog: *www.americanscientist.org/blogs/science-culture*

A Timely Window into Cosmic Threats

Research scientist Cassandra Lejoly reviews *Target Earth: Meteorites, Asteroids, Comets, and Other Cosmic Intruders That Threaten Our Planet* by Govert Schilling.

Cosmic Detectives

Mike Boylan-Kolchin

BATTLE OF THE BIG BANG: The New Tales of Our Cosmic Origins. Niayesh Afshordi and Phil Halper. 360 pp. University of Chicago Press, 2025. $32.50.

Cosmologists grapple with the universe on scales not typically considered in everyday life. They attempt to make sense of unimaginably hot epochs before matter as we know it even existed, and of unimaginably cold futures where matter may decay into nothingness. At any time, cosmologists may require a detailed understanding of general relativity, quantum mechanics, or both as they ponder the evolution of matter and energy over the entire history and possible futures of the cosmos.

In their new book *Battle of the Big Bang: The New Tales of Our Cosmic Origins*, physicist Niayesh Afshordi and science communicator Phil Halper go beyond the history of the cosmos and explore speculative ideas about its prehistory: How did the Big Bang come to happen? What kind of physics might have preceded the Big Bang? Did the universe have a specific moment of birth, or did it always exist in some form? And how does a relatively small, closely connected, but often fractious community of scientists approach these issues—which can often seem to be beyond the boundaries of our understanding—without tearing itself apart?

These are ideas that may strike even veteran readers of popular science books as questionable or even unscientific, yet Afshordi and Halper make a convincing case that there is much to be gained by considering what happened before the classical idea of the Big Bang. Starting with a whirlwind tour through 2.5 millennia of cosmology, they quickly converge on a story that many readers may find familiar: Within the past hundred years or so, a confluence of theory (general relativity) and observations (the recession velocities of galaxies, the cosmic microwave background) pointed inexorably to the Big Bang, often referred to as the very beginning of space and time. This idea rests on well-established and observationally tested physics: At some finite time in the past, everything in our observable universe—some 40 billion light-years in radius around us today—was contained in an infinitesimally small patch of space that was unimaginably hot and dense. Questions of what preceded this Big Bang are often met with a rejoinder that such queries are meaningless, the cosmological equivalent of asking what is north of the North Pole. Afshordi and Halper proceed to demonstrate that this answer is not satisfactory.

For example, they explain how the idea of cosmological inflation—a postulated period of exponential growth of the universe that is fully enshrined as part of standard teaching of cosmology—is already an example of physics that actually *precedes* the hot Big Bang. In this picture, inflation really puts the "bang" in the Big Bang: In a stupendously short period of 10^{-32} seconds, distances in the universe expanded in size by at least a factor of 10^{27}, the equivalent of expanding from the size of a grapefruit to the size of our observable universe today. This hypothesized period of exponential growth explains several otherwise troubling aspects of the classical Big Bang model, including the origin of cosmic structure (from quantum fluctuations during inflation) and why the universe appears to be so homogeneous and isotropic on large scales. The question of what preceded or initiated the epoch of inflation requires physicists to understand the properties of matter and energy on scales that are so small in size and

so short in time that the very laws we take for granted *must* break down; this condition is referred to as a *singularity*. The authors write:

> To imagine the Big Bang singularity is to ignore the contradictions of quantum mechanics and general relativity, the pillars of the physical world. Resolving this conflict by creating a theory that unifies the physics of the subatomic and the celestial, a quantum theory of gravity, remains the backdrop for much of this book.

Afshordi and Halper go to great lengths to demonstrate that many of the world's most renowned cosmologists have wrestled with the thorny and challenging question of what preceded the well-established period of the hot Big Bang. They describe models in which the universe does indeed have a defined beginning, but also many alternate models in which it does not. For example, cyclic theories posit that the universe undergoes an infinite sequence of expansions and contractions. The *ekpyrotic universe* is a model in which the universe began from a merger of *branes*, higher-dimensional objects posited by string theory. In other string theory–inspired models, our universe does not have a singularity that marks its beginning; instead, our universe is connected to another "dual" universe that contracts as ours expands, meaning the Big Bang was a moment of transition, not a beginning in itself.

But the book does not merely catalog theories. Readers are also introduced to a dizzying cast of characters whose actions are befitting of a Shakespearean drama. We learn how theoretical physicists Neil Turok and Paul Steinhardt went from developing key ideas around inflation to arguing that inflation is a fundamentally flawed idea. Veering a bit more into the absurd, we read about Paul Frampton, who came up with a theory about a universe that cycles between expansion and contraction, but who was also involved in an international drug-smuggling ring and so had to supervise graduate students via jailhouse telephone. We meet famous Nobel laureates and scientists whose achievements have been overlooked or underappreciated, encounter fruitful scientific partnerships and bitter rivalries, and see the international and collaborative nature of modern science.

