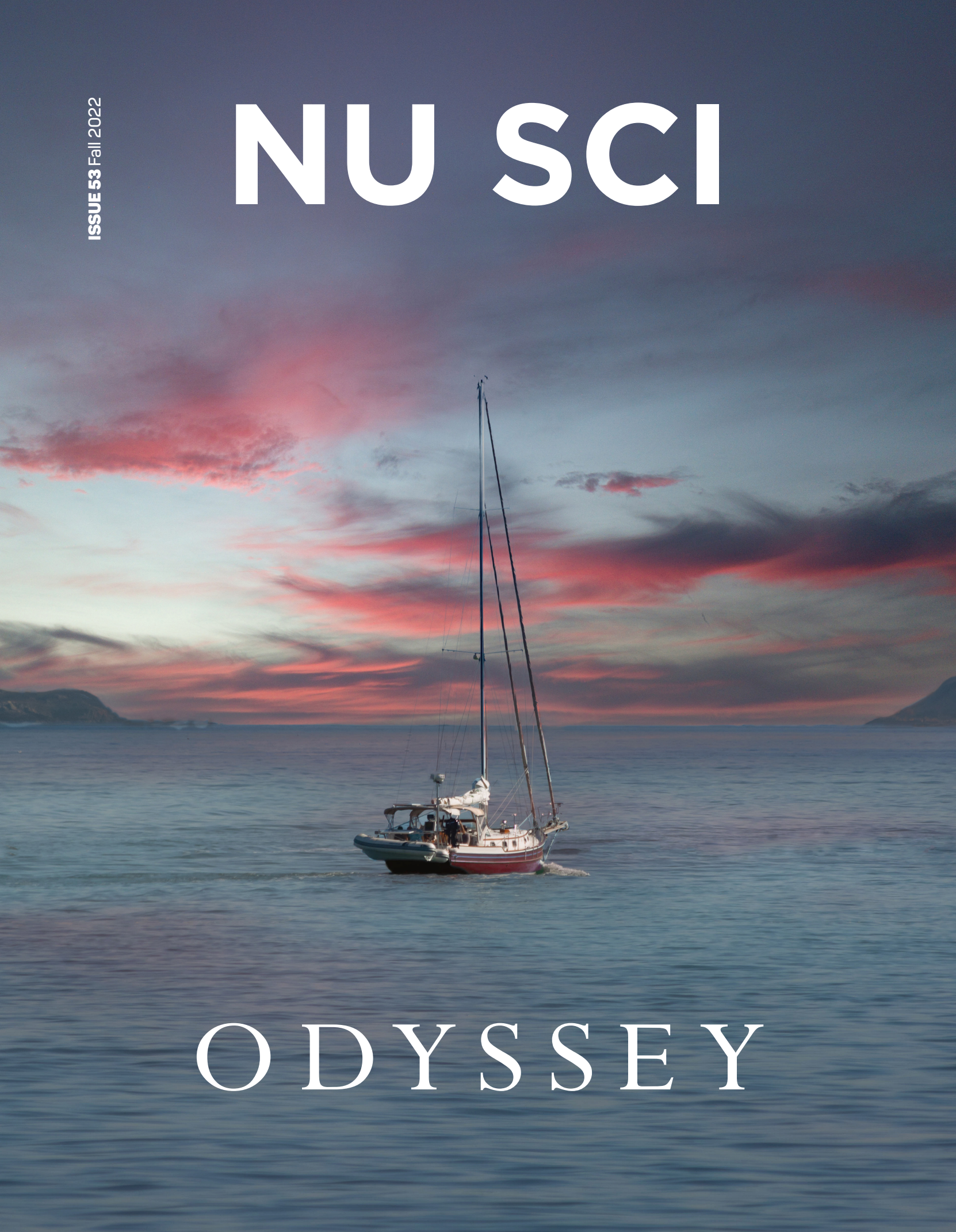
ISSUE 53 Fall 2022

NU SCI



ODYSSEY

Fall 2022

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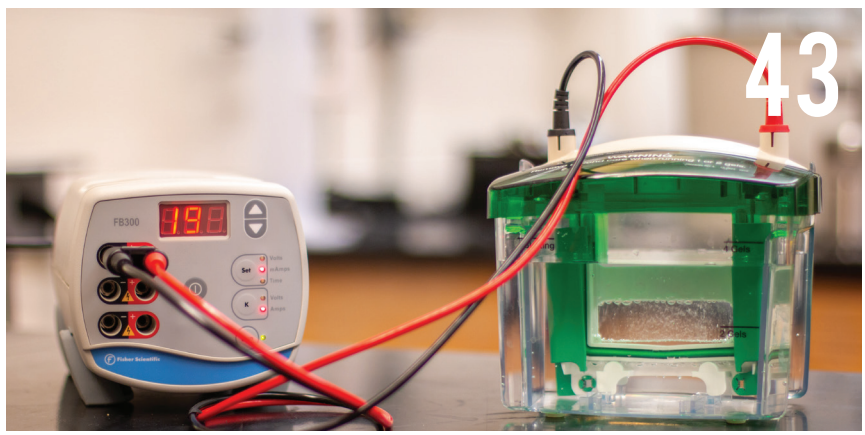

LETTER FROM THE EDITOR

The progress of science ebbs and flows. Like a great river, it can course forward as a calm, unified body. It can clash in violent rapids and turbulent currents, clumsily yet forcefully. It forks and recombines. It forges new channels — some of which may trickle out. Regardless, it has the power to shape and chisel the earth around it.

The practice of science focuses on incremental progress. As the body of science and the complexity of our understanding grows, researchers spend years laboring over and nursing single seeds of knowledge — single drops of new information in the ocean of scientific understanding.

As a human ideal, science is founded on our optimism, our intrinsic need for social connection, and our profound sense of curiosity about the world around us. The stories of science tell epic tales of the struggle, heartbreak, joy, and adventure found within every small step of scientific progress. We hope to share this sense of scope, awe, and humanness present in every endeavor of science in issue 53 of *NU Sci*, "Odyssey."

This issue of *NU Sci* explores scientists and everyday people still grappling with the reverberations of the COVID-19 pandemic, plants and animals fighting to survive in the face of climate change, humans' continued reach for the stars, and our culture's evolution toward ideals of justice and sustainability. As you read this collection of stories, I hope you can begin to feel the truly sublime scale of our collective struggle for scientific truth.

For my first time as editor-in-chief, I thank the writers, designers, and photographers; the members of our marketing, outreach, and web teams; the e-board; and our readers, all of whom make NU Sci a community hub of accessible scientific ideas.

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Cover Photos by Ian Hay and Gus Mueller

National bird turned military threat: Australia's Great Emu War

BY MACKENZIE HEIDKAMP, BIOENGINEERING, 2026

DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

One could reasonably expect national symbols to be protected and upheld by their respective countries. In America, patriotic men and women wear shirts bolstering their beloved eagle, while in Canada, proud citizens have even brandished their currency with the fallen leaves of their national plant: the maple tree. The people of 1930s Australia, on the other hand, did not view their national bird with the same affection. Not only did they see the emu as an annoyance, but they also viewed the species as an enemy of the nation's armed forces.

The Great Emu War of 1932 occurred during the world's economic crisis and America's Great Depression. Desperate ex-soldiers from Britain fled to Australia to expand and buy open land for agricultural use. While they tried to rely on their wheat crops during the economic crisis, these new settlers had not considered the native life of their unfamiliar area. Meanwhile, as the emu population followed its normal migration pattern toward the water in southwest Australia, the birds encountered the freshly grown crops and took a snack break. Within 40 square miles of the farmers were approximately 20,000 emus, which "averaged out to be about 500 birds per square mile," according to a *History Nuggets* article. Furious about their sudden loss of crops, the farmers convinced the country's minister of defense, Sir George Pearce, to enact a military mission to use machine guns and ammunition against the birds. They argued that the use of military resources would benefit the nation's economy and allow for useful shooting practice.

> "Not only did they see the emu as an annoyance, but they also viewed the species as an enemy of the nation's armed forces."

When the soldiers went to battle against the birds, they discovered them to be unarmed yet challenging opponents. The birds were extremely agile and able to avoid a majority of the soldiers' bullets, while also being able to sustain some of these shots. The men were understandably embarrassed as their expensive military efforts not only spanned multiple attempts, but their small casualty number of 200 emus had "used 2,500 rounds of ammunition," according to an article in the *Journal of Australian Studies*. A local paper, *The Sydney Morning Herald*, later wittingly compared the nation's bird to high-grade military equipment, saying, "if we had a military division with the bullet-carrying capacity of these birds, it would face any army in the world… They can face machine guns with the invulnerability of tanks."

Journal of Australian Studies (2009). 10.1080/14443050609388083

PHOTOS BY SHUTTERSTOCK

The innovation of fabric and its properties

BY ADRIANA ALVAREZ, CELL & MOLECULAR BIOLOGY, 2025
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

Sustainability has always been a nonsense noun for the fashion industry. Used to market pieces from brands, the word "sustainable" no longer serves a purpose. When, why, or how to use it has become difficult and in a way, purposeless. What is truly sustainable; what is simply for the sake of the brand; and what is in fact, just greenwashing? The fashion industry has made this unfeasible to comprehend. This is where science comes in.

The Slow Factory Foundation and Swarovski have teamed up to launch One X One. Labeled as the first science and design incubator to pair fashion designers with innovators and scientists, One X One establishes the initiative to make clothing better. Phillip Lim and scientist Charlotte McCurdy are working to develop the true definition of sustainability: a dress that is both carbon neutral and completely made out of algae sequins. Mccurdy is making garments entirely out of natural material.

"When you see this dress, you will not even know it is seaweed," Lim explains as he features a long leather-like sequined dress that satisfies both the fashion and science aspects. Lim and McCurdy want to challenge what it truly means to be ethical in one's own process by giving the idea of sustainability a whole new meaning.

While this specific dress won't show up at department stores, the sole idea of this dress is to create a conversation about innovation and the possibility that sustainability isn't what people think. It's not a piece of material that comes from recycled cotton but finds itself in landfills in a month or so. It isn't a brand. It's a word. A word that needs to be rightfully used: not for the sake of monetization, but to plant a seed.

PHOTO BY SHUTTERSTOCK

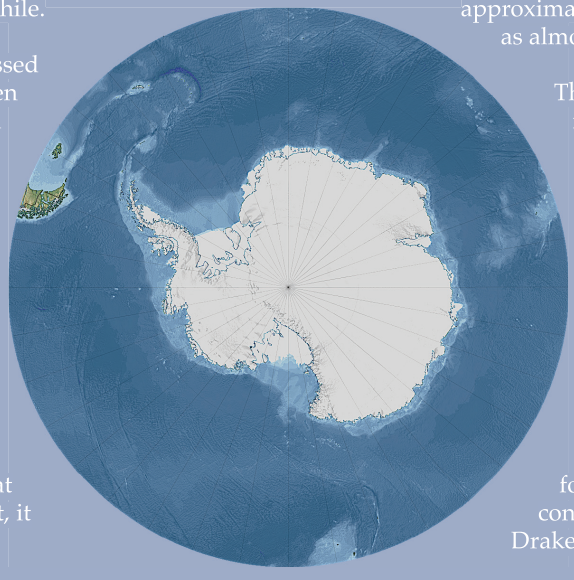
THE DRAKE PASSAGE

The final barrier to Antarctica

BY ANNA DUCROISET, BIOCHEMISTRY, 2025
DESIGN BY PARKER HITT, BIOLOGY, 2023

This past summer, I worked at Woods Hole Oceanographic Institution (WHOI), a marine science research institute with a variety of labs and facilities. In the middle of the summer, a lab I was involved with found out that some members would be taking a trip to Antarctica to collect samples. One of my good friends was asked to spend four months in Antarctica working at the base used by the lab. This prompted conversations about apparel, hobbies, and duties. However, it also welcomed stories from scientists who had already taken this trip. Many of those stories surrounded the Drake Passage, the infamous body of water that stands between the tip of South America and Chile.

This passageway is often crossed using a massive vessel often provided by a national organization and equipped with incredibly experienced and well-trained staff. Recently, a group of six men crossed the Drake Passage in a rowboat. This voyage was particularly shocking because it was completely dependent upon the constant usage of manpower. Meaning, three of the six men had to be rowing at any given time. If the boat were to be still for any moment, it would capsize.



The men crossed the passage on a 29-foot boat, the Ohana, in 13 days. They faced 40-foot waves, wind from all directions, and extremely cold water washing over them as they struggled to keep the boat afloat. According to an article from the Associated Press, five of the six men are recognized as champion rowers and adventurers. However, their rowing skill was not their only capability put to the test. Avoiding icebergs and whales was essential; one bad move would sink their ship.

Despite the "record-breaking" language surrounding this incredible feat, these men were not the first to cross the Drake Passage in a row boat. In 1988, a four-man team led by Ned Gillete reached an island surrounding Antarctica.

The treacherous nature of the Drake Passage can be attributed to the location and history of the passage. There is much debate surrounding the formation of the Drake Passage, with many believing that it formed sometime around when the Eocene Epoch ended and the Oligocene Epoch began approximately 34 million years ago. The Drake Passage likely formed as a result of the separation of South America and Antarctica due to plate tectonics. It has been proposed that some of these plates sank below each other, creating sudden increases in depth. The depth of the Drake Passage is one of the major factors that create such rough conditions. The average depth of the Drake Passage is approximately 11,000 feet with portions as deep as almost 16,000 feet.

The opening of the Drake Passage was incredibly significant to global oceans due to its constriction of the Antarctic Circumpolar Current. This current encircles Antarctica and acts as a barrier, protecting the Antarctic ice sheet from warmer waters. It has been proposed that the Drake Passage enabled the solidification of the Antarctic as the home to massive ice sheets, as warm water has been largely unable to reach the ice. This current and the winds associated with it provide a reason for the incredible waves and stormy conditions experienced when crossing the Drake Passage.

Despite the infamy of the Drake Passage, this trip is common to scientific and tourism communities. Currently, there are scientists stationed around the continent. The National Science Foundation has even declared Palmer Station (a base on a series of islands close to the southernmost point of Chile) to be a "long-term ecological research site." This is one of many stations on the continent – all of which have a variety of research being done at them. In addition to scientific expeditions, if one were willing to pay almost $20,000, they could find themselves among the Antarctic penguins, icebergs, and humpback whales.

PHOTOS BY SHUTTERSTOCK AND WIKIPEDIA COMMONS
Geochemistry, Geophysics, Geosystems (2007). DOI: 10.1029/2005GC001224

FLUFFY BEARDS

Safeguard or just for show?

BY DARREN EASLER, CHEMICAL ENGINEERING & PHYSICS, 2026
DESIGN BY PARKER HITT, BIOLOGY, 2023

Today, the longest beard measures 17 feet, 6 inches. On average, facial hair grows about a half inch per month. To many, the beard is a common feature of a man — one that is rarely looked at when discussing evolution. What is its purpose? Does a beard have specific uses, or is it just a physical trait used for show?

Puffy facial hair is typically seen as a form of masculinity. Sexual dimorphism gives males this trait, which has been used as male competition over the years of human evolution. The question, however, is whether this is the only or best reason for the facial blanket to be where it is anatomically. Some animal features, such as lion manes, are evidence of sexual dimorphism giving males an identifiable trait as well as an edge in higher competitive territories. However, biologists argue the mane of a lion can also be used as a form of protection from attacks to the lower head and neck. In a biology study done in April 2020, researchers from the University of Utah designed an experiment to test whether this theory proved the same with beards of human men, serving not only as a visual difference between men and women but as a development of protection against hits to the head and neck.

The human mandible, or jawbone, is one of the most fragile bones in the body. It is highly susceptible to fractures and breaks when put under stress due to violence. This knowledge inspired the hypothesis that facial hair was developed to minimize the damage of impacts during violence, which was then tested by a University of Utah research team. In their experiment, a mandible and supporting bones were constructed out of a fiber epoxy composite, which was then attached to sheep skin and fleece. While sheep fleece is not a perfect replica, it was approximated to be about the same thickness and density as follicles of facial hair. Using an anvil and striker, the team tested various levels of beard thickness on the mandible. They record the amount of force intake as well as the time the hit took to reach full impact on the mandible. The results showed a variation of data for each level of sheep fleece thickness, the largest variation being in the time it takes for the full force of the striker to reach the mandible. The greatest advantage of protection to male jaws: the amount of force is widely distributed and not absorbed in the same spot, making the force of the hit less likely to cause substantial amounts of damage to the mandible or other facial bones.