Pablo Carlos Budassi

This illustration is an artistic rendering of our view of the universe, with the Solar System in the center. Moving outward, there are multiple galaxies, including the Milky Way, and the outer ring represents the cosmic microwave background, the oldest light in the universe. This image is a creative interpretation of a logarithmic map of the universe, made by astrophysicists Richard Gott III, Mario Jurić, David Schlegel, Fiona Hoyle, Michael Vogeley, Max Tegmark, Neta Bahcall, and Jon Brinkman.

These colorful stories remind us that science is a fundamentally human endeavor performed by flawed but inquisitive and ambitious people who have made stunning progress in understanding the universe and our place in it. In an age when science and scientists are scrutinized for pursuing knowledge and its applications and when theoretical research is sometimes derided as being superfluous to the needs and wants of society, an engaging tale of some of the biggest questions imaginable and the stories of the scientists pursuing those questions is welcomed.

However, although the anecdotes about fellow scientists can be entertaining and revealing, these tales can also feel forced and distracting. Similarly, the sheer breadth of topics covered and the immense historical scope sometimes renders the writing disjointed or discursive. Perhaps necessarily, the book jumps around in time, following the flow of distinct ideas in cosmology rather than any specific chronology of discovery. Given the amount of the material covered, a reader without any previous experience with cosmology texts may find the scope somewhat overwhelming. For these readers, the appendix summarizing the many models discussed may be especially helpful.

Overall, Afshordi and Halper present a compelling scientific and personal perspective on one of the biggest—yet somehow underexplored—questions in cosmology: Does the universe have a beginning? And in true scientific fashion, the authors avoid prizing any one of the many possible answers. Rather, they present strengths and weaknesses, evidence for both pro and con (if it exists), and then allow the reader to wander through the maze of possibilities.

Battle of the Big Bang is not a retrospective but rather a forward-looking

book that details controversial theories that are still very much under debate. Perhaps in the next century, we will look back on the question of the origin of the universe as settled science, or maybe scientists will still be debating some of the ideas outlined in this book along with new ones. As Afshordi and Halper make clear, however, we can be sure that scientists will not be content with stating how the universe started unless they can also answer the question of what came before.

Mike Boylan-Kolchin is the Samuel T. and Fern Yanagisawa Regents Professor in Astronomy at the University of Texas at Austin. His research focuses on galaxy formation theory and its interface with cosmology, confronting observations with numerical simulations and analytic models.

Infinite Quest

Corey S. Powell

I AM A PART OF INFINITY: The Spiritual Journey of Albert Einstein. Kieran Fox. 336 pp. Basic Books, 2025. $30.

Alan Richards (1953), used with permission of the Institute for Advanced Study

Albert Einstein, in his study in his Princeton, New Jersey, home in 1953, with a picture of Mohandas Gandhi on the wall behind him. Although Einstein never met Gandhi, he held him in higher regard than any other living person. Einstein read and studied various books by and about Gandhi, learning not just about Gandhi but about Indian culture.

Many physicists have achieved fame within their fields. A few have achieved fame among the general public. But none has ever risen to the kind of multi-hyphenate celebrity status enjoyed by Albert Einstein. Even now, 70 years after his death, Einstein retains a unique status as an icon of physics-cosmology-imagination-humanism-pacifism-spiritualism authority.

The last of those *isms* is the focal point of *I Am a Part of Infinity*, Kieran Fox's exploration of the rich belief system behind Einstein's pat-sounding epigrams such as "Science without religion is lame, religion without science is blind." It's an ambitious undertaking, especially considering that Fox is neither a physicist nor a theologian, but a neuroscientist and physician by training, with a strong interest in meditation, psychedelics, and spiritual practice. He is currently a research track resident in psychiatry at the University of California, San Francisco. That unusual background helps explain his equally unusual, concept-driven approach, which largely avoids the conventional structures of both science history and personal biography.

Einstein's ideas about God and religion began to attract widespread attention almost as soon as he rocketed to international fame in 1919, after a high-profile study of a solar eclipse that year confirmed the validity of general relativity. A century later, many of his pithy quotes about science and God remain embedded in pop culture. In 1921, Einstein ridiculed the possibility that other evidence might contradict general relativity, insisting that "the Lord is subtle, but malicious he is not"; that line became the title of a renowned Einstein biography. Later that decade, Einstein argued against statistical models of quantum physics, famously citing divine authority when he claimed that "I am at all events convinced that He does not play dice."