Of course, the mane of a lion supplies a larger amount of protection than human facial hair, though they still share many common traits that lead biologists to believe their functions are similar. The sexual dimorphism of manes and beards suggests they evolved to be identifiers of the animal's sex and to be potential tools used during male competition. In a study done by research biologists at the University of Minnesota in 2005, male lions were found to be more likely to die within a year of receiving an injury to the neck or mane area, while females would typically die within a month after receiving similar injuries. Also, in humans, a 1990 paper by Jonathan Shepherd suggests women make up only 8% to 32% of interpersonal violence, meaning, based on evolution theories, they had less need for facial hair protection.

The flip side argues that violence between males is becoming less about environmental competition. For lions, nearly all interpersonal violence between males is a result of male competition for mating, so some argue there is no connection between the two traits. Similarly, some may be skeptical about the data done in the experiment by the University of Utah researchers, as it was done with sheep products and an epoxy composite, rather than true human anatomy. Either way, when arguing the hypothesis that facial hair was developed as a form of protection against violence, it's hard to argue the findings that it aids in the distribution of forces from violence on top of being a dimorphic trait for show.

Integrative Organismal Biology (2020). DOI: 10.1093/iob/obaa005
Frontiers in Behavioral Neuroscience (2010). DOI: 10.3389/neuro.08.045.2009
Journal of Industrial Textiles (2022). DOI: 10.1177/15280837221124926
Animal Behavior (2006). DOI: 10.1016/j.anbehav.2005.06.009
Journal of the Royal Society of Medicine (1990). DOI: 10.1177/014107689008300206

PHOTOS BY SHUTTERSTOCK

ONE in 158 trillion

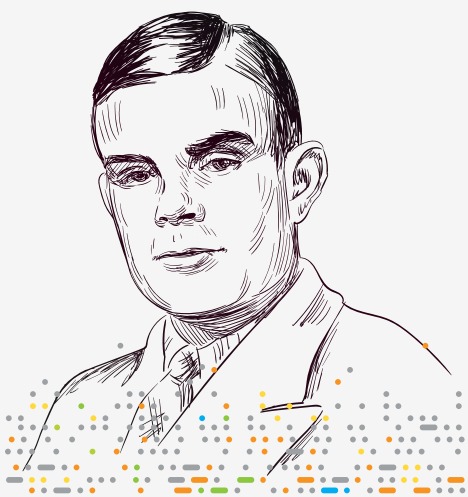
How Alan Turing cracked the Enigma

BY CURIE CHA, COMPUTER SCIENCE & BEHAVIORAL NEUROSCIENCE, 2026
DESIGN BY PARKER HITT, BIOLOGY, 2023

The logical basis of all computers can be traced back to the ingeniousness of one man: Alan Turing. Turing, born on June 23, 1912, grew up with a keen interest in using mathematics and logic to explain the world around him. He went on to study mathematics at King's College and eventually joined the Government Code and Cypher School at Bletchley Park. This would mark the beginning of Turing's most notable achievement in world history and computer science.

Around the time of the Second World War, the use of radio communication increased and allowed for efficient two-way transmission. To avoid interception and exposure, the German military encrypted these messages using a machine called the Enigma machine.

The machine had many components that contributed to the complex nature of the encryption process. The wires were mixed and matched by rotors so that a letter would enter as itself but leave as another letter. A single Enigma machine could also have multiple rotors connected side-by-side. This meant that letters could change multiple times. The machine also contained a plugboard, which swapped the letters in a reciprocal way. Each day, the Germans would be given a predetermined setting that told them how to orient the rotors and the plugboard so that they could decode the messages using an Enigma machine. However, without knowing these settings, it was almost impossible to figure out which combination out of the 158 trillion possibilities was the correct one.



In response to the perplexing conundrum, British Intelligence created a group of the top minds at Bletchley Park, among them Turing, to decode the signals.

Turing, rather than finding the correct code, deduced that it would be easier to eliminate the ones that were surely wrong. This would leave an increasingly smaller number of possible solutions, bettering the odds. He knew two things: a letter could not be coded as itself and two letters code for each other. He then used this knowledge and common German phrases (cribs) sent every day to crack the code. The cribs were usually German greetings or weather reports, so it was almost certain that they were in the message. The phrases were lined up with the encrypted message so that each letter aligned. Turing checked all of these pairs, and if there was a pair of letters that were the same, he knew that this orientation was incorrect. He would then shift the word one letter over so there would be new pairings, repeating this process. In the end, there would be many possible correct alignments, and Turing would have to test each alignment to find the correct one. Although logically sound, this method required meticulous work, so Turing created a machine, the Bombe, to do it for him.

In order for the machine to crack the code, it needed a template code: the crib message. Turing would create maps, or menus, that would show the connection between the letters in the given message.

By wiring the back of the Bombe to resemble the menu, a circuit could be formed to test which rotor settings produced a continuous electric signal. A comparator would essentially check for a complete circuit with that specific setting. If not, one of the rotors would click one notch, and the next setting would be checked. This continued until the comparator unit detected a complete circuit. At this point, the machine would stop, and the operator would read which settings the rotors were at to produce a successful circuit. Additionally, because the machine had a total of 36 sets of rotors, multiple settings could be checked simultaneously. This allowed the team at Bletchley Park to crack the daily Enigma code in under 20 minutes. Much of the code decrypted revealed integral information that saved thousands of lives and shortened the war by nearly two years.

While Turing contributed greatly to the final demise of the Axis powers and the greater world of computer science, his work remained unrecognized for many years. Even more unfortunate was the mistreatment he received by the law for being gay. Turing was forced to succumb to hormone treatment that was believed to change his sexuality. However, he still continued with his work, producing many more papers and theories in the field of mathematics and science. His work at Bletchley Park along with his many foundational theories prove his undoubted role as the catalyst for what is known as the odyssey of computer science.

PHOTO BY SHUTTERSTOCK

Cryptologia (1999). DOI: 10.1080/0161-119991887793

Geographic landmarks often hold uniquely deep and personal cultural meanings to the people who encounter them. Mount Moran and the Teton Range was a transient home and spiritual monument for members of the Shoshone Tribe before becoming a subject of the 19th-century landscape artist Thomas Moran, the namesake of the mountain. Now, it hosts skiers and climbers from around the world.

PHOTO BY IAN HAY, BIOENGINEERING & COMPUTER SCIENCE, 2023

WHEN THE MONSTER UNDER THE BED COMES TO LIFE

BY IPEK OZCAN, DATA SCIENCE & BEHAVIORAL NEUROSCIENCE, 2026

DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025

If you have awoken at night unable to move and experiencing hallucinations, you might be part of the 40% of people that have experienced sleep paralysis. Although terrifying, this nightmarish state can be explained through the neuroscience of sleep.

Sleep paralysis happens during the REM stage when two brain structures known as the dorsolateral pons and medial medulla secrete inhibitory neurotransmitters such as glycine and gamma-aminobutyric acid to create a state of paralysis known as muscle atonia. This state of paralysis developed as an evolutionary trait, allowing us to sleep on trees and in small spaces without attempting to attack the "monsters" in our dreams. Normally, we don't notice this state of atonia, however, sometimes a person will regain consciousness while remaining paralyzed.

Sleep paralysis experiences can be categorized into three, non-mutually exclusive groups: incubus, intruder, and vestibular motor sensation. In incubus sleep paralysis, the sleeper will feel a deep pressure on their chest as if someone is sitting on it, making it difficult to breath. This can be explained by our short and quick breathing patterns during REM sleep, an unnatural and uncomfortable state for those conscious to experience it. This can be combined with intruder sleep paralysis, where the sleeper will imagine a figure in the room. This is due to the inactivation of the temporoparietal junction, responsible for our ability to distinguish what is physically real and create our body image. The inactivation of the temporoparietal junction is also the reason for vestibular-motor sensation where the sleeper will feel disassociated from their body, either floating above it or looking from a third person point of view.

Even though we now know the neurobiological processes occurring during sleep paralysis, researchers still are not certain as to how external variables are associated with sleep paralysis and possible cures. In a study by Dan Denis and his team at Beth Israel Deaconess Medical Center, a correlation was found with usual sleep inhibiting external factors such as substance use, stress, and PTSD. However, researchers still have not been able to pinpoint why these factors lead to consciousness during REM sleep. Regardless, these external correlations open the way for future studies observing the neurobiological effects of these external factors.

Neurotherapeutics (2021): DOI:10.1007/s13311-020-00966-8
Sleep Medicine Review (2018): DOI: 10.1016/j.smrv.2017.05.005

PHOTO BY SHUTTERSTOCK

Into the dreamscape

BY DIVYA RAVIKUMAR, BIOENGINEERING, 2025

DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025

When our heads hit the pillow at night, we are usually swept away by dreams that feel vividly real, despite the unbelievable things that might happen. However, sometimes the illusion is shattered when people become aware that they are dreaming while they are still asleep. This phenomenon is known as lucid dreaming, and it is starting to prove as a powerful tool for researchers to explore people's minds by communicating with them in their sleep.

Lucid dreaming is a gray area of consciousness that involves aspects of both waking and dreaming. Although scientists still are not clear on why it happens, according to research done by Denholm Aspy, it's possible that lucid dreamers "might tend to produce more of the neurotransmitters that pause REM sleep." On top of that, a 2017 study found that there is increased activity in brain regions related to higher cognitive functions during lucid dreaming, like the prefrontal cortex, which includes working memory, self-consciousness, and self-determination. These factors come together to imitate a similar decision-making process compared to a wakeful state and allow people to control certain parts of their dream. People who naturally lucid dream have a larger prefrontal cortex and tend to be more self-reflective and open to new experiences, but anyone can become better at lucid dreaming by changing their habits and practicing the skill.

In a 2021 study, researchers at Ken Paller's lab at Northwestern University were successfully able to hold a two-way conversation with participants who were lucid dreaming during REM sleep. Scientists asked study participants to answer simple math questions in their sleep by moving their eyes from left to right to indicate the solution. The eye movement was then detected by electrodes, and the answers were found to be correct.

This achievement opens up a whole new world of possibilities. If people could narrate their dreams in real-time, it could help scientists understand REM sleep and how to utilize the dream state to its fullest potential. The ability to intentionally dream about practicing certain tasks or skills could prove invaluable for many different reasons. As scientists dive deeper, lucid dreaming might be the gateway into the untapped world of sleep.

PHOTO BY PIXABAY

Opinion: The odyssey of medical training and how burnout can lead to tragedy

BY LILY WEBER, BIOLOGY & ENGLISH, 2023
DESIGN BY CARINA HALCOMB, EXPERIENCE DESIGN, 2024

Most people know that doctors must complete residency as part of their medical training, but have you ever wondered where the term originates? The origin of the term dates back to the late 1800s and early 1900s when residents were actually required to live at the hospitals in which they worked. In other words, from the program's inception, it presented an inherent tip to the scale of work-life balance. It's no wonder that the residents of today, despite not literally "living" in the hospital, often struggle with burnout, long hours, and comparatively low pay.

Resident hours are notoriously long and arduous. To put things in perspective, the average American work week is around 40 hours. In 2003, the Accreditation Council for Graduate Medical Education limited resident work weeks to 80 hours. Notably, that limit refers to the average hours within a four-week period, meaning that residents could be working well over 80 hours a week, so long as other weeks compensate. The long hours, though obviously important for education, can be disastrous when one considers their impact on lifestyle.

> "The conditions imposed by residency run contrary to the very values that underlie the practice of medicine in the first place."

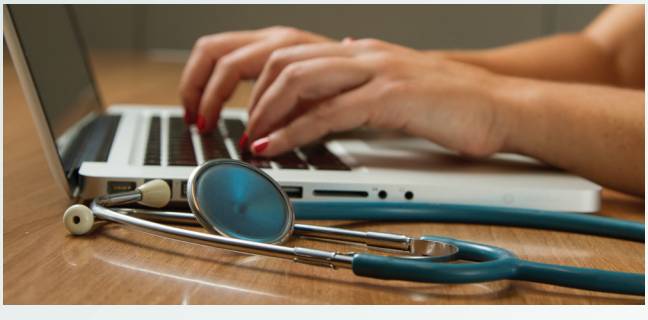
It is no surprise then that the burden of residency can end in tragedy. In September 2022, Dr. Jing Mai, a first-year resident in California, took her own life. She was only three months into her residency. In a statement, Her family described how Dr. Mai suffered from severe anxiety and depression, both of which were likely exacerbated by the pressures of residency training. Stories like this are unfortunately not rare. In fact, a study conducted by Yagamour and collegues at the Accreditation Council for Graduate Medical Education in 2017 found that between 2000 and 2014, 324 individuals died during residency, with the second leading cause being suicide. The study cites a lack of mental health support as a likely reason for this, which could have helped circumvent physician burnout.

Burnout is defined as a state of physical and mental exhaustion in relation to work or caregiving activities, both of which are inherent to practicing medicine. This state is especially important to study in the medical field, where burnout can directly impact patient care. In fact, the aforementioned 80-hour limit was initially adopted by New York state after the death of Libby Zion, a patient whose father believes her death to have been caused by overworked resident physicians. Accordingly, a 2009 systematic review conducted by a team of researchers at Cedars-Sinai Medical Center found that between 25% and 75% of residents experienced burnout. Furthermore, the researchers found a burnout rate of between 28% and 45% in medical students, indicating that the problem may begin before residency even starts. If medical students enter residency already experiencing burnout, it can only lead to more issues down the line.
In 2011, a cross-sectional study at Hofstra North Shore School of Medicine aimed to assess residency schedules and how they correlated with burnout. The reported rates were similar to those of the 2009 study, with 76% of survey respondents meeting the criteria for burnout. Moreover, overnight calls were found to be associated with higher burnout rates and fatigue. Receiving overnight calls, where physicians can be called upon at any moment to advise medical care or even come into the hospital, is yet another way in which the lines between work and life are obliterated in the medical field. The study also found that those with higher burnout scores were more likely to report making errors and less likely to report delivering satisfactory patient care. In short, the conditions imposed by residency run contrary to the very values that underlie the practice of medicine in the first place.

Famously, one of the principles of the Hippocratic oath that all medical students take is to "abstain from all intentional wrong-doing and harm." Those who endeavor to enter the field of medicine do so with a spirit of altruism to help others and contribute to their welfare. But how can residents fulfill the ever-growing need for medical care in an environment that does the exact opposite? In learning to care for people's ailments, training is destined to be difficult and emotionally taxing, but residency programs can and should do more to support their physicians during their training. As demand for physicians continues to increase, doing nothing is certain to alienate potential future doctors and decrease the quality of care delivered by those who do ultimately choose to enter the field. If nothing changes, the healthcare system will continue to be strained, and that can only serve to harm both patients and the physicians that undertake their care.

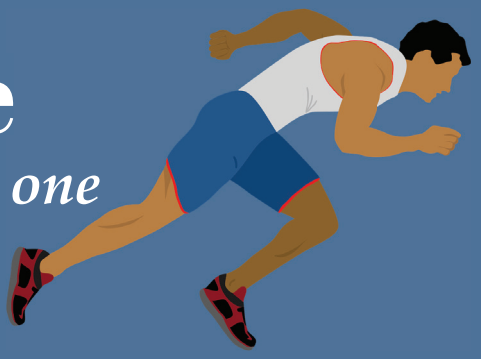
Journal of Graduate Medical Education (2009). DOI: 10.1097/ACM.0000000000001736
Post Graduate Medical Journal (2013). DOI:10.1136/postgradmedj-2012-131743
Academic Medicine (2017). DOI:10.1097/ACM.0000000000001736

PHOTO BY NATIONAL CANCER INSTITUTE



Secrets to an endurance athlete

and how to become one



BY AMANDA BELL, DATA SCIENCE & BEHAVIORAL NEUROSCIENCE, 2023
DESIGN BY ANANYA JAIN, BEHAVIORAL NEUROSCIENCE, 2025

People often perceive endurance as an ability that takes significant time and patience to develop or something limited only to those with "good" genetics. While both can be true, anyone can become a solid endurance athlete with the right training. Performance training that targets metrics that scientists use to assess fitness is one place to start.

One of the most common metrics to assess fitness is VO_2 max, the maximum amount of oxygen the body can use during exercise. In endurance events, this is important because oxygen is required to perform cellular respiration, which allows muscles to keep working. The more oxygen you can use at a time, the more work your body can do. A similar metric often referenced in training programs is lactate threshold: the point where lactate, a chemical byproduct of intense physical exertion, accumulates in the bloodstream at a faster rate than it can be broken down. When you exercise above this threshold, you fatigue more rapidly; so the higher this threshold is, the longer you could prolong fatigue.

Training programs often target VO_2 max and lactate threshold with specific workouts. This might look like 3–5 minutes at VO_2 max pace, with 50%–100% recovery time between intervals, or it might look like 20– 30 minutes at lactate threshold pace. You can determine paces or heart rate ranges for these workouts with online calculators that account for your recent race times. If you wanted to implement these types of workouts into your routine, you could look for training programs online and adapt them as needed to match your current fitness level and desired goals.

Another common assessment metric is exercise economy, which measures the efficiency of movement. Scientists define exercise economy as the amount of oxygen required to move at a given speed. A 2012 review published in Sports Medicine explains that older athletes tend to have a greater exercise economy since they have more endurance training experience; however, "explosive strength training" can also improve exercise economy. This gives athletes with less experience in their endurance sport another way to boost efficiency. Scientists hypothesize that improved neuromuscular control from this training improves exercise economy by better regulating the stiffness and elasticity of muscles. For example, stiffer muscles are better able to store and release energy, therefore lowering the amount of oxygen needed.

A 2021 study published in the Journal of Applied Physiology assessed physiological differences in the spleens of endurance athletes and untrained individuals. One function of the spleen is storing and releasing red blood cells into circulation to transport oxygen to tissues in need. The scientists hypothesized that athletes would have larger spleens and greater splenic contractions during exercise because they are frequently exposed to high oxygen demands through training and would need an efficient mechanism to adapt. In accordance with their hypothesis, results showed that athletes in the study had larger spleens and greater splenic contractions, in addition to elevated levels of hemoglobin, a protein in red blood cells that carries oxygen. Higher levels of hemoglobin suggest an enhanced oxygen carrying capacity in athletes, but can anyone attain this physiological benefit?

A few studies cited in the 2021 publication found that participants who trekked in high altitude conditions for at least two months or engaged in static apnea training had increased splenic volume following the studies. Participants in the apnea training studies held their breath for almost as long as they could 5–10 times per day, then breathed normally for 2 minutes before starting the next breath hold. In theory, integrating this breathing exercise into your daily routine could help you attain the physiological benefits of an endurance athlete. The other practice you could engage in is regular exposure to high-altitude conditions. If you don't live in a high-altitude area, you could simulate exposure through high-elevation training masks, but more research is needed to evaluate whether wearing a high-elevation training mask achieves the same benefits as regular exercise in high altitude.

With these science-backed suggestions, building endurance doesn't have to be a daunting task. If you would prefer more guidance in your journey to becoming an endurance athlete, joining a group for your desired sport or hiring a coach would also be reasonable steps to take. Although this training requires discipline and commitment, anyone can improve their endurance. So, enjoy the process, and don't give up!

PHOTOS BY PIXABAY

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The journey of the little pill through your body

and how your posture can speed it up

ARTICLE AND DESIGN BY VIANNA QUACH, PHARMACEUTICAL SCIENCE, 2025

Got a headache? At this point, many would go to their medicine cabinet and wash down a pill or two of painkillers. Sometimes the drug does as it was intended. Other times, no results come from swallowing that little capsule, or perhaps the effects are slower to come than expected. It would be easy to brush it off and simply say the medicine was "not for me," but what if it was possible to improve the effectiveness of the medication just by rolling over on the couch?

Oral ingestion is a widely popular method of medicine intake while simultaneously being a difficult journey for the drugs to take. Once the drug passes from the mouth to the stomach, resisting degradation in highly acidic stomach fluids, it makes its way into the small intestine where it gets absorbed into the bloodstream. In this trip, it must pass through the liver and other body organs where it must survive partial metabolism. By the time the drug makes it to its location of effect, a smaller amount than what was originally ingested is available to function; researchers call this fraction of the dose the bioavailability of a drug.

Various studies agree that the bioavailability and absorption time of some drugs could be attributed to the amount of time it remains in the stomach. Gastric emptying, where the contents of the stomach move to the small intestine, could be affected by multiple factors, one studied currently in pharmacokinetics being posture. Observations of the influences of posture on drug absorption are not new. Studies on this effect date back to 1918 and have since been observed for various drugs, according to a 2008 review by Christian Queckenberg from the Clinical Pharmacology unit at the University of Cologne. According to Queckenberg and a 1992 study by the Clinical Pharmacology Group from the University of Southampton, lying on one's right side, sitting, and standing can increase both the drug's absorption time and bioavailability. Lying on one's left side and supine, in contrast, resulted in opposite effects. A recent 2022 study by researchers at Johns Hopkins University corroborates these findings in their model of the GI tract. Their simulation showed that, when leaning right, gravitational forces set the pill in an optimal position for the stomach's series of contraction and expansion pulses to push it through to the duodenum: the upper segment of the small intestine. Some studies propose that this increased gastric emptying rate could allow drugs to rapidly bypass their first metabolism with a greater concentration intact.

The stomach isn't the only organ affected by position either. Researchers know position affects other regions of the body as well. This list includes plasma distribution in the body, hepatic blood flow, metabolism, renal elimination, and the autonomic nervous system via skin pressure. For example, lying on the right side stimulates the vagus nerve, a component of the parasympathetic nervous system. This system relaxes muscles in the body — opposing stress responses — which would encourage digestion.

Implications of these findings can do more than quicken pain relief. One study highlighted by Queckenberg's review even recommended using posture to aid in overdose treatments. Since lying on the left side decreases rates of absorption of some drugs, the researchers suggested laying patients in this position as a first aid step. Whether or not posture has a known significant effect on the drug at hand, repositioning may assist in the process of detoxification by slowing further absorption.

Nevertheless, posture can only do so much for a drug's journey. There are numerous other factors that play even larger roles in how the body metabolizes these substances, and even those effects depend on the properties of the medicine itself. It would be difficult to say that one posture has significant effects on all drugs. The researchers from the University of Southampton claimed that posture effects worked best in cases where the drugs were quickly absorbed into the bloodstream after gastric emptying. Likewise, others found that the effects of posture decreased when drugs were taken with solid food or nutrient-rich liquids — both of which decrease gastric emptying rates. So the next time you feel a headache, perhaps it would be a good idea to take that Tylenol on an empty stomach, and then lie down on your right side for a bit.

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THE RETURN OF MONKEYPOX

BY DESSY DUSICHKA, COMPUTER SCIENCE & BIOLOGY, 2025

DESIGN BY PARKER HITT, BIOLOGY, 2024

Just when the world thought it had gotten a grasp on COVID-19, monkeypox emerged as another infectious disease and public health concern. Monkeypox is a viral disease classified as an Orthopoxvirus, a genus that includes smallpox, cowpox, camelpox, and similar diseases. Excluding smallpox, all human cases of orthopoxviruses are considered zoonoses, or diseases transmitted to humans by animals. Monkeypox was first discovered in a monkey in a Danish lab in 1958, but contrary to what the name suggests, the virus is more common among rodents.

The disease is characterized by the rash it causes, which eventually develops into blisters and lesions — patients can have anywhere from a few lesions to thousands. Other symptoms include fever, headache, fatigue, and enlarged lymph nodes; people typically show symptoms for two to four weeks. Transmission often occurs via contact with an infected person's lesions, bodily fluids, or respiratory secretions, but monkeypox can also be contracted by touching objects used by an infected person.

More severe complications are possible, including pulmonary distress, blindness, and even death. People at risk are immunocompromised individuals, pregnant women, and children under age eight. The mortality rate is around 10%, but this is likely a high estimate and result of the disease being more prevalent in regions with limited access to healthcare. Luckily, this is still significantly lower than smallpox's mortality rate of 30%.

A crucial tool for controlling monkeypox is vaccination. Since the viruses are so closely related, the smallpox vaccine (widely administered in the mid-20th century during the smallpox eradication campaign) offers strong monkeypox protection. However, since smallpox eradication was achieved in 1980, this vaccination is no longer routine, leaving people vulnerable to monkeypox

The first human case of monkeypox was identified in 1970 in the Democratic Republic of Congo, and it has been an endemic (locally contained) disease in Central and West Africa for over 50 years. Virologists have noted migration into animal habitats as a cause, along with the high prevalence of HIV and AIDS in the region, which left much of the sub-Saharan African population immunocompromised and vulnerable. This, combined with the fact that smallpox vaccinations and immunity were waning, allowed monkeypox to thrive in Africa.

The current 2022 outbreak began in mid-May, marking the first time monkeypox spread widely beyond Africa. According to CDC data from October 2022, there have been nearly 70,000 confirmed cases in 107 countries, 100 of which have not historically reported monkeypox. The countries with the most cases this year are the United States with over 26,000, then Brazil with over 7,800, and France with around 7,100. Recently, the disease has been largely transmitted through sexual activity; the CDC reports that 99% of US monkeypox cases occurred in men, 94% of whom "reported recent male-to-male sexual or close intimate contact." Disease statistics can be influenced by many biases, so it is critical that community health officials work in an equitable manner to minimize stigma and reduce barriers against prevention, testing, and treatment. Fortunately, very few cases of monkeypox have resulted in death throughout this 2022 outbreak, and treatments are generally effective.

Experts attribute the current monkeypox outbreak to improper disease monitoring and inadequate public health measures. Monkeypox surveillance in Africa has not been consistent or adequate, enabling international spread. Additionally, monkeypox researchers have historically struggled to receive funding. Many important questions surrounding the disease still need answers, including the specifics of transmission, the severity for different risk groups, patterns of pre-symptomatic transmission, and the stability of the virus on surfaces and in air.

An especially important concern is reverse zoonosis, or the spreading of monkeypox from humans back to animals in new regions. The establishment of the disease in an animal reservoir (likely a rodent) in Europe or North America would make eradication nearly impossible.

Thankfully, antiviral drugs are useful and a monkeypox vaccine exists. One positive side effect of this outbreak is the fact that it allows scientists to assess their arsenal of treatment against orthopoxviruses. Monkeypox has historically been studied by researchers as a surrogate for smallpox, and the link between the two is yet another reason to support monkeypox research.

Diseases have complex odysseys, often with significant effects on global populations. It is crucial that scientists work to uncover as much information as possible and that healthcare becomes increasingly available and equitable. This way, both prevention and treatment are prioritized, drastically improving human health outcomes and limiting the scale of future outbreaks. Hopefully, these challenging past few years encourage scientists and policymakers alike to realize the importance of monitoring and controlling disease before it gets out of hand, and maybe someday, monkeypox can join smallpox as another eradicated disease.

PHOTO BY SHUTTERSTOCK

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BREAKING THE PATTERN

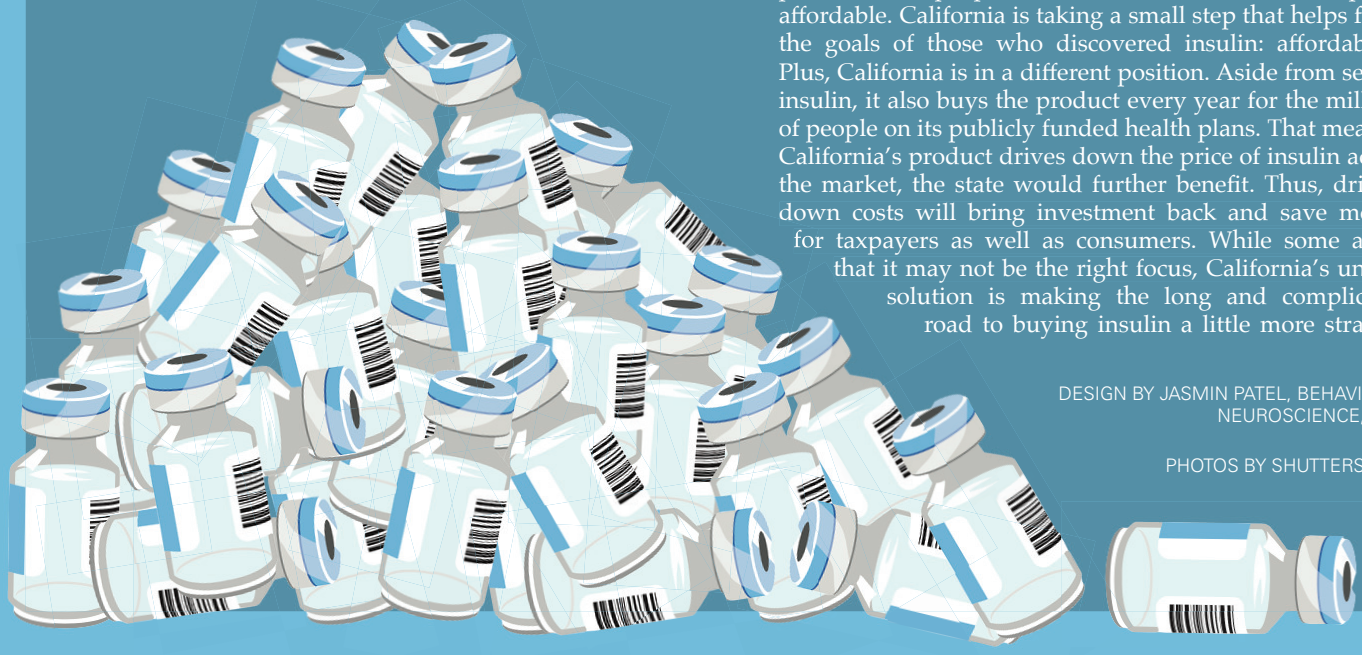
California's step into reducing insulin prices

BY ALEENA JACOB, HEALTH SCIENCES, 2025

Insulin is a necessity. A peptide hormone produced by the pancreas, insulin is important in controlling blood glucose levels as well as carbohydrate, fat, and protein metabolism. In fact, without insulin, glucose can not be stored, and its absence causes fat to be broken down into keto acids, triggering diabetic ketoacidosis, a harmful condition often showing symptoms of rapid deep breathing and a high thirst.

Some people cannot produce enough functional insulin to maintain homeostasis, a condition called insulin-dependent diabetes or Type 1 diabetes. Fortunately, a team of Canadian scientists in the 1920s was able to discover a way to inject pure insulin via a needle into the body so that people with this condition can live well-balanced lifestyles. Aware of the significance of their discovery, the original intent of the scientists was to ensure that the prices of insulin would be affordable. They were able to sell their patent on insulin to the University of Toronto for just one dollar. By selling it to a university, they hoped this would prevent a monopoly from building a high-priced marketplace for their discovery.

But, in the United States today, this is far from the truth. Though the discovery of insulin was relatively straightforward, the price for this essential hormone has had a long and complicated journey. In 1995, the price for a vial of insulin was $25. But today, the same vial can cost more than $300. Even though the cost of production is relatively low at around $10, only in the United States has the price of insulin been on the rise in the past three decades.



The high prices have largely been due to pharmaceutical companies wanting to monopolize and maximize profits. This quest for profit has led to the involuntary sacrifice of consumers and has left many patients who are in need of insulin left with only two options: find a way to pay for it or die.

One state in the United States has recognized the large toll the price of insulin can have on patients and looks to challenge the pharmaceutical industry: California. Since several of the insulin patents are nearing their expiration date within the state, California wants to disrupt that market by making and selling its own insulin at a cheaper price.

Dr. Mark Ghaly, the secretary of the California Health and Human Services Agency, believes this is an "opportunity to create a blueprint for healthcare affordability."

Because the line between an insulin manufacturer and a patient is not straightforward, many believe the plan in California will not be successful. Some argue it might be better to focus on solutions that address the role pharmacy-benefits managers play in insulin pricing. In other words, critics of the plan suggest taking the whole system of pharmacies down instead of focusing on the prices alone, which can have positive impacts beyond just insulin.