In *I Am a Part of Infinity*, Fox strives to make sense of those views and to distill them into a coherent spiritual philosophy. Einstein became increasingly overt in developing and sharing his thoughts about science and God, starting in the 1930s and continuing up to the end of his life in 1955. Most notably, Einstein penned a 1930 essay in *The New York Times*, titled "Religion and Science," where he outlined what he saw as the three phases of human faith. The first phase was fear-based religion; the second, moral religion; the third and highest was "cosmic religion," a sense of connection to the rational universe and a deep desire to understand it. All three phases still existed widely in the world, in Einstein's view, meaning that anyone could succumb to the pit of fear, but also that anyone could aspire to the summit of ecstatic reason. Fox boils down the concept of cosmic religion to the aphorism that gives his book its title: "I am a part of infinity."

But the key to understanding the book is found in the telltale word "journey" in its subtitle. All his life, Einstein was a restless explorer. With the development of the special theory of relativity in 1905, he merged the concepts of space and time; with general relativity a decade later, he added gravity into the mix. He then spent decades in a fruitless search of an even grander theory that could describe all the forces of nature with a single set of equations. Often, Einstein's intellectual instincts led him to question the meaning of his own equations. He doubted the physical reality of gravitational waves and black holes, even though both are described by the laws of general relativity. After Einstein uncovered the basic principles of quantum physics, he relentlessly sought to overthrow the standard interpretation of quantum theory and preserve his notions of cause and effect.

In his religious conceptions, too, Einstein was constantly testing new ideas and reconsidering old ones. It's easy enough to identify what he did not believe: Einstein was outspoken in his disdain for the concept of a punitive God that responds to prayer, and he dismissed the Bible as a set of "primitive legends." As for what Einstein did believe, Fox makes a naked confession early in his book: "What Einstein *did* believe still remains to be discovered." *I Am a Part of Infinity* does not describe Einstein's definitive spirituality for an excellent reason: His views were complex, ever shifting, and sometimes self-contradictory. Although Einstein did not consider himself traditionally Jewish, his process of continuous investigation and reconsideration intriguingly resembles the methodology of Talmudic scholars.

Fox mostly ignores the famous Einstein quotes, insisting (implausibly) that "the spiritual side of history's greatest physicist has been all but forgotten." In the process, he misses an opportunity to address a major misconception: The meme-friendly image of Einstein as a pious scientific saint is sharply at odds with his actual religious views, which ran much closer to pantheism than to mainstream Judaism or Christianity.

Einstein was eloquent in describing the feeling and motivations behind his beloved cosmic religion, but he struggled to define it and to articulate how to apply it in everyday life. Fox predictably struggles with these issues as well. Einstein called himself an "agnostic" and renounced the concept of a personal God, but he also spoke about God in deliberately personal terms and included "religious geniuses of all ages"—from the authors of the *Tao Te Ching* to Mohandas Ghandi—within his tent of cosmic religion. At one point the reader can practically hear Fox throw up his hands in frustration, sputtering that some of Einstein's comments "border on the incoherent."

Fox's clever solution is to frame Einstein's religious journey within the broader historical search for transcendent truth. The expansive middle section of the book is therefore structured as a collection of meetings with the minds who inspired Einstein's conception of cosmic religion. The ancient Greek philosopher Pythagoras helped instill in Einstein the notion that "nature could be understood as a relatively simple mathematical structure" and inspired him in his search for harmony in science. Fox also drops in on the renegade Jewish philosopher Baruch Spinoza, the martyred pantheist Giordano Bruno, German philosopher Arthur Schopenhauer, Bengali polymath Rabindranath Tagore, and the renowned pacifist Albert Schweitzer. Collectively, it's a giddy, if sometimes superficial, tour of our millennia-long effort to find spiritual meaning in the rational world.

Despite all that breadth, there are some surprising gaps in Fox's discussion of other scientists who influenced Einstein's spiritual notions. For instance, Fox acknowledges the eccentric religious speculations of physicist Wolfgang Pauli, but ignores the work of mathematician Emmy Noether, whose investigations of symmetry and conservation laws were foundational to Einstein's concept of scientific unity. *I Am a Part of Infinity* also lapses into simplistic thinking when Fox compares Einstein's views with those of traditional faiths. Early on, Fox breezily claims that whereas Einstein sought out unity, "mainstream religions have always been enamored with dualism." A lot of theologians and religious leaders would surely dispute that statement, which brushes aside the entire legacy of Jewish monotheism, to name one example.

Perhaps the biggest omission here is that Fox sidesteps the ways that people experience and practice religion in their lives. Einstein spoke out about cosmic religion in the hope that more people would be able to let go of the destructive effects of religions rooted in fear and retribution. "The human race finds itself in a new habitat to which it must adapt its thinking," he said. Fox likewise seeks to inspire a "radical alteration of perspective" and an "inner metamorphosis" in the reader. But religion is not merely a tool for finding personal meaning. It is also a source of group identity, cultural connections, shared rituals, storytelling, artistic inspiration, and moral teachings. In the end, Fox concedes that a sense of the divine infinite "can only be experienced on an individual level," which may explain why cosmic religion shows no sign of displacing the more "primal" (to use Einstein's term) versions of religious belief.