However, by taking this initial step against price gouging, California is trying to break a pattern of corporate greed among pharmaceutical companies. By breaking the pattern, more people can enter the market to make prices affordable. California is taking a small step that helps fulfill the goals of those who discovered insulin: affordability. Plus, California is in a different position. Aside from selling insulin, it also buys the product every year for the millions of people on its publicly funded health plans. That means if California's product drives down the price of insulin across the market, the state would further benefit. Thus, driving down costs will bring investment back and save money for taxpayers as well as consumers. While some argue that it may not be the right focus, California's unique solution is making the long and complicated road to buying insulin a little more straight.

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

PHOTOS BY SHUTTERSTOCK

HOW AI CAN IMPROVE MRI IMAGING SPEED

BY MICHELLE WILFRED, HEALTH SCIENCE, 2026
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

Magnetic Resonance Imaging (MRI) technology has greatly accelerated advancements in the medical field. Today, MRI machines are a staple in hospitals across the world. The machines use a magnetic field and radio waves to produce anatomical images. They provide doctors with the ability to see abnormalities or defects in certain body parts. MRI machines are more powerful than ever before and have stronger magnetic fields and clearer, more accurate images than just ten years ago. However, anyone who has experienced an MRI scan knows that the process is very slow and it can be uncomfortable to hold still for the duration of the scan. The scans can last anywhere between 15 and 90 minutes. Given this inconvenience, it is reasonable to wonder if it is possible to speed up MRI scans. It turns out that AI can be used to decrease the time it takes to scan a patient.

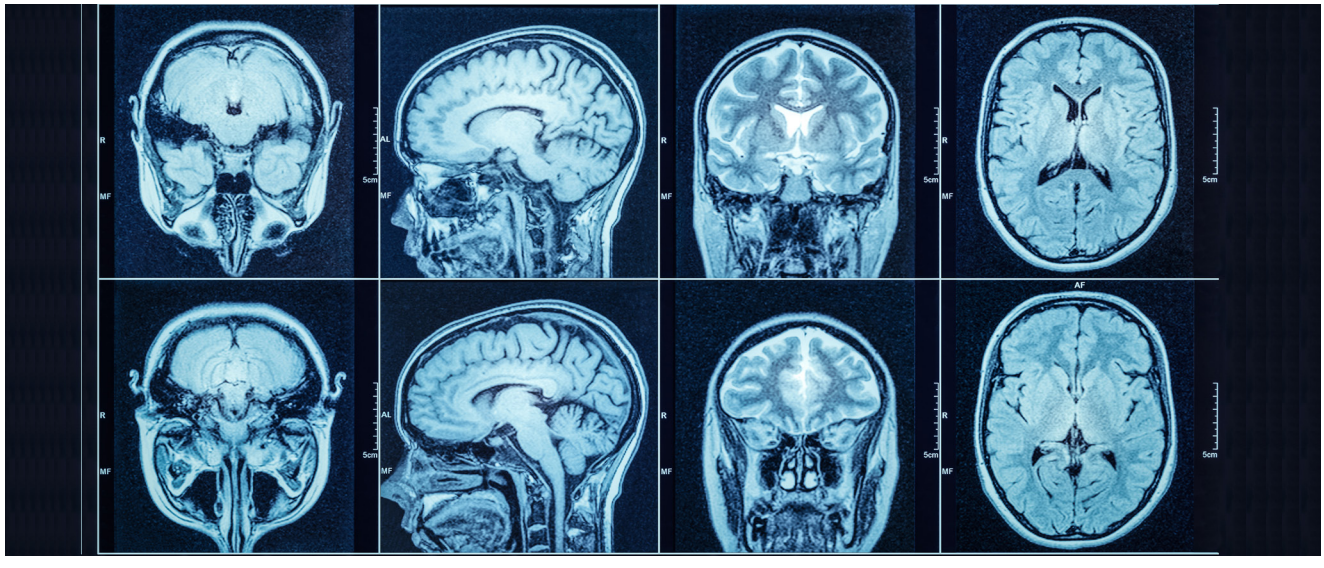
> "The potential for using MRI technology in clinical practice is boundless."

At NYU Langone Health, physician and researcher Dr. Michael P. Recht is leading a project called fastMRI to create a model that speeds up the rate of MRI scans. His group theorizes that by using AI, the scan could take in less data and still be able to create the same quality image as a standard MRI image. Recht tested images from 108 patients: a set of classic MRI knee images and a set of fastMRI knee images and asked radiologists to read them (checking for abnormalities or defects) without telling them which one was which. The researchers found that the radiologists arrived at the same diagnoses using both images and even agreed that the fastMRI images were of better quality. Normally, with MRI technology, it's a constant war between upping image quality or speed, but fastMRI seems to have the whole package.

How exactly does the fastMRI work? fastMRI uses a type of artificial intelligence called neural networks. Neural networks mimic the human brain when making decisions. It takes in inputs and applies quantitative representations of importance to each. It then uses the inputs and their importance to make decisions. Researchers used a neural network and trained it on a large set of images and had the machine reconstruct the image. Because of the ability to reconstruct the image, only one-fourth of the image data was needed, and thus, completed the scan in a faster time. The AI machine learned the pertinent details of the images and automatically removed the structures that make up standard MRI images. Thus, it comes up with a cleaner version of the knee.

The one challenge that the researchers are facing right now is standardization. It is difficult to get the same results multiple times in a row and to reproduce the work with the same accuracy. Therefore, new researchers are taking advantage of the fact that all the research and datasets are publicly available online and attempting to reproduce the work in their own AI models. In the future, researchers at NYU are looking to confirm that this technology works for organ imaging too. Perhaps the most significant use of MRI technology is the scanning of the brain, and it would make a significant impact if this research can be implemented in this area.

The potential for using AI in MRI technology in clinical practice is boundless. Patients can be diagnosed faster and with less effort on the doctor's end. The scan time could be cut down to as short as five minutes. Meta AI, which is partnered with NYU on this research project, has been providing consistent updates on its blog. According to Meta, if all goes well, fastMRI could begin "allowing doctors to use MRIs in place of X-rays and CT scans for some cases" reducing the necessity for radiation exposure.



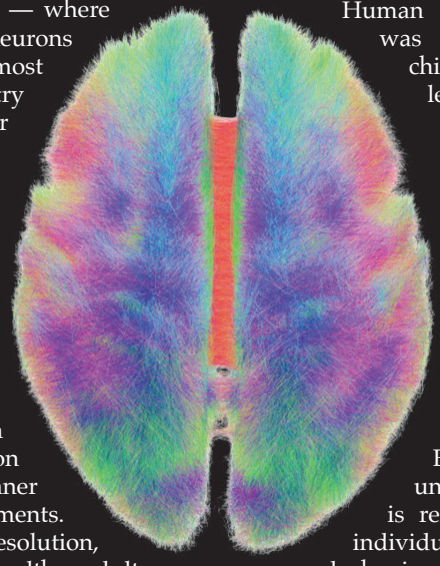
PHOTOS BY SHUTTERSTOCK

Mapping the human brain

ARTICLE AND DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Thirteen years ago, scientists of the NIH embarked on a journey to do the seemingly impossible: create a map of the human brain. They coined this undertaking the Human Connectome Project (HCP). This crusade is nothing new to the field. Starting with Santiago Ramón y Cajal, who discovered intricate neuronal networks in the late 1800s long before imaging, and for centuries since his time, scientists have been piecing together neuronal networks with the ultimate goal of finding a consistent guide to the human mind. Since its outset in 2009, the HCP has transformed neuroscience research and only plans to grow from here; the scientific community reflects on its purpose, progress, and future.

The average human brain has 86 billion neurons, forming trillions of connections. Neurons send messages down their axons — known as white matter — where connections are formed. These neurons intertwine to ultimately form the most complex and interconnected circuitry known to man. In fact, the cables — or neuronal axons — account for over half of total brain matter. Anatomically, understanding the map of neural connections in the brain, or the connectome, is an integral step toward understanding the fundamental aspects of cognition, systemic brain activity, and functional neuroanatomy.



The HCP contains two branches of research focus: mapping the human brain's connections in high resolution and creating a new neural imaging scanner that optimizes connectome measurements. To map the human brain in high resolution, the HCP collected data from 1,200 healthy adults, specifically the twins and their siblings from 300 families. Data was collected using non-invasive brain scans — task-evoked functional Magnetic Resonance Imaging (tfMRI) — to map the structure and function of the individual brains. The HCP compiled this data to generate a collective map of neural circuitry using overlapping networks within the 1200 scans. Further, they created a scanner that mapped neurons with long-distance axons. These axons reached different and highly specific tissues within the periphery of the human body, allowing the brain to be seen with higher detail and clarity when stimulated.

Being a part of the NIH and highly engaged with their large participant network and the general public, the HCP released the 1200 subjects' data in 2017. Anyone who has access to the internet also has access to the data library of 1200 different people and the collective structural network. Not only did the HCP transform decades of research, but the project shared it with the public, in turn redefining the open science movement.

Releasing the first round of major data brought not only a surge of knowledge regarding the connectome but a glimpse into the clinical power and applications of connectome data. Scientists broaden their horizons from new research approaches to familiar neurological issues. For example, the Alzheimer's Disease Connectome Project (ADCP) was launched to develop technology to map Alzheimer's disease across every stage of its progression. Similarly, the Human Connectome Project for Early Psychosis was launched to collect high-resolution imaging and data on early psychosis patients to share with other researchers. The Lifespan Human Connectome Project in Development was launched to study how common childhood experiences, such as literacy learning, can shape cortex connectivity.

With such intensive and expansive research regarding the human connectome comes newfound excitement — and comfort — in the prospect of having a map that carefully explains emotion, behavior, decision-making, and the human experience. However, this new research brings up an old and persistent question: what does it mean to map the human brain?

Every person is objectively unique, and this universal difference amongst individuals is reflected in their brains. Moreover, each individual person's brain is constantly changing and shaping in reaction to their experiences. Thus, many find themselves apprehensive about the idea that one collective map can define a highly individualized and evolving entity. However, the differences in connectivity that define individuality involve much fewer neuronal networks and connections than it would seem. Although people show individual variation in connectivity, much of the connectome responsible for foundational behavior is similar across all people. Thus, a relatively universal connectome can be created and used for investigation into common, yet often poorly understood neurological and psychiatric diseases.

Just like the ever-evolving nature of the human brain, the HCP is far from the end of its journey. The project is not only traveling into a new era of research regarding the connectome, but also a new culture of scientific inquiry and curiosity.

NeuroImage (2021). DOI: 10.1016/j.neuroimage.2021.118543

LONG, LOST COVID

How 10 million children have become orphaned due to COVID

ARTICLE AND DESIGN BY LILY GARRETT, BIOCHEMISTRY, 2025

The long crusade of the coronavirus pandemic began in late 2019. Fast forward to present time, and we are approaching three years since the premier cases of the virus. During these long and "apocalyptic" years, COVID-19 has taken a tragic toll on the lives of people globally. Millions of exposures and deaths have inevitably occurred due to the fast-spreading and easily-transmittable nature of the respiratory virus. Responsively, several therapeutics companies such as Moderna, Pfizer, and Johnson & Johnson have developed groundbreaking vaccinations and booster shots to protect people from the harmful symptoms of the virus. Amidst the whirling storm of the past few pandemic years, a heartbreaking wave has crashed down on humanity: a shocking 10 million children have become orphaned due to losing their caregivers in the wake of COVID-19.

It has become an increasingly difficult process to quantify principal total COVID-19 deaths, meaning deaths of individuals actively affected by COVID-19 symptoms at the time of death. Global aggregate deaths have previously been inaccurately estimated due to common biases. For example, countries with less available hospital resources tend to underreport deaths: in turn, they create downwardly biased COVID-19 statistics. Further, nations have differing jurisdictions on the types of COVID-19 death statistics and records that can be released publicly and hence have created inconsistencies in the data. Yet now, through statistical analyses of mortality, there are new and realistic estimates of the global COVID-19 excess death toll.

> "The issue of vast orphanhood due to the death of parents and caregivers hits disadvantaged communities and nations the hardest; these children are in severe deprivation of what they need to move forward with their lives."

It is important to not only obtain accurate COVID-19 data but also to utilize the data to make a positive global impact. A 2022 research study in *JAMA Pediatrics* achieved just that by successfully estimating COVID-19 excess mortality totals with the specific intention of observing caregiver and primary parent loss. The study used the "Guidelines for Accurate and Transparent Health Estimates Reporting" and collected data primarily from the World Health Organization. Total deaths from Jan. 1, 2020, through Dec. 31, 2021, and Jan. 1, 2020, through May 1, 2022, were gathered and computed to present regional and national statistical estimates. The findings of the carefully gathered statistics showed that a globally estimated 10.5 million children lost a parent due to COVID-19 and 7.5 million children were left orphaned as a direct result of a caregiver's death by COVID-19.

An important aspect of this data is that children in African and Southeast Asian nations experienced significantly more orphanhood compared to the Americas and Europe. The lack of crucial resources such as access to health care, hospitals, and vaccinations has continued to exacerbate the effects of the COVID-19 pandemic in some of these nations. Specifically, the issue of vast orphanhood due to the death of parents and caregivers hits disadvantaged communities and nations the hardest; these children are in severe deprivation of what they need to move forward with their lives.

The possible realities for many of the millions of children bereaved of parents by COVID-19-associated death are grave and heartbreaking. Orphaned children are at higher risk for institutionalization, emotional and behavioral complications, lack of proper education, poverty, abuse, and absence of overall support for their well-being. Due to the lack of time allotted to prepare for the devastation of orphanhood, many children end up in adverse situations and experience mental health challenges. They are at notably higher risk for contraction of chronic diseases and adolescent pregnancy.

What needs to change? Many researchers who have analyzed excess COVID-19 mortality and resulting orphanhood believe that the acceleration of equitable vaccine access is imperative. To change the future narrative for children affected by the COVID-19 pandemic who have lost their caregivers, global prevention of disease and allocation of necessary medical resources and care is the first step. Further, communities must work to create publicly available personal and educational resources and fundraise in order to better advocate for orphaned children.

It is essential to provide an accurate and articulated global understanding of the extent of COVID-19 deaths to increase awareness of its severity. Through sharing this perspective, people can then become further educated about the millions of bereft children as a result of the virus and find ways to support them. For the many individuals affected by COVID-19 who haven't experienced facing the death of a loved one or peer, the pandemic may have less gravity — for orphaned children, the COVID-19 pandemic will define the rest of their lives.

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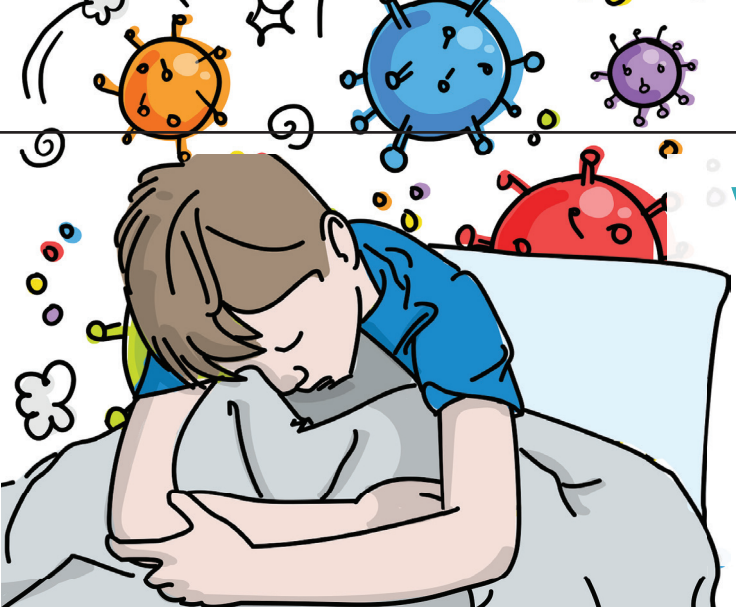
PHOTO BY INNOVATIVE GENOMICS INSTITUTE



What it's like inside pediatric long COVID clinics

BY SHRUTI PATEL, PSYCHOLOGY, 2025
DESIGN BY ANANYA JAIN, BEHAVIORAL NEUROSCIENCE, 2025

Despite contracting COVID-19 many months earlier, 9-year-old Jack Ford is still unable to get through a full school day without overexerting himself. As *CNN* reported, even being mentally engaged for a long time by playing Fortnite or watching TV completely exhausts him to the point of feeling sick the next morning.