The tentative nature of Fox's plea for blending science and spirituality is a flaw, but it's also what makes his book a compelling read. We all, in one way or another, spend our lives searching for bridges between ourselves and the world around us. We all look for ways to break down the barriers between the individual and the whole. Einstein's journey (and Fox's as well) therefore inevitably echoes our own. And, as happens to all of us, Einstein died with his work incomplete, his journey unfinished.

Einstein never succeeded in replacing quantum mechanics with a more absolute, deterministic description of physics. He never realized his unified field theory. He even had to soften his pacifism, one of his moral absolutes, in the face of Nazi atrocities in his German homeland. Nevertheless, he remained steadfast in his belief that we can find meaning and morality through the study of nature, without any need for an angry creator showing us the way. Fox admiringly quotes Einstein's challenge to us all: "My God may not be your idea of God, but one thing I know of my God—he makes me a humanitarian."

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The Science of Better Choices

Shannon Sauer-Zavala

WHAT WE VALUE: The Neuroscience of Choice and Change. Emily Falk. 304 pp. W. W. Norton, 2025. $29.99.

Emily Falk's new book *What We Value: The Neuroscience of Choice and Change* explores the neurological mechanics of decision-making. Falk is a professor of psychology, communications, and marketing at the University of Pennsylvania, and in the book, she utilizes the neuroscience research program she directs to examine the cognitive processes that inform our everyday choices.

With so many demands competing for our attention—family, career, health, and relationships—we can struggle to prioritize what truly matters to us. It often feels easier to fall back on what's familiar: old habits, quick fixes, or whatever feels most urgent. But Falk contends that if we better understand the neuroscience behind decision-making, we can increase the likelihood that our choices align with our values.

The first question posed by Falk is simple: Why don't we put our time and energy into the activities and relationships that are important to us? The answer lies in what she calls the brain's *value system*: a set of neural processes tasked with crunching a lot of data, including both the moral and economic value of a choice, the consequences of your past decisions, your mood, and the opinions of others around you. For example, on finding it difficult to prioritize quality time with her grandmother, Falk explains, "I understood myself as a hardworking leader in the lab I had founded, and I understood those around me as people who also prioritized work, maybe parenting, or even being up on the latest trash TV—but not hanging out with their grandmas." These thoughts were just some of the input that contributed to Falk repeatedly choosing to focus on other parts of her life, despite knowing that visiting her grandmother was the choice that best fit with who she is and what she values.

When we interact frequently with others, our neural activity can synchronize with theirs.

For many people, when our value system is running on autopilot, the short-term relief we get from scrolling on our phones after a long day wins out over pulling out art supplies or organizing family game night. Falk suggests that once we take stock of our value system and better understand the brain processes involved in decision-making, we will be better able to place more weight on long-term payoffs in our value calculations.

In part one of the book, "Choice," Falk briefly reviews decades of behavioral research. She notes that, across different studies, researchers could determine the value of each behavioral option being weighed based on activity in the *ventromedial prefrontal cortex*, a part of the brain that plays an important role in social, affective, and moral functions. Importantly, there wasn't a set value for each option under consideration; for example, despite having a general preference for coffee, one might assign a higher subjective value to decaf tea in the late afternoon.

Falk contends that understanding this basic science can translate to better decision-making, and she highlights three places within our value systems where we can make changes that better align with our long-term goals. First, our brains can weigh only the options of which we are aware, and our choices are limited by that which we consider to be possible. Next, our brains move forward with what is deemed the highest value choice in that moment, but because we know that the subjective value of a choice can change, we also actively bring in additional perspectives that may affect our calculations. Finally, the brain carefully tracks the outcome of a choice—how rewarding it was—and Falk suggests that we can pay specific attention to the aspects of the outcome that support better choices in the future.

The main question explored in part two, "Change," is more practical: How do we turn this insight into action? Falk provides strategies to help change the process of decision-making within a value system to favor the choices one wants to make, rather than what feels good in the moment. For example, with regard to outcomes, Falk writes that when we think about ourselves in the future, the area in the brain that is activated is the same as when we think about other people. She explains:

> If Future You is more like a different person to your brain's value system, then benefits accruing to Future You are seen as less self-relevant, and therefore less valuable, than the ones you would enjoy here and now.

To combat this phenomenon, Falk suggests one strategy of pairing a task with delayed payoff (walking on the treadmill at the gym, for example) with something immediately rewarding (listening to an audiobook).

She also introduces another neural mechanism, the *self-relevance system*, which she asserts is responsible for one of the biggest barriers to change: defensiveness. Falk notes that the brain's value system and its self-relevance system are linked such that we often conflate what we value with who we are. She describes a study in which some students in a class at Cornell University were given a mug: Those with the mugs were told they could either take the mug home or sell it to their mugless neighbors. The researchers found that those who chose to sell the mug asked for twice as much money than their neighbors were willing to pay for it and others even chose to forgo generous offers so they could keep the mug. In other words, once a mug was considered theirs, it was viewed as more valuable. This aspect of human nature may help explain why we often cling to habits that no longer serve us, simply because they're ours.

Finally, Falk explores the larger interpersonal context in which choices are made. When we interact frequently with others, our neural activity can synchronize with theirs: If we're around people who prioritize productivity, that might steer our value calculation toward working late, rather than going home for family dinner. Falk shares research suggesting that the more time people spend together, the more their brain activity mirrors one another—though she falls short in describing how exactly this phenomenon happens. However, she posits that by surrounding ourselves with people who are already choosing actions consistent with the person we want to be, we can alter our value calculations to be in favor of our long-term goals.

What We Value challenges readers to reevaluate their decision-making process. Many of the strategies Falk describes are mainstays of cognitive behavioral therapy, which has decades of support for its effect on behavioral changes. She explains why these strategies work at the neural and cognitive level, and she bridges the gap between complex neuroscience and everyday experience through compelling anecdotes, along with clear action steps readers can practice at home. In this way, neuroscience becomes less about circuitry and more about clarity—an avenue to make daily decisions a little more deliberate and much more meaningful.

Shannon Sauer-Zavala is a licensed clinical psychologist and treatment outcome researcher at the University of Kentucky. She specializes in developing interventions to shift the personality traits that underlie common mental health conditions.

Sigma Xi Today
A NEWSLETTER OF SIGMA XI, THE SCIENTIFIC RESEARCH HONOR SOCIETY

IFoRE Virtual Student Research Competition

STEM students from all research disciplines are encouraged to attend the 2025 International Forum on Research Excellence (IFoRE), powered by Sigma Xi. This year's conference will take place as a virtual event October 30 through November 1. A virtual student research competition will be held October 18–26, with student award ceremonies taking place during the IFoRE conference.

This year's virtual format provides increased opportunity for international attendees, as well as students wishing to participate in a world-class research competition without the high travel and conference expenses typically associated with in-person events. Additionally, discounted rates for students and Sigma Xi members are available.

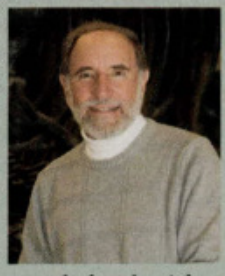
This marks the third time that Sigma Xi will hold its annual meeting in a virtual format. The Society previously hosted online events in 2020 and 2021 during the COVID-19 pandemic.

This year's virtual student research competition is open to high school, undergraduate, and graduate students. Awards will be given at each education level across all disciplines. Interested attendees can learn more and register at **experienceifore.org**.

Sigma Xi Today is managed by Jason Papagan and designed by Chao Hui Tu.

From the President

Exciting but Challenging Times



As I assume the presidency of Sigma Xi, I am excited, yet daunted. The excitement is natural—it comes from taking the helm of an influential society that champions science and honors those who solve crucial problems, leaving lasting impacts on our lives, our society, and our planet.

The Society honors excellence at all levels of research. For more than 100 years, the Grants in Aid of Research program has provided undergraduate and graduate students with some of their first true research funds. After a lifetime of research excellence, some of our most impactful members receive the high distinction of being named a Fellow of the Society. And in recent years, Sigma Xi has expanded its reach by priming the pipeline of young scientists. By working with mentors in their schools and nearby research facilities, budding high school students are able to present their work at the Society's annual events, the virtual Student Research Showcase and the International Forum on Research Excellence (IFoRE).

Despite my excitement for Sigma Xi and all it does to champion science, I have become daunted (to put it mildly) by the assault we are witnessing in the Trump administration's shackling of science. Budgets for the National Institutes of Health (NIH) and the National Science Foundation (NSF) are being slashed, and many science-based programs within other government agencies are being gutted by firings of dedicated and creative scientists. We all agree that inefficiency within any bureaucracy should be addressed, but these wholesale and seemingly arbitrary cuts, along with top-down declarations of what can and cannot be researched, is crippling what America does best—solving critical questions that affect all of our lives.

Unfortunately, some of our Society's members have already lost their jobs to these cuts. And though Sigma Xi has created online support portals to provide some moral and emotional support, it is our duty as scientists and colleagues to stand up and let our elected officials know that what is happening is unacceptable. I urge you to call the U.S. Capitol switchboard (202-224-3121) and ask to speak to your representatives. Tell them what you do, because personal stories matter. And let them know how these cuts are likely to affect your ability to do research.