Persistent headache, fatigue, muscle pain, and difficulty breathing are just a few of the most prevalent symptoms of long COVID-19. According to the World Health Organization, long COVID refers to the long-term symptoms developed during or after a COVID-19 infection that persist for at least 2-3 months and cannot be explained by any other diagnosis. Although more common in adults than children, the long-term consequences of COVID-19 can make routine actions extremely taxing.

Long COVID symptoms vary from person to person but are generally similar to typical COVID-19 symptoms. Researchers worldwide have examined the clinical characteristics and illness manifestations of patients in pediatric long COVID clinics. A team of researchers from Tel Aviv University assessed 90 children at a long COVID clinic within a pediatric center. At least half of the surveyed patients reported experiencing fatigue and difficulty breathing. Muscle aches, sleep disturbances, headaches, loss of or distorted sense of smell, and memory impairment were also common among the patients. Out of the 90 children in the sample, 82 experienced only a mild severity of symptoms when initially contracting COVID-19.

Similarly, researchers affiliated with Emma Children's Hospital in Amsterdam surveyed 89 pediatric long COVID patients across the Netherlands. Fatigue, difficulty breathing, and concentration difficulties were the most reported symptoms. The children also reported the extent of the limitations in daily functioning attributed to their long COVID diagnosis, with 48% reporting mild limitations and 36% reporting severe limitations. Within this sample, 25% of patients required physical therapy and 16% were regularly meeting with a psychologist as part of their treatment.

Children and adolescents with long COVID around the world are facing similar hardships despite the variance in symptom presentation. Ranya Ribera, an 18-year-old from New Jersey, had her hair fall out as a side effect of COVID-19 infection. In a *PBS News Hour* story, she reveals that her anxiety and lack of motivation still prevent her from seeing her friends and socializing over a year after contracting the illness. Luckily, Ranya's experiences with a long COVID support group associated with the RWJBarnabas Post-COVID Recovery Program connected her with people who experienced similar symptoms and helped her feel less alone.

Fifth-grader Aurora Burt from Dover, Massachusetts, suffers from parosmia, which is a distorted sense of smell and taste, deterring her from eating most foods. Having such a restricted diet has become a nutritional issue for Aurora who, according to a *Boston 25 News* interview, now has lower energy levels, a compromised immune system, and worsening mental health. Treatment methods such as smell retraining have failed to work for her, but health experts are optimistic for her recovery due to the resilience associated with young age.

Despite its prevalence and wide recognition, the cause of long COVID symptoms is debated by some healthcare professionals who claim symptoms such as headache and fatigue may not be the direct result of COVID-19 infection. Instead, they believe it is possible these symptoms stem from social restrictions like self-isolation and school shutdowns, which can cause unprecedented levels of stress on a child. Moreover, some healthcare professionals assume long COVID patients' symptoms are purely psychological or psychosomatic, which can lead to a patient's dismissal.

A group of researchers based in Rome, Italy, recorded the experiences of young long COVID patients including 17-year-old Cecilia, who was dismissed by doctors who insisted her pain was imaginary. Cecilia finally received a long COVID diagnosis after two months of constantly experiencing debilitating symptoms. Experts argue that legitimizing a patient's suffering would remove one of the many barriers long COVID patients face when attempting to acquire treatment, as well as relieve them of the psychological burden of their pain not being believed.

Most pediatric long COVID patients attest that their symptoms have limited daily activities and decreased quality of life in some way. Cecilia's ability to concentrate and understand material while studying has diminished compared to before she contracted COVID-19, which may hurt her chances of reaching her goal of being admitted to a medical university.

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PHOTOS BY PIXABAY

The evolution of CRISPR

BY LILLY SCHAR; HISTORY, CULTURE & LAW; 2025
DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

CRISPR-Cas, without a doubt, is a buzzword in the modern scientific community. It holds immense potential, above all else, to implement change within medicine and by extension people, policy, and the world. However current the potential of CRISPR-Cas may seem, the discovery of the CRISPR-Cas system dates back almost 40 years. The focus now applied to CRISPR-Cas studies came about when scientists around the globe slowly aligned their research goals and even more scientists built on it. The evolution of CRISPR-Cas has been everything from incremental to controversial, and it is certainly ongoing.

The term "clustered regularly interspaced short palindromic repeats" was coined by Francisco Mojica in 1993. Six years prior, Mojica, Yoshizumi Ishino, and their team discovered these DNA repeats accidentally in the genome of E. coli. At the same time, a research team in the Netherlands found that different strains of bacteria contained spacer sequences between DNA repeats and that these spacers could reversely be used to identify strains of bacteria. Unfortunately, Ishino, Mojica, and others could only learn so much about these sequences due to the lack of DNA sequencing technology. The best hypothesis was that these DNA sequences functioned as a kind of repair mechanism for archaea and bacteria.

It was only in the late 1990s and early 2000s that DNA sequencing technology took off for a second time and sequencing an organism's genome became faster, more accurate, and more efficient. The advantages of this tech gave way to Mojica and his team identifying that the spacer sequences were not random, but were similar to existing prokaryotes. The team further found that viruses cannot infect bacteria with a homologous spacer sequence. This led his team to make a new hypothesis, involving CRISPR as an adaptive immune response for bacteria against viruses. Together with Cas (CRISPR-associated sequence) proteins, the CRISPR system fights reinfection by analyzing the DNA of a specific virus.

In 2007, French scientist Philippe Horvath proved Mojica's hypothesis by demonstrating how a bacteria commonly used in the dairy industry could defend itself against viral attack by introducing a phage and then successfully locating the phage's DNA sequence in the CRISPR array. Horvath further identified that of the various Cas proteins, Cas9 was the only protein necessary to split target DNA in a CRISPR system.

From 2007 to 2012, research in the Netherlands, the United States, Canada, Sweden, Austria, and Lithuania revealed the mechanisms of CRISPR-Cas. It was through this research that an application began to emerge. Virginijus Siksnys and his team in Lithuania were able to reprogram a Cas9 protein to target a chosen sequence in foreign DNA, which showed that the CRISPR-Cas system could be personalized. Simultaneously, Jennifer Doudna and her lab in California synthesized the CRISPR system, making it more accessible as a "cut-and-paste" genome editing application. In 2013, Feng Zhang of MIT and George Church of Harvard brought down the house by successfully applying the CRISPR-Cas system to mammalian cells in laboratory experiments. Both Zhang and Church labs engineered Cas systems to target sequences of their choosing.

Since these foundational studies, new goals of eradicating previously incurable human diseases arose. Clinical trials using CRISPR-Cas approaches to treat sickle cell anemia have been ongoing and have more recently been implemented in cancer research and treatment. Diagnostic tests for saliva, blood, and urine using CRISPR-Cas have become fast and accurate alternatives to amplifying sections of DNA.

But applications of CRISPR-Cas go beyond the medical realm. The conjunction of agriculture and technology has shown promise in editing food for longevity and consistent growth. CRISPR-Cas systems applied to bacteria have been shown to activate pathways for creating the components of biofuels. All of these applications carry huge benefits for people and the planet. There is a reason CRISPR-Cas has stayed relevant. Forty years later, the road of experiments, trials, and research still stretches far into the horizon. The story of CRISPR-Cas is not over; it is just beginning.

Science (2013) DOI: 10.1126/science.1232033
Journal of Bacteriology (1987) DOI: 10.1128/jb.169.12.5429-5433.1987
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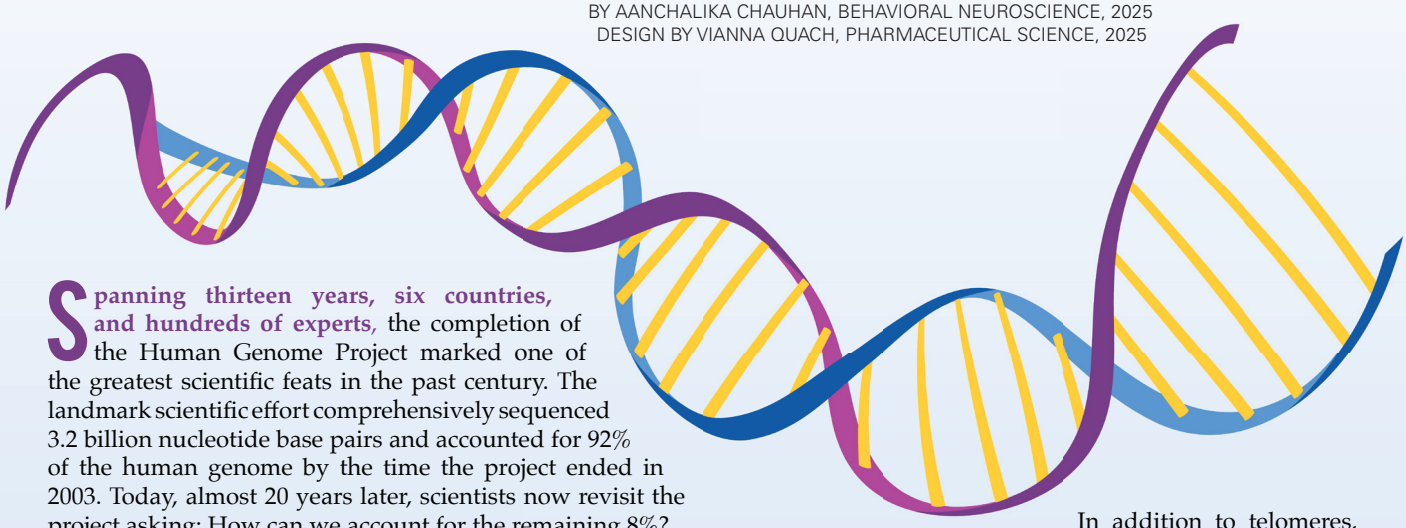
PHOTOS BY SHUTTERSTOCK

RESEQUENCING OF THE HUMAN GENOME

BY AANCHALIKA CHAUHAN, BEHAVIORAL NEUROSCIENCE, 2025
DESIGN BY VIANNA QUACH, PHARMACEUTICAL SCIENCE, 2025



Spanning thirteen years, six countries, and hundreds of experts, the completion of the Human Genome Project marked one of the greatest scientific feats in the past century. The landmark scientific effort comprehensively sequenced 3.2 billion nucleotide base pairs and accounted for 92% of the human genome by the time the project ended in 2003. Today, almost 20 years later, scientists now revisit the project asking: How can we account for the remaining 8%?

This question led to the formation of the group "Telomere to Telomere" whose goal is to fill the "black hole" of the human genome project by sequencing telomeres and centromeres; these components of the human chromosomes were unable to be sequenced due to technological limitations during the original Human Genome Project. Now, the group has access to two major advancements in technology: The Oxford Nanopore DNA sequencing method and the PacBio HiFO DNA sequencing method. The Oxford Nanopore method can sequence up to 1 million DNA nucleotides in one reading, while the PacBio HiFi DNA method can read up to 20,000 nucleotides with almost perfect accuracy. During the original Human Genome Project, researchers were only able to sequence short pairs at a time, rendering the methods at the time costly and time-consuming.

Telomeres, which are repetitive sequences that protect and preserve the chromosome from nucleolytic degradation, were originally regarded as "junk DNA" by scientists. However, recent studies have found that telomeres house vital genes that influence protein development, chromosome division during meiosis, and those that define the human species. Telomeres have also been linked to various forms of cancer and aging, opening a new portal of potential diagnoses forms and diagnostics:

"We've discovered millions of genetic variants that were previously not known across samples of thousands of individuals whose genomes have already been sequenced," said Rajiv McCoy, an assistant professor at Johns Hopkins University. "We will have to wait until future work to learn more about their associations with disease, but a big focus of work now will be on trying to discover new genetic variations that were previously uncharacterized."

IMAGE BY BRGFX VIA FREEPIK

Science (2022). DOI: 10.1126/science.abj6987

In addition to telomeres, centromeres, which bind the two chromatids of a chromosome together also have the potential to give new insight into molecular genetic pathology. Centromeres are highly influential in neurodegenerative diseases and brain development and are speculated to be involved in immunodeficiency; centromeric region instability; and facial anomalies syndrome, which is a rare disease that is characterized by rearrangements in proximity to centromeres on chromosomes 1 and 16.

In addition to sequencing telomeres and centrosomes, the next step computational biologists are looking at is to sequence both maternal and paternal sets of chromosomes. During fertilization and meiosis, the blastocyst inherits one set of chromosomes from the mother and the other set from the father. The original project found it difficult to separate and match maternal and paternal sequences. The issue is described as having two puzzles in the same box: scientists have the sequences, but connecting and identifying if a sequence belongs on one chromosome or another remains a daunting yet rewarding task.

Since 1990, the Human Genome Project has accelerated medical research in numerous ways, from providing diagnoses at a molecular level, to opening doors to genetic engineering, to prevent these diagnoses. The study has also influenced our treatment of rare disorders. Now, there is increased cohesion of genomic profiles across multiple individuals in a population, helping identify correlations and other factors which may influence diseases. Although the project has been extended for over 30 years, the continuous progression of science has saved many lives and has the potential to save even more.

"This is the joy of science and research: the work is never complete," said Eric D. Green, the director of the National Human Genome Research Institute. "Each advance opens new vistas of opportunities with the frequent sense that the best is still yet to come."

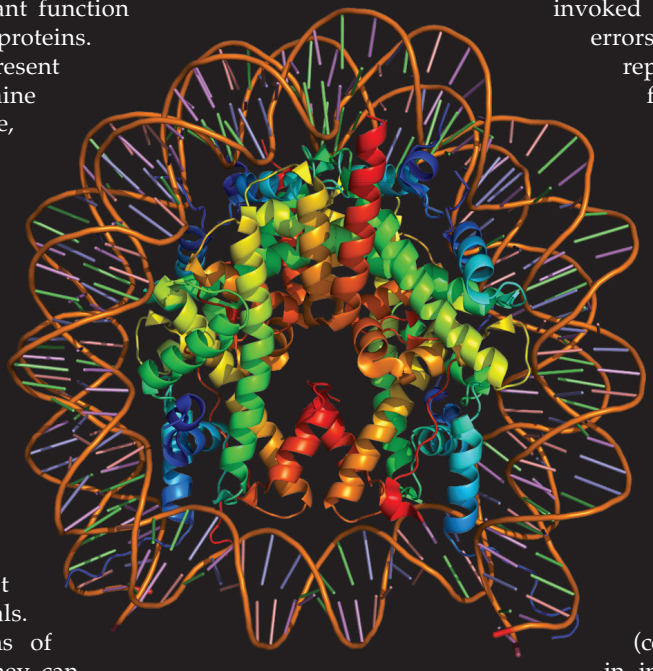
HISTONES THE MASTERMINDS BEHIND GENE EXPRESSION

BY RESHIKA SAI DEVARAJAN, HEALTH SCIENCE, 2025

DESIGN BY AMANDA BELL, DATA SCIENCE & BEHAVIORAL NEUROSCIENCE, 2023

Cells make up tissues, which make up organs, which form organ systems, which ultimately are the key to keeping us alive. But what is the key to unlocking how various types of cells are made? How does a neuron know to transmit information from the brain to parts of the body, and how does a muscle cell know to contract and extend to promote movement? If the cell is the most basic unit of life, capable of affecting a cascade of structures increasing in complexity, what exactly is regulating them?

The answer lies in a concept called epigenetics. The prefix epi- is a Latin root, meaning over or upon. Therefore, epigenetics refers to the various factors that affect how genes are expressed, without physically altering the DNA sequences that exist. A codon is a three-nucleotide sequence in DNA and is the physical unit of heredity. The most important function of genes is to code for proteins. The types of proteins present in a cell ultimately determine its function. For example, certain highly-expressed genes in neurons produce neurotransmitters and chemical protein signals that are transmitted to other cells to relay important messages that determine cell activity across the body. Muscle cells may receive these signals and carry out necessary functions, but because the genes that code to produce neurotransmitters are turned off, they do not produce the chemical signals. In this way, the functions of cells are divided so that they can communicate and become extremely specialized for the area of the body they reside in.