Continued on page 255

Brown University Student Chosen for Sigma Xi's 2025 Lindau Nobel Student Fellowship

Sigma Xi is pleased to announce the selection of Meg Shieh to attend the 74th Lindau Nobel Laureate Meeting dedicated to chemistry. A fourth year PhD candidate at Brown University, Shieh has been a Sigma Xi member since 2023. She will attend the prestigious six-day event beginning June 29 in Lindau, Germany. As a member of the meeting's 2025 cohort of Young Scientists, Shieh will represent Sigma Xi's academic partnership by serving as the Society's 2025 Lindau Meeting Fellow.

Following an extensive application and review process, Shieh was nominated by a Sigma Xi selection committee and chosen by the Lindau Meeting's scientific review panel. She will be part of the meeting's elite body of student attendees, featuring 634 of the world's most promising young scientists in chemistry and related fields, representing 84 countries.

The unique atmosphere of the Lindau Meeting provides students an opportunity to connect with more than 30 Nobel laureates. Additionally, students can contribute to the meeting by submitting their own research for presentation at the Next Gen Science Sessions. This distinctive meeting component allows students to share their research with a preeminent audience, including the Nobel laureates.

"I'm incredibly grateful and deeply honored to have been selected as a Young Scientist for this year's Lindau Nobel Laureate Meeting in Chemistry," Shieh said. "This unique opportunity to engage with and learn from Nobel laureates and fellow Young Scientists from all over the world is sure to be a transformative experience."

Now in its second year of academic partnership with the Lindau Nobel Laureate Meetings, Sigma Xi invites students and early-career scientists to apply annually for nomination to the Young Scientist cohorts of future meetings. Applicants should be active members of Sigma Xi, be among the top 5 percent in their class, and meet additional posted criteria. The application portal is open annually from late summer to early fall at **sigmaxi.org/lindau**. Questions can be directed to **executiveoffice@sigmaxi.org**.

"After a highly successful debut in 2024, Sigma Xi looks forward to continuing its partnership with this year's Lindau Nobel Laureate Meetings in Chemistry," said Sigma Xi Executive Director and CEO, Jamie Vernon. "We are thrilled to provide this opportunity to Ms. Shieh to help advance her research career while representing Sigma Xi as a graduate student member."

Since their foundation in 1951, the Lindau Nobel Laureate Meetings have evolved into a unique international scientific forum. The annual meetings facilitate exchange between different generations, cultures, and disciplines. The meetings are alternately dedicated to the three Nobel Prize disciplines in the natural sciences: physics, chemistry, or physiology/medicine. An interdisciplinary meeting is held every five years, while the Lindau Meeting of Economic Sciences takes place every three years. More than 35,000 students, PhD candidates, and postdocs have taken part as Young Scientists.

New Chapter Installed at California State University San Marcos

On March 25, Sigma Xi installed its newest chapter at California State University San Marcos (CSUSM). The ceremony was held in person and celebrated the new chapter's members, officers, and commitment to the growth and advancement of the university's research enterprise.

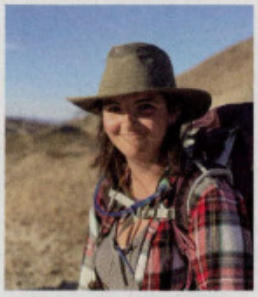
Dr. Tieli Wang, director of Sigma Xi's Comprehensive Colleges and Universities Constituency Group, was the installing officer for the chapter, with a video contribution from Sigma Xi President Dr. Kathy Lu. The new chapter president is Dr. Robert Iafe, associate professor and chair of chemistry and biochemistry at the university. He will lead a group of 12 founding members through the initial years of the chapter's development. The chapter's other founding members are Afra Panahi, Betsy Read, Charles De Leone, David Barsky, Deanna Schmidt, Dennis Kolosov, Erika Díaz Almeyda, Jane Kim, Julie Jameson, Kang Du, and Sajith Jayasinghe.

Founded in 1989 as the 20th California State University campus, CSUSM is a regional comprehensive university with a growing student body of approximately 17,000 undergraduate and graduate students. The founding officers presented a three-year plan of projected activities and recruitment efforts for the new chapter, which will fill a critical gap in honor recognition in research at the university. The chapter will provide a platform to celebrate STEM students while opening new avenues of support for grants, networking, and presentations at professional STEM conferences. The in-person ceremony included the election of officers, a networking dinner, and the presentation of the official charter upon installation of the new chapter.

FACES of GIAR: Samantha Motz

Students may apply for Sigma Xi research grants by March 15 and October 1 annually at **sigmaxi.org/giar**.