Just as plants do not require all the same functions as humans, genes in the DNA of different organisms differ. However, certain subsets of genes are highly conserved throughout all organisms and through billions of years of evolution, many of which are associated with epigenetics. A conserved gene has essentially remained the same throughout evolution and has not been changed. If all organisms are different, why are epigenetic genes a constant, even as organisms have branched off and evolved? The answer to this question is rooted in cell specialization. Complex organisms require different cells to perform a variety of distinct and specific tasks, and epigenetics is a solution to regulating this specialization of cells.

One of the most highly conserved epigenetic-related genes is the one that codes for histone proteins. Histones are proteins that attach to the surface of DNA, genetic information winds tightly around histones, creating packages called nucleosomes, which are later further packaged into chromosomes. Histones play a major role in how compact DNA is packaged, which has great effects on how accessible genes are to transcribe and translate into viable proteins. Various cells have different parts of their DNA more or less tightly packed, affecting the yield output of specific protein-coding genes.

A recent study conducted by the Spanish Ministry and the Andalusian Government analyzed the effect of histone depletion. The depletion of histones is important in turning on and off certain functions, especially time-sensitive processes such as DNA repair. In fact, histone depletion is invoked as a response to DNA breaks and errors, to promote the proliferation of DNA repair proteins to perform restoration functions. In this way, histones are adaptable components of cells that can meet the needs of the situation at hand.

Histone availability has important implications on health outcomes as well; many diseases can be attributed to a lack of regulation of protein production due to an inadequate amount of histone control. Lupus, an autoimmune disease that is due to over-reactive immune cells, was recently linked to histone degradation in a study done in 2021. Degradation of histones was present in peripheral blood mononuclear cells (cells important in immune function) in individuals suffering from Lupus but absent in healthy individuals. Histones play an important role in the defense of cells, as they can control proteins that may help or hurt a cell.

As millions of molecular processes occur simultaneously in the millions of cells of your body, they remain distinct due to the unique regulation power of histones. The masterminds of a cell, histones determine what path a cell diverges to and its impact on the health outcomes of the body.

PHOTO BY WIKIMEDIA COMMONS

RNA Biology (2016). DOI: 10.1080/15476286.2016.1189071
The FEBS Journal (2022). DOI: 10.1111/febs.15903

Nature's miracles: Hippocampi

BY DHRITI AIYLAM, BEHAVIORAL NEUROSCIENCE & ENGLISH, 2024
DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

There is no doubt that seahorses are fascinating creatures. Ranging from the size of a pine nut to nearly a foot long, sporting funky colors and an aura of mythicism, they have long been a source of wonder to human civilizations. Scientists find them intriguing for a host of reasons — their elongated, suction-like snout, lack of teeth and pelvic fins, body covered with bony scales, and of course, male pregnancy. So in 2016, through an international collaboration, Professor Qiang Lin and his colleagues decided to investigate these oddities by mapping the entirety of the seahorse (specifically, the tiger tail seahorse, *Hippocampus comes*) genome.

They found that these tiny fish have 23,458 genes — quite comparable to our own genome of around 20,000 genes. A quarter of these genes are transposable elements — nifty DNA sequences that jump around the genome. The phylogenetic tree reveals why seahorses are so different from other fish species. Seahorses diverged from other percomorphs — a certain class of fish that includes tuna, pufferfish, and anglerfish — 103.8 million years ago and their branch length is longer. This indicates that they have a higher protein evolutionary rate than average, due in part to a greater rate of neutral nucleotide substitutions (substitutions that don't change anything) and a higher molecular evolutionary rate.

If you watch a video of a seahorse eating food, they are voracious eaters, eating up to 3,000 pieces of food a day! They suck up their food like vacuum cleaners since they lack teeth. There is a class of gene called SCPP (secretory calcium-binding phosphoproteins) responsible for the formation of all mineralized tissue. SCPPs come in two forms: acidic (for bone formation) and proline/glutamine (P/Q) (for teeth formation). While a seahorse's acidic SCPPs are normal, they have no intact P/Q SCPPs, with only closely related P/Q gene Scpp5 functioning as a pseudogene. This is a loss-of-function mutation — which is not necessarily bad. Without it, the seahorse wouldn't have one of its evolutionarily unique oddities!

Seahorses also lack the Tbx4 gene which explains the lack of pelvic fins. Tbx4 is a transcription factor that regulates the development of hind limb formation. There could be many reasons seahorses do not have pelvic fins — maybe they don't face significant pressure from predators (as pelvic fins allow for subtle swimming maneuvers), or it would not work with their elongated body plan. Knowing this, Venkatesh et. al used CRISPR-Cas9 to knock out the Tbx4 gene in zebrafish to see if this would influence pelvic formation. They found that the zebrafish were viable — except for the lack of pelvic fins. Interestingly, that's not the case in mice, where knocking out Tbx4 leads to a lack of hind limb formation and issues in lung and placental development.

What about the genes that don't code for anything? Vertebrate genomes have thousands of CNEs (conserved noncoding elements) that perform regulatory functions. However, H. comes lacks more CNEs than other percomorphs, displaying the most loss in Sall1a, Shox, and Irx5a. These genes are involved in the development of the limbs, nervous system, kidney, heart, and skeletal system — indicating that these systems could potentially develop differently in seahorses than in other vertebrates and that the loss of these CNEs could have contributed to seahorse morphology, although further research is needed to confirm this.

Finally, we turn to the phenomenon of male pregnancy — how does that work? Upon fertilization of the eggs, the female deposits them into the male's brood pouch where the hatchlings will stay for two to four weeks until they develop. A subfamily of genes called C6AST, HCE, and LCE (high and low choriolytic enzymes, respectively), allow for the chorion — an important developmental membrane — around the egg to be lysed and the embryos to be hatched. Among this subfamily is a gene subtype called pastristacin (Pastn) which is highly expressed in the male's brood pouch. There are six of these genes, expressed in different stages of pregnancy. Looking at the closely related *H. erectus*, the researchers saw that some of these genes — particularly, Pastn1, Pastn2, and Pastn3 — were highly expressed during male pregnancy and that these genes are functionally similar to pregnancy genes in another type of female fish.

There is still so much more to learn about seahorses — we are just beginning to unlock the secrets of their genome. Regardless, it remains evident that every new bit of knowledge renders them even more fascinating, even more whimsical than we have ever thought them to be.

Nature (2016). DOI: 10.1038/nature20595

PHOTOS BY SHUTTERSTOCK

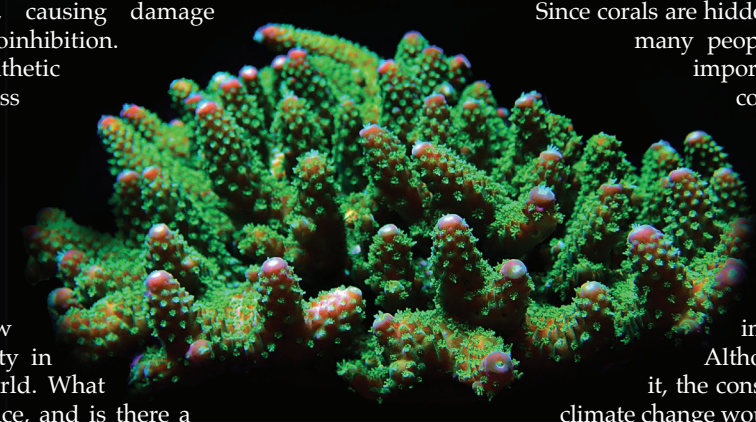
A FLUORESCENT CRY FOR HELP
HOW CORALS USE "SUNSCREEN" TO STAY COOL

BY SOPHIE DONNER, ENVIRONMENTAL & SUSTAINABILITY SCIENCES, 2025
DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Glow sticks are part of a happy childhood memory for many. Beneath your fingertips, you snap the plastic stick in half, revealing a beautiful vibrant color show in the dark. While glowing colors may remind us of nostalgic times, fluorescing corals are a sign of a last-ditch effort to survive bleaching in the battle against climate change.

When corals face environmental stress, such as excess light or increased temperature, they expel the photosynthetic algae living in their tissues, known as zooxanthellae. These algae produce carbohydrates through photosynthesis, providing food that corals depend upon to survive. Once the zooxanthellae have abandoned the coral, the coral appears translucent, revealing the chilling sight of exposed white skeletons. At this point in bleaching, corals can still recover, but if the algae do not return for long periods, the coral is left vulnerable to disease, starvation, and eventually death.

Zooxanthellae require sunlight to photosynthesize, but excessive exposure to light can exceed the algae's photosynthetic capacity, causing damage and leading to photoinhibition. With damaged photosynthetic machinery and the stress of increased light and temperature, corals are extremely susceptible to bleaching.



Amidst the sea of white bleached coral skeletons, some have begun to glow vividly, sparking curiosity in scientists around the world. What is this sudden fluorescence, and is there a purpose behind it?

Scientists at the University of Southampton and the University of Western Sydney studied this phenomenon, speculating that these fluorescent colors are from chromoproteins in corals that may serve as a sunscreen-like protective layer. Researchers proposed that chromoproteins act as a layer that screens incoming light, absorbing and reflecting photons away from the algae in coral tissue. One particular study, done by Aanya Salih and a team of researchers at the University of Western Sydney, used two different colors of Acropora valida coral, a brown morph and a purple morph with differing amounts of chromoproteins, to see how the presence of chromoprotein pigments in coral tissue impacts the response of algae to high light stress. At the end of the experiment, coral branches lacking chromoproteins, known as CP pigmentation, showed signs of bleaching, while branches with CP pigmentation did not suffer from bleaching. Coral tissues containing high amounts of chromoproteins in the purple morph experienced much less photodamage than the tissues with fewer chromoproteins present in the brown morph. This indicates that chromoproteins successfully screen out excess light, protecting the algae from damage to their photosynthesizing machinery. Scientists have coined this occurrence as an optical feedback loop.

Not only do these fluorescent photoprotective pigments provide a sunscreen-like protective layer to zooxanthellae in coral tissues, but they also could encourage algae to recolonize bleached tissues. The research team from the University of Western Sydney believes that the presence of CP pigmentation in "growth zones" assists in the colonization of new coral tissue by providing photoprotection. As CP pigments mitigate light stress on corals by screening and reflecting photons away, this could draw algae back to corals, assisting in the recovery of already bleached vulnerable corals. Upon return of the algae, the chromoprotein genes are turned off, efficiently saving energy and increasing coral productivity.

Since corals are hidden below the ocean surface, many people are not aware of their importance. Corals protect coastlines from erosion, absorbing wave energy from major storms. They support high levels of biodiversity, provide food and medicines for millions of people, and hold a large economic importance through tourism. Although people may not realize it, the consequences of losing reefs to climate change would be detrimental.

However, do not lose hope. It is not too late for corals. When speaking at the American Museum of Natural History on her research with corals and their fluorescence, Salih said "if we care, as people, about these natural resources, then we can influence what happens to these resources." If enough people understand how crucial it is to save coral reefs, changing actions can make a difference. Corals cannot survive future climate change on their own solely with their chromoprotein "sunscreen."

It is hard to miss these neon survival signs that corals have created. This is nature's way of begging us to take responsibility. Asking us to help corals in their battle against climate change. Imploring us to change our harmful actions before it is too late.

PHOTO BY SHUTTERSTOCK

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BACK TO BASICS

A bird's preference for native species over their invasive counterparts

BY JEFFREY PAN, ENVIRONMENTAL & SUSTAINABILITY SCIENCES, 2024

DESIGN BY PARKER HITT, BIOLOGY, 2023

PHOTO BY NISHI PATEL
PHYSICS & DATA SCIENCE, 2024

As food availability in the Northern Hemisphere decreases in the fall, many birds travel southward. This seasonal trend of mass travel is known as migration. To prepare for a large migration, birds often stock up on fruits and other food sources. But with invasive plant species overtaking their native counterparts, birds are struggling to obtain the nutrients they need to migrate.

Throughout the world, invasive plant species have outcompeted their native counterparts, often overwhelming entire habitats due to an optimal growing climate and lack of natural predators. Native species may be "phased out" and completely removed from their environments, with invasive species providing for the ecosystem. Many of these invasive plant species propagate and spread their seeds via fruits, hoping that animals such as birds consume them and bring them elsewhere to grow. However, as the Earth warms due to climate change, bird migrations and plant phenology are altered in a way such that native plants produce fruit earlier than their invasive counterparts. According to a 2015 study led by Utah State University researcher Amanda Gallinat, this creates a situation where "birds could encounter fewer native fruits in late-autumn, creating an opportunity for invasive plants to have enhanced fruit dispersal due to lower competition for dispersers."

Would these birds prefer native species to invasive ones now that there are fewer native fruits as the season progresses? To test this hypothesis, Gallinat studied birds' eating patterns in Manomet, Massachusetts, a prime location for migration stops for many birds in the Northern Hemisphere. Gallinat teamed up with Boston University biology professor Richard Primack and Trevor Lloyd-Evans, a researcher at the Manomet Bird Observatory. In Manomet, there are plenty of native and invasive plants that provide food sources for these migratory birds. This makes the region an attractive area for birds to stop by during the migration season. Before birds migrate, they prefer fruits that are dense in energy, fat, and antioxidants so that they have more stamina for their upcoming odyssey, according to a study from the University of Rhode Island.

The team decided to focus on 25 fruiting species in the area, 10 of which are classified as invasive species. To determine the diets of the birds that were consuming the fruits these plants were bearing, 970 fecal samples were taken over a two-year period and analyzed to see if there were any seeds of the plants found within them. The seeds were then identified via color, shape, surface patterns, and size. The results favored native species. Gallinat and her collaborators concluded that the majority of the birds sampled showed strong evidence of choosing "to consume native species that were present in low abundance or were no longer ripe, rather than the abundant invasive ripe fruits on site." This means a lot in regard to native seed dispersal and plant distribution. It shows that many migratory species still depend on these native resources for their high nutritional value, despite the abundance of invasive fruits in the area.

This case study provides further incentives to protect our native species against invasive ones. Without the proper nutrition provided by these native fruits, many of these migratory birds would have to stop more frequently during their migration, putting themselves at risk of predation or starvation. These birds also run a chance of an incomplete migration due to weakness caused by a lack of proper nutrition. Furthermore, the ingestion of invasive species by migratory birds can cause the birds to spread invasive seeds along the migratory corridor, which can destroy native habitats across hundreds of miles. It is important to be aware of the implications of invasive species and the damage they cause to natural ecosystems. Birds continuing to choose native species provides a promising light to the preservation and hardiness of our native species.

Biological Conservation (2020). DOI: 10.1016/j.biocon.2019.108268
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PHOTO BY JIAJIA FU, BIOENGINEERING, 2024

TRIALS OF THE GOLDEN FLEECE

WHAT BEES MUST OVERCOME WHEN COLLECTING POLLEN

BY KEVIN LU, COMPUTER SCIENCE & MATHEMATICS, 2026

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Contrary to our peaceful perception of the humble bee, foraging for pollen can be a treacherous journey filled with seduction and trickery. Bees don't get a "free lunch" in their mutualistic relationship with flowers. Instead, flowers often exploit bees as vessels for pollination, forcing them to endure trials reminiscent of Jason's endeavors for the Golden Fleece.

Students often learn that flowers attract bees through visual and olfactory stimuli. Flowers develop traits to advertise their nectar in a bid to woo bees in "pollinator Tinder." From seductive colors and scents to UV spectrum "bullseye nectar guides," flowers have evolved to be as alluring as possible to any passing bee.

> "Despite flowers' extensive efforts to attract pollinators, they are incredibly selective with who receives their nectar."

Despite flowers' extensive efforts to attract pollinators, they are incredibly selective with who receives their nectar — a high-calorie and nutritionally expensive substance to produce. According to a study by State University of New York professor Edward Southwick, nectar production can take up to 37% of a plant's daily phosphate intake. Thus, flowers seek efficient pollinators who will spread pollen widely and need minimal nectar as an incentive. Like Jason, bees must prove themselves through Olympic challenges before receiving their prize.

Orchids, for instance, are a particularly picky plant. The bucket orchid forces bees through a treacherous obstacle course: dangling upside down, wading through puddles of liquid, and finally, trudging up a narrow spout. When the bees finally arrive at safety and nectar, the flower cunningly plants pollen on the bees' backsides — primed for pollinating other flowers but useless for feeding fellow bees.

To further manipulate pollinators, species of flowers may resort to false nectar pockets, traps, and even sexual seduction. The cruelest trial comes from the bee orchid and its deceptive mimicry. The journey begins with seducing male bees, using the alluring scent of an amorous and available female. Captivated male bees then pounce on the bee-like flowers and proceed with pseudo-copulation, attempting to inseminate the flower. Tragically, as the bee realizes its mistake, two pollen packets have been carefully placed on his abdomen for delivery to the next flower. American biologist Thor Hanson captures the ingenuity of the bee orchid: "All those male bees 'attacking' bee orchids excel at pollination without even realizing they've visited a flower."

However, bees are not powerless victims to be exploited by flowers. Jason overcame King Aeete's challenges with sheer ingenuity and specialized potions. Similarly, bees have developed all kinds of techniques for circumventing a flower's carefully constructed pollination scheme. Short-tongued bumble bees, for instance, will chew through the base of flower blossoms to reach nectar, providing other pollinators with easy access as well. Other bees engage in a sort of "bee thievery," which involves sneaking behind the gaps between petals and has perhaps encouraged the evolution of tightly clustered flowers with protected backs.

Even when bees play nice, pollinating flowers is more of an offshoot consequence. Bee interests lie in efficiently gathering pollen for their personal use, with highly evolved species carefully grooming stray pollen from their bodies and packing it into dense clumps on their back legs. The stark truth is this: Bees perceive flowers as a resource, while flowers use bees as convenient tools.

Rather than a simple "win-win," the relationship between bees and flowers is akin to an arms race of evolution and ingenuity. Coevolution has created many exclusive relationships between species of bees and flowers, evident in the specialization of traits from bee tongue lengths to the depths of flower spurs. According to a team of researchers from the California State University biology department, the specialized relationship between zygomorphic flowers — those that are bilaterally symmetric — and their pollinator species results in overdependence and a heightened risk of extinction for both species.

The beauty of flowers represents generations of evolutionary forces in the natural process of competition, making the spring blooms all the more awe-inspiring and powerful. Every floral color, smell, and structure is artfully crafted with the exploitation of bees in mind. We are simply witnesses to the heroic efforts of bees and the intentional treachery of flowers in this incredible evolutionary odyssey.

Ecology (1984). DOI: 10.2307/1937773
Biology Letters (2020). DOI: 10.1098/rsbl.2020.0307
Buzz: The Nature and Necessity of Bees (2018). ISNB: 978-0465052615

CITY LIGHTS AND BIRD FLIGHTS

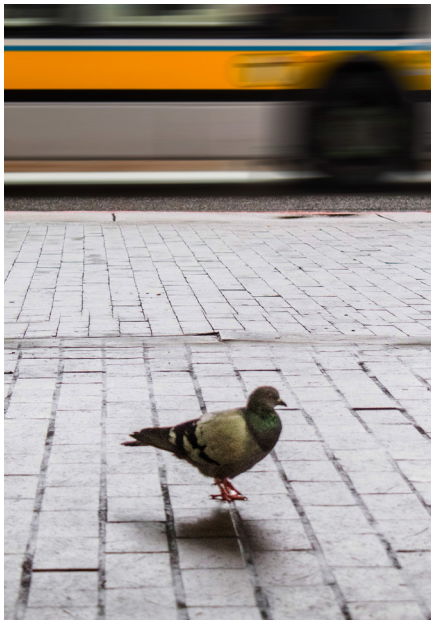
How human activity affects migration

BY CLAIRE MA, HEALTH SCIENCES, 2025

DESIGN BY STEPHANIE CHEN, DATA SCIENCE, 2026

The tradition of treating travelers with respect has been a long-held one, spanning many cultures and periods. As early as the Greeks and Romans, townspeople were hospitable to any and every stranger in the hopes that one may be a god in human form testing them. However, it isn't hard to find winged travelers that come from above. Migratory birds travel up and down the globe each season, using American skies as their route for migration. Species like the bar-tailed godwit fly 7,000 miles almost non-stop from Alaska to New Zealand, second only to the arctic tern's journey of over 9,000 miles, from one arctic pole to another. How good is the hospitality people lend to these travelers? Horrible. So horrible that, according to a 2019 study from Cornell University researchers, there has been a larger than 40% decline over the past 50 years in North America's grassland birds — that's around 1 in 4 birds lost.

This steep decline is unique to migratory birds, largely due to the rapid urbanization and development that has taken place over the last 50 years. To examine why it is unique, it is necessary to understand the mechanism of migration. The majority of migratory birds are nocturnal migrators that rely on the position of the stars to determine their paths. Using sight, smell, and magnetoreception, young birds migrating for the first time must learn to locate the North Star and use their 24-hour circadian rhythm to calibrate their sun compass. However, these navigation senses are found to be light-dependent. Studies suggest that the internal magnetic compass birds have is created in the birds' retinas through photochemically-formed radical pairs that contain spin angular momentum. Particles with this "spin" create microscopic fields of magnetism that can interact with environmental magnetism, allowing birds to sense the Earth's magnetic field. In short, birds use light-dependent quantum effects along with the orientation of the stars in the night sky to find their way.



Because light is so integral to a bird's internal navigation system, light pollution, which researchers termed as artificial lights at night (ALAN), seems to be the obvious culprit for the falling bird population. ALAN can produce skyglow, where particles within the atmosphere scatter light into areas that are not inhabited by humans, covering more than 80% of the world's airspace. This light can trigger disorientation, which may cause traveling birds to collide. Collisions are the biggest man-made killer of birds worldwide — up to 1 billion birds die from colliding with buildings annually in the United States alone, with most of the collisions occurring among nocturnal, migratory birds getting disoriented and attracted to glass-paneled buildings with strong interior lighting. However, fatal collisions are not the only issue. Any type of injury from a collision, fatal or not, can leave a bird too weak to continue its migratory path, preventing it from reaching its destination on time. Since many birds migrate seasonally to catch the few days when breeding occurs, if they miss that time window, they won't be able to reproduce, thus reducing the population further.

The negative effects of ALAN are not limited to blunt impact and disorientation. ALAN has also been found to disrupt the 24-hour and annual circadian rhythm within birds. The circadian rhythm is integral in initiating migration seasons and is especially important to species that spend the winter seasons near the equator, as the weather is too constant to provide environmental cues for migration. Additionally, melatonin, a hormone that is produced to trigger sleepiness, is released on a cycle that is determined by the circannual rhythms. When the migration season approaches, melatonin secretion is adjusted accordingly to allow for nocturnal migration. The avian circadian receptors lie in the retina and are reactive to light, so when birds interact with ALAN, it can alter their internal clock and melatonin secretion, leading to missed migration and loss of sleep. Additionally, melatonin disruption can decrease fitness, leading to impaired metabolism and immune systems, and ALAN implicates declined memory and visual-spatial learning in birds. The lack of total darkness at night can cause a slow decline in an avian population's overall ability to thrive, leading them to be sleep deprived, unable to recall where they need to go, and unable to initiate migration at all.

As travelers, birds need humanity's respect to survive. There is a need to be more hospitable to the tiny travelers that traverse the skies before our actions cause irreversible damage to their populations and to the world.

PHOTO BY ELIANA GILMAN, ARCHITECTURE, 2026

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Monarch migration:
A trip of a lifetime

BY CAROLINE GABLE, UNDECLARED, 2026

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

The monarch butterfly exhibits perhaps the most advanced migration pattern of any insect. Their migration pattern is equivalent in complexity to that of birds, demonstrating a two-way migration. This consists of migrating from point A to point B multiple times. Point A refers to the location the butterflies reside from late March to early October. In this case, point A is North America, where monarch butterflies are split into two populations: one population east of the Rocky Mountains and the other residing west. Point B is the location where the monarchs 'overwinter' or reside during the colder weather to survive. For the eastern population of monarchs, point B is the Sierra Madre Mountains of Mexico, and for the western population of monarchs, is along the Pacific coast, near San Diego, California, according to researchers at the United States Department of Agriculture. Starting in early October, monarchs utilize environmental cues to begin their incredible journey toward their southern point B location, with some monarchs beginning a journey of up to 3,000 miles to reach their overwintering location.

The monarchs return to the same forests of the Sierra Madre Mountains and Southern California each year, with some monarchs even overwintering on the same trees as their ancestors. Scientists and researchers aren't sure how monarchs know exactly where to go, especially given that individual butterflies only make the journey once in their lifetime. However, in 2016, a team of researchers headed by Assistant Professor Eli Shilzerman at the University of Washington, found that using their complex eyesight and their inherent internal clock to determine the time of day, monarchs are able to follow a "sun compass" southwest. The study discovered two neural mechanisms — one inhibitory and one excitatory — that control signals from the monarchs' internal clock genes. In simple terms, these mechanisms are able to encode the sun's position at different times of the day based on signals from the eyes. These signals tell the monarch's brain which direction to fly, whether it's south in the winter or north in the spring. While the findings of this study have yet to be fully confirmed with monarch behavioral and anatomical patterns, it is the best theory scientists have as to the monarchs' impeccable directional awareness.

As temperatures begin to rise near the end of March, the monarch butterflies begin their journey back to point A and begin their reproduction processes. Most male monarchs die soon after mating, while the female monarchs continue their flight north, laying eggs of the new generation in milkweed plants. The female monarchs die after laying their eggs, and the newly-born caterpillars take on the responsibility of reproducing, dying, and continuing the journey north. It takes about 3–4 generations of butterflies to completely return to the northern United States.

In July 2022, monarch butterflies were added to the World Wildlife Fund's endangered species list. Climate change, habitat loss, and the loss of milkweed, the plant the monarchs lay their eggs in and eat, pose a serious threat to these butterflies. Monarch butterflies are essential to our ecosystem as they are primary pollinators of flowers and fruits. Without monarchs, there would be a significant impact on the food that humans consume daily as well as on the common plants and flowers that rely on the butterflies' pollination. Conservation efforts, such as the Western Monarch Milkweed Mapper project, encourage individuals to plant milkweed and other flowers in their own backyards to provide vital resources for monarchs. Other projects report on and map the locations of milkweed plants in the United States, especially along common monarch migration paths. These conservation efforts will ensure monarch butterflies and their "sun compass" can complete the amazing journey for years to come.

PNAS (2019). DOI: 10.1073/pnas.1904690116

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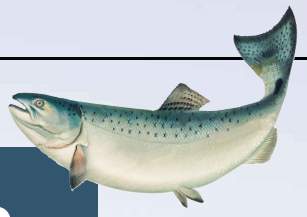
PHOTO BY SHUTTERSTOCK



Run, salmon, run

BY MADISON YORK, POLITICAL SCIENCE, 2025

DESIGN BY NIKKI SUZUKI, ECOLOGY & EVOLUTIONARY BIOLOGY, 2023

A salmon's life begins with death. Hundreds of miles inland, adult salmon swim against fierce currents, passing hundreds of predators to reach the stream they were born in. There, they spawn and lay thousands of eggs in nests, called redds. For eggs to hatch and new life to begin, mature salmon commit themselves to death mere feet from the redd they hatched from years before.

Salmon are diadromous, meaning they spend part of their lives in freshwater and part in saltwater and undergo lengthy migrations between the two. They spend just a few years after they hatch gathering the strength to swim from their gravel bed homes to the open ocean. These young salmon "fry" are around 10 centimeters long, but they are prepared by the genetics of generations before them to make the trip. Fry use river currents to move from freshwater streams to brackish estuaries to the salty ocean waters that house their feeding grounds. Before they make it to the ocean, fry turn to smolts as they adapt to their new salty environment and lose their spots in favor of camouflaging silver scales. In these estuaries, the salmon will develop incredible homing abilities that will allow them to track the Earth's magnetic field and their redd's chemical signature to once again find their natal stream.

For the next one to five years, these young salmon bulk. Feasting on the nutrients provided by the ocean, some species of Pacific salmon, like the Chinook, can grow upwards of 100 pounds. This is intrinsic to their strength during migration – once they reenter freshwater, many salmon will never eat again.

Whether caused by changes in water temperature or the sun's height in the sky, springtime pulls a trigger within mature Pacific salmon telling them it's time to spawn. Ready to begin their journey home, the fish use the Earth's polarity like a compass to lead themselves back to the river mouth they passed through years before. From there, salmon smell their way home.

Following these fish home, the first threat to their run appears at the coast — fishing vessels. For sport fishers to commercial enterprises, salmon are considered a prized catch. Also lurking nearby are sea lions, seals, and — the most fearsome among them — killer whales. Every year these marine mammals congregate by river mouths waiting for salmon to appear. The salmon that make it through these initial trials are not guaranteed to make it to spawning, they will face many more challenges before returning to their natal redds.

PHOTOS BY RAWPIXEL AND BROOKE ARNOLD, BIOCHEMISTRY, 2024

Past these predators' maws, salmon, now called spawners, reach estuaries. This will be the first time these fish have been in freshwater since their initial migration to the ocean. In these early stages of the run, male spawners will develop a hook-like beak, called a kype. Among males, the size of the kype determines the reproductive pecking order: The larger the kype the more desirable the male.

Moving upstream also means moving up. Salmon sometimes have to jump upwards of a meter to clear large rocks to continue to calmer streams. Along the sides of the bustling, narrow rivers await massive grizzly bears looking to feast before they enter hibernation. Grizzlies line the width of rivers, pouncing on the nutrient-rich and fatty salmon. This battle upstream is draining for the salmon who have not eaten in weeks.

Though salmon's migrational patterns are among the most difficult across animal species, they complete it for a simple reason - salmon know their natal redds are safe places for hatchlings. When they finally make it home, the salmon reproduce. Females lay thousands of eggs, of which very few will survive to spawn, but it is all they need to continue their vital population. Salmon that cannot find their natal stream will try to find another. If they fail, the fish will circle, searching for a protective gravel bed until they can no longer swim.

Here, at their natal redds, most salmon will die. Some species of Atlantic salmon can make it back to the ocean, but for Pacific salmon, this run is their end. They cannot eat in freshwater and are so exhausted from their thousand-mile migration that salmons' organs will quickly fail. This sacrifice will never be in vain; not only does the salmon run fuel future generations of salmon, but the nutrients their decomposing bodies release into streams help maintain healthy rivers, and, by following the current, ocean. After their run, mature salmon end their life cycle, but they begin a new generation too.

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Respiratory Physiology & Neurobiology (2012). DOI: 10.1016/j.resp.2012.07.019

The world's oldest heart

Evolutionary insights from the 380-million-year-old fossil

BY MAYA BRINSTER, BEHAVIORAL NEUROSCIENCE, 2025

DESIGN BY EVELYN MILAVSKY, CELL & MOLECULAR BIOLOGY, 2025

In September of 2022, a research team working at the Gogo Formation sedimentary deposit in western Australia discovered the world's oldest heart, located inside a fossilized prehistoric fish. The fish, classified as a placoderm, had been dead for approximately 380 million years.

The placoderm is crucial to studying the evolution of modern-day vertebrates. Because they are among the earliest jawed vertebrates, their study provides information about the skeletal structure and tissue anatomy changes that arose due to jaw development. Previous studies of placoderms, for example, have given insight as to how the first teeth, jaws, skull bones, and limbs of the jawed vertebrate evolved.

The fossilized heart — as well as a stomach, intestine, and liver that were also discovered — are incredibly valuable for studying the evolution of jawed vertebrates because they are soft tissue fossils, or fossils of tissue such as skin, muscles, and organs. They provide much more detailed insight into the organisms' anatomy and offer more information about the organism's ecology and evolution than their hard tissue fossil counterparts, which include bones, shells, and teeth. Intact soft tissue fossils are incredibly difficult to find since most are present only in minuscule quantities and flattened into two-dimensional remains that destroy their original anatomy. These soft tissue remains were preserved in their original three dimensions and are considered some of the world's best fossils for this age, and they were so well preserved that some intestines even showed the remains of the placoderms' last meal: a crustacean.