Grant: $1,000 in Fall 2022
Education level at time of the grant: Undergraduate student



Project Description: The mechanism and timing of the Colorado River from the Grand Canyon into the Gulf of California has long been a topic of discussion. While early research developed a "bottom-up" model due to Pliocene marine incursion and regional uplift, more recent research shows a "top-down" integration by progressive filling of lake basins, seen through mapping, stratigraphy, and geochemical analyses. One unit proved critical to these interpretations: the Pliocene Bouse Formation, which marks the arrival of the lower Colorado River. The GIAR grant supported me in compiling a dataset of detrital zircon (U-Th)/Pb geochronology (1,774 single-grain ages) on sand horizons in the Bouse Formation, spanning four subbasins in the lower Colorado River corridor and modern samples from potential source areas. With the exception of three samples from the Mojave subbasin, we found that the Bouse Formation has a nonlocal provenance consistent with a large drainage area comparable to the modern Colorado River. While our analysis does not support deposition of the Bouse Formation in separated and locally sourced lake basins, it does support deposition by a single, rapid, high-discharge river that progressed southward, integrating previously separated subbasins.

How did the grant process or the project itself influence you as a scientist/researcher? The project gave me valuable experience in the field, the lab, data analysis, writing, and presenting my work. The experience of writing small grants as an undergraduate allowed me to build crucial writing skills and to see my potential for graduate school and beyond. After finishing my undergraduate degree, this opportunity allowed me to continue some of the procedures for detrital zircon U-Pb geochronology on Georgia Institute of Technology's (Georgia Tech's) new inductively coupled plasma mass spectrometry (ICP-MS) system.

What advice would you give to future applicants? Give yourself plenty of time to work on your grant applications for the sake of your mentor and yourself. Apply, even if you feel like you won't get it. Rejection is part of being a scientist, and it teaches you to modify and improve your writing for future applications. The more you write about your research, the easier it will be to present it.

Where are you now? I am currently a graduate research fellow at the National Science Foundation and a Cota-Robles fellow at the University of California, Santa Cruz. I am working to perform storage selection modeling to build an understanding of how water moves through two adjacent headwater catchments in Blue Oak Ranch Reserve—a Mediterranean climate dominated by nonperennial streams, a vital system sensitive to climate change.

From the President

Exciting but Challenging Times

Continued from page 253

This assault should be seen as a wake-up call for everyone in our Society. While we all aim to do good science, we often do less well in sharing our results with neighbors, friends, and the public in general. We are the best tellers of our own stories. But it is often difficult for scientists to connect with an anonymous public whose trust in science is waning. This is where Sigma Xi can play a powerful role. We often forget that we are a society composed of chapters. Some chapters are highly active and provide lively gathering places where companionship blossoms and unique programs flourish. Other chapters have a hard time even coming together and selecting members to maintain critical mass. And let's not forget that chapters are local nodes of neighborly social networks that connect scientists to schools, businesses, clubs, and so on. As such, chapter members can and should use these networks to share exciting stories about their research, how evidence makes science work, lectures, demonstrations, hands-on experiences, and so much more.

As president of Sigma Xi, one of my priorities will be to energize local chapters. I plan on meeting with regional directors and chapter leaders to identify activities that keep active chapters pulsing. By spreading best practices and actively seeking funds, I hope to expand the reach of as many chapters as possible. It will take money to enable chapters to develop vital and far-reaching social networks, so I will actively seek funds to enable chapters to explore new ways of connecting with the public. Our interdisciplinarity fosters a diversity of viewpoints, so if you have ideas, I hope you will share them with me via email (dir@sigmaxi.org) or during our virtual IFoRE gathering this fall.

D. I. Rubenstein **Daniel Rubenstein**

2025 Student Research Showcase Winners

On April 15, awards were presented to the winning participants in Sigma Xi's 2025 Student Research Showcase. The virtual competition included 181 students across 13 disciplinary categories. Awards were given for first place ($500) and second place ($250) winners in the high school, undergraduate, and graduate divisions. Additional prizes were awarded for the top overall winner and the People's Choice Award.

The 2025 overall winner was Hannah Swarm, a graduate student from Virginia Tech. Her project, *New Insecticide Application for Virginia Wireworm Control*, was awarded an additional $500 prize. The People's Choice Award winner was Illinois Mathematics and Science Academy student Matthew Nowak, who received a $250 prize for his project, *Nucleoporin93: Endothelial Cells' Nuclear Morpher*.

The Student Research Showcase is an annual virtual competition aimed to build students' science communication skills so they can convey the value of their research to technical and nontechnical audiences. Participants submitted abstracts for entry into the competition in early spring. During a month-long evaluation period, students built websites, videos, and slideshows to present their research to a panel of judges and public audiences. Judges' evaluations were based on how well students communicated enthusiasm for their projects; explained the significance of their research; used text, charts, and diagrams; and responded to questions.

Overall Winner

Hannah Swarm, Virginia Tech
New Insecticide Application for Virginia Wireworm Control

People's Choice Award

Matthew Nowak , Illinois Mathematics and Science Academy
Nucleoporin93: Endothelial Cells' Nuclear Morpher

First Place, High School Division (two-way tie)

Ana Spiride
Plano East Senior High School
HandTalk: A Two-Way Translation System for ASL

First Place, High School Division (two-way tie)

Eddie Zhang, Evan Zhang
The Harker School
Bio-Inspired Pneumatic Soft Robotic Inspection System

Second Place, High School Division (five-way tie)

Tiffany Ye
William G. Enloe Magnet School
Acoustofluidic Extraction of miRNA for Parkinson's Disease Diagnosis

Raghav Vij
Heritage International Xperiential School
Consumer Perceptions, Purchase Intentions, and Eco-Labelling

Akshay Kumar
American Heritage Broward
Novel siRNA Design Workflow: Fighting Catastrophic Pandemics

Dhairya Mathur
West Windsor Plainsboro High School South
SSRI-Linked Serotonin Signaling in Stress-Driven Metastasis

Sagnik Das
Raleigh Charter High School
A Comparative Study of the Cuban Healthcare System

First Place, Undergraduate Division

Glenda Rodrigues Santos Giordani
State University of New York at New Paltz
Gradient Temperature Analysis of Hempcrete

Second Place, Undergraduate Division

Noa Croitoru
Virginia Tech
Role of Early Maladaptive Schemas in Substance Use Disorders

First Place, Graduate Division

Hannah Swarm
Virginia Tech
New Insecticide Application for Virginia Wireworm Control

Second Place, Graduate Division

John Kyle Cook
Duke University
Heart Transplant: DCD Using Normothermic Regional Perfusion

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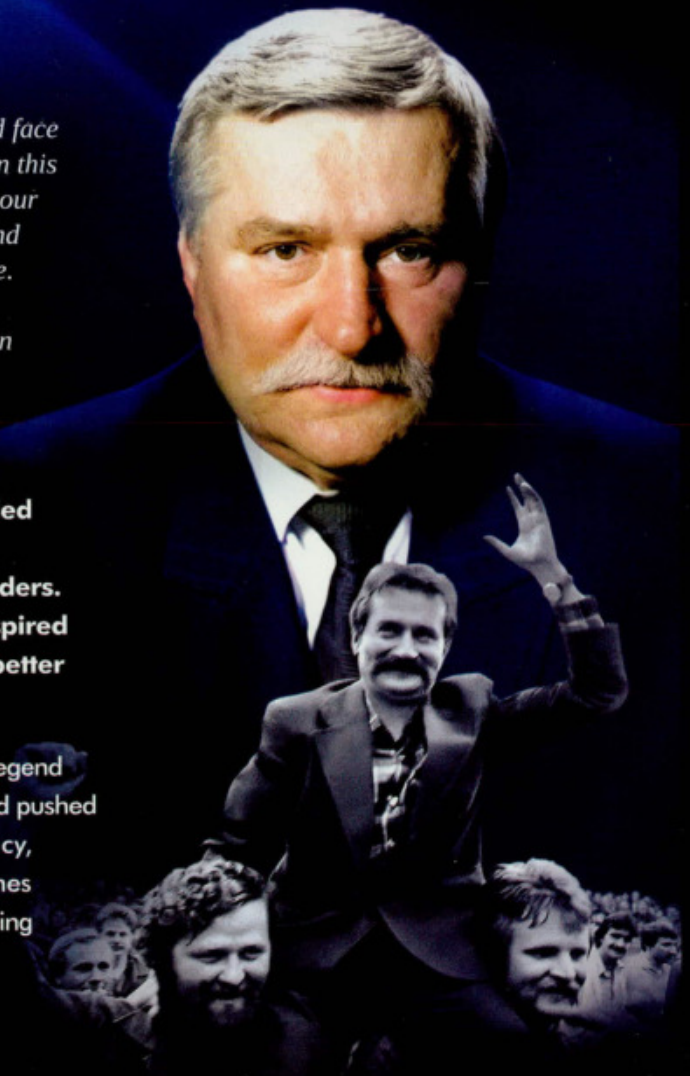

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Sep 12	Denver, CO
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Sep 20	Dallas, TX
Sep 22	Atlanta, GA
Sep 24	Columbus, OH
Sep 26	Pittsburgh, PA
Sep 27	Baltimore, MD
Sep 28	Cleveland, OH
Sep 30	Minneapolis, MN
Oct 2	St. Louis, MO
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