Researchers used scans of the samples to create three-dimensional images of the tissues based on the varying densities of the surrounding rock and minerals deposited by bacteria. They created the first three-dimensional model of a complex placoderm heart with two distinct chambers, as well as a model of the stomach with a liver and intact intestines.

Virtual reconstruction of the fossilized tissue revealed the previously unknown location of the placoderm heart, which was underneath their gills and in the back of their throat. This is much different than the more primitive jawless fish whose hearts are closer to their liver, with the chambers sitting sideways instead of on top of one another.

This information regarding the placoderm heart supports the hypothesis that the repositioning of the heart in jawed vertebrates is linked to the evolution of the jaw and neck in modern-day bony fishes. Fossil scans show that to accommodate jaws in bony fishes, their head, necks, and organ arrangement changed dramatically to resemble the anatomy of modern sharks. According to lead researcher Kate Trinajstic, this finding shows a much larger evolutionary leap between jawed and jawless vertebrates, which contrasts with the common idea that evolution progresses in much smaller steps.

These findings also answer one of the most difficult evolutionary questions regarding bony fishes: whether lungs were present in the more primitive jawed vertebrates. Fish have gills, but lungs provide buoyancy to allow sinking and rising. Current primitive bony fishes have lungs, but the more modern ones use a swim bladder for buoyancy. There have been debates as to whether ancient primitive types of bony fishes also had lungs. Previously, studies of a more primitive type of placoderm, *Bothriolepis*, seemingly supported the hypothesis that lungs existed in primitive placoderms, but further analysis of the Gogo Formation placoderm structures revealed that these structures that were thought to be lungs were actually the liver. Much like modern sharks, the placoderms are now thought to have relied on their livers for buoyancy instead of their lungs. The forward movement of the heart would have made room for the development of lungs in a later lineage, however, and the team's findings reveal that another type of bony fish, the Osteichthyes, was the true origin of lungs.

This virtual reconstruction and the evolutionary information it provided is only one example of how valuable three-dimensional soft tissue preservations and modern-day imaging and visualization technologies can be. They allow specimens to be studied in an immense amount of detail and can restore incomplete specimens, leading to remarkably accurate visualization of the anatomy and general appearance of ancient organisms that have been dead for hundreds of years and providing answers to even the most

PHOTO BY UNSPLASH

BioEssays (2018). DOI: 10.1002/bies.201700167
Virtual Paleontology (2016). DOI: 10.1017/scs.2017.10

SENDING HUMANS TO MARS
OUTLOOK, BARRIERS, AND TIMELINE

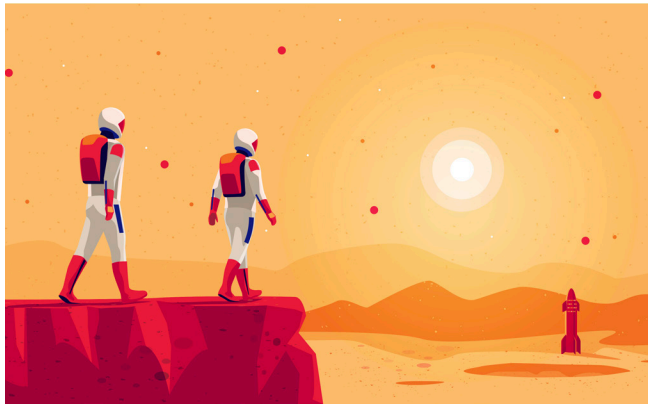
BY JULIE RATLIFF, BIOLOGY, 2023

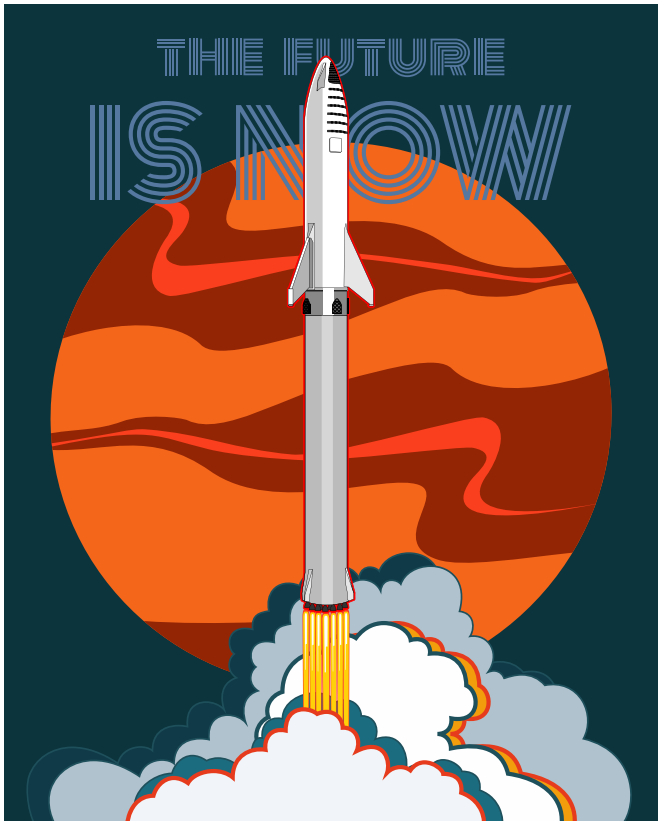
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

The United States has landed nine payloads on Mars — the fourth planet from the sun, with a reddish-brown coloration — dating all the way back to 1976. And yet, no human has ever set foot on Mars.

> "Despite the numerous complications, there are signs that an attempt at such a journey is not too far away."

Although Earth's and Mars' days are approximately equivalent lengths, many stark differences exist between the two celestial bodies. Mars' diameter is roughly half of Earth's. A year on Mars is nearly double the length of that on Earth. However, more consequential differences pose barriers to travel. Gravity on Mars is 37.5% as strong as that on Earth, a phenomenon that increases the risk of bone lesions and osteoporosis, with a primary symptom of weak and brittle bones. Additionally, astronauts on Mars would need supplemental oxygen because Mars has far too little oxygen for humans to breathe. Temperature is also another major problem. Mars' average temperature is negative 81 degrees Fahrenheit: 138 degrees below Earth's and non-survivable.





However, NASA's space suit, the Pressure Garment Assembly (PGA), combats two of these issues. The PGA provides breathable oxygen, allowing humans to rebreathe it in a purification process that takes out CO_2 and other unwanted gasses. Also, the suit aids human survival in temperatures down to negative 250 degrees.

Radiation, which is quite powerful in space, poses a serious risk to astronauts. Dissimilar to Earth, Mars lacks a magnetic field that can provide protection from radiation. While NASA's space suits already combat the harmful impact of radiation, NASA is designing vests for further safety. Whether or not the vests would provide adequate protection against the severity of radiation or other health hazards for the long and treacherous trip to Mars is still unknown.

It would take approximately eight months to travel to Mars. To save the most fuel possible, the spacecraft must take off when Earth and Mars are in the ideal positions in their orbits, which occurs merely once about every 2.2 years.

Despite the numerous complications, there are signs that an attempt at such a journey is not too far away. Elon Musk, Chief Executive Officer and Chief Engineer at the spaceship engineering corporation SpaceX, implied earlier this year that a crewed mission to Mars could launch in 2029. NASA intends to send astronauts to Mars during the 2020s or 2030s. It may seem to stretch the limits of science, but humans reaching Mars would be an enthralling achievement.

PHOTOS BY SHUTTERSTOCK

Starchild awaits

The technology of "2001: A Space Odyssey"

BY JIAJIA FU, BIOENGINEERING, 2026

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

You awaken to your Alexa alarm blaring. You ask the virtual assistant for the weather report and a reminder of the day's appointments. After a quick FaceTime with a friend across the world, you casually scroll past the headline "New SpaceX crew blasts off to International Space Station."

Only 50 years ago, Stanley Kubrick's cult classic "2001: A Space Odyssey" ingrained these now-mundane technologies into the public imagination. Life in these decades has been defined by technology firmly entrenched in the screens of science fiction — increasingly tenable AI chatbots, deep-space expeditions, and terraforming projects. Has "2001: A Space Odyssey" accurately portrayed human and technological evolution thus far?

The antagonistic red spot, HAL 9000, is now synonymous with the dystopian risks of artificial intelligence. Operating the spaceship Discovery One's Jupiter mission, HAL one day malfunctions and descends into murder. He employs modern techniques like computer vision and natural language processing to discover the astronauts' plan to disconnect him. He personifies general artificial intelligence, which can theoretically replicate individual human consciousness. "2001" was produced at the cusp of the AI boom of the 1960s, after the first ELIZA chatbot. AI experts like Marvin Minsky, the movie's scientific advisor, predicted that HAL-like intelligence would exist within mere decades.

Clearly, their estimates were overly optimistic. Nonetheless, an explosion in progress blossomed. The first AI mobile robot, Shakey, arrived a year after the movie. Deep learning and big data were major developments, generating social media feeds and predicting protein folding with remarkable accuracy. Deep learning uses multilayered "neural" networks, and models are trained on massive datasets to perform regression, classification, or generation of new data. However, deep learning models often overfit: performing well only on the training dataset but failing when introduced to new data.

At present, the basic mechanisms of consciousness in biological life are not understood or replicable. Fortunately, HAL-type intelligence that can alter its own parameters is likely centuries away. Still, the greatest gift of "2001" was its timeless introduction of AI to the public sphere and inspiration of generations of researchers to come.

The enigma of "2001" is the great monolith — the black rectangular totem which inspires toolmaking and the rise of humanity. It is discovered eons later on the moon and awaits Dave orbiting Jupiter as he completes his odyssey. What secrets does it hold? What is our place out here in the cosmos?

Exploration and the growth of humanity are the beating heart of the film, made possible by its spaceships. Beyond its highly accurate depiction of space itself, "2001" set the standard for science fiction ship design to come: a spacecraft with spinning rings to generate artificial gravity. Just like a spinning carnival ride that pins its riders to the walls, the principle of centrifugal motion can provide similar acceleration as gravity does on Earth.

"2001" was once again overzealous in its deadline, but got artificial gravity's crucial role in deep space exploration right. Long-term stays on the International Space Station have demonstrated health consequences of microgravity environments like bone and muscle atrophy, which would devastate a longer mission. NASA is now partnering with Blue Origin to centrifuge-ify their New Shepard rocket. Perhaps in a few years, centrifugal spacecrafts will be hurtling into the void in search of answers from the mysterious monoliths.

Beyond the grander visions of human progress in "2001," its near-Promethean predictions on daily-use technology were equally precise. In August 2011, Apple claimed Samsung infringed on their "unique" tablet design, to which Samsung presented a frame from "2001." A scientist video calls his daughter from a flat-screen computer display on the orbiting Earth space station. A Pan-American space plane shuttles between Earth station and the lunar colonies — the stuff of dreams of buzzy billionaire space-tourism ventures like Blue Origin and SpaceX. "2001" may have helped inspire entrepreneurs to commercialize space in the first place.

"It occurred to us that for the Greeks the vast stretches of the sea must have had the same sort of mystery and remoteness that space has for our generation," Kubrick said.

Since the dawn of humanity, technology has been an extension of society. It is an ever-evolving, iterative process that improves understanding of the universe and interactions with it. "2001: A Space Odyssey" posits many questions. Was human evolution unique? What lies beyond the stars? Is synthetic life possible? The film wasn't completely correct, but as humans and technology evolve together, one day we can venture into the cosmos and attempt to verify its predictions.

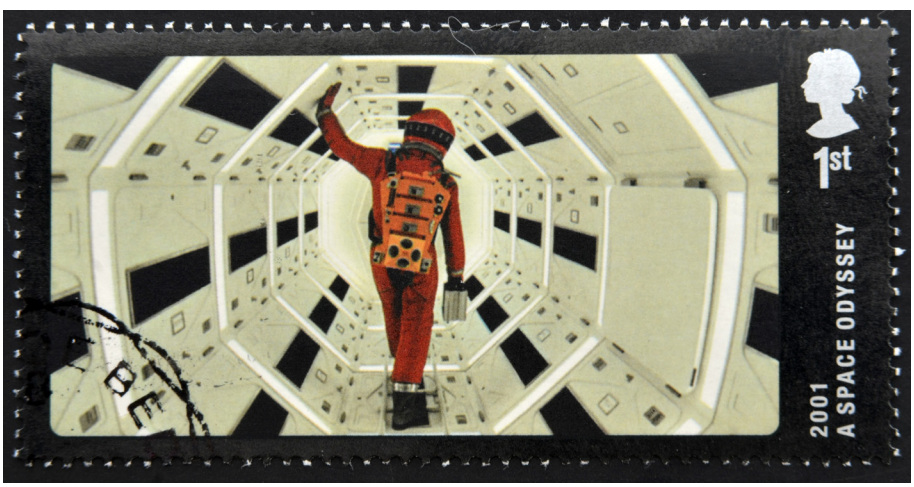


PHOTO BY SHUTTERSTOCK

The Lost Worlds of 2001 (1972). ISBN: 0-283-97903-8
Nature (2018). DOI : 10.1038/d41586-018-05773-y

Perseverance rover perseveres to explain Mars' atmosphere

ARTICLE AND DESIGN BY VY PHAN, BIOENGINEERING, 2025

NASA, as part of its everlasting odyssey to acquire knowledge about Earth's infamous neighbor, has launched yet another rover to embark on a treacherous expedition to the red, rocky terrains of Mars. The spacecraft was granted the name Perseverance, a title fitting for the government agency's undertaking: This mission would be no straightforward task.

Prior to Perseverance's journey on the red planet, the nature of Mars' atmosphere had remained rather ambiguous to NASA researchers. Beyond being aware of its notoriously smoggy ambiance and dust storms, NASA lacked a deeper, quantitative understanding of the driving forces behind these phenomena. However, during this mission, Perseverance has already made striking notable discoveries about the planet's atmosphere – a result of key hardware that its predecessors did not have: the Mars Environmental Dynamics Analyzer (MEDA) and microphones. According to NASA, these state-of-the-artsensors have the capability of providing quantitative data regarding Mars' "temperature, wind speed and direction, pressure, relative humidity, and dust size and shape."

Overall, very little was understood about Mars' aeolian and acoustic environments. A planet's aeolian environment is characterized by the way the sand, sediment, and dust of the terrain are transported and deposited by the wind all throughout the surface. The acoustic environment of a planet pertains to its quality of sound, which is a result of the way waves, especially sound waves, propagate through its atmosphere and cause vibrations.

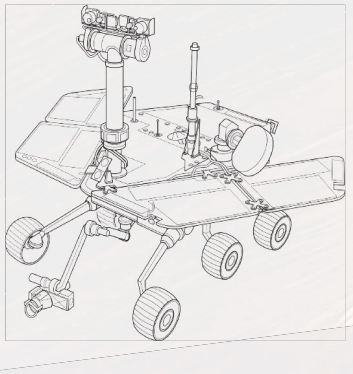
The ever-changing, dynamic qualities of Mars' surface can be attributed to the aeolian processes, such as dust storms that keep it in perpetual motion. Since the atmosphere of Mars is never stagnant, researchers from the Mars 2020 Atmospheres Working Group found that the "large dust storms drastically alter atmospheric temperatures, densities, and circulation, presenting hazards to robotic and human missions." Perseverance's devices can discern and recognize dust clouds by gathering evidence of the way sunlight changes every second. Additionally, its microphones grant, for the first time, the opportunity to record sounds of turbulence and wind, and as the Mars 2020 Atmospheres Working Group researchers noted, "high-resolution cameras … may be used to image aeolian activity and features, such as dust devils and surface wind streaks."

PHOTO BY PIXABAY

From this, they concluded that at its landing site, the Jezero crater, the direction of the wind is a result of the upslope flow of the Isidis basin and the downslope flow of the crater During the height of the day to sunset, the wind blows from east to southeast, as controlled by the Isidis basin, while at night, it usually blows from west to northwest, as controlled by the crater rim. Researchers have also noticed a remarkable relationship between the characteristics of the wind vortices and the concentration of dust present. Vortices that contain more dust undergo more significant pressure drops and have higher wind speeds. Therefore, when a vortex has strong tangential winds combined with a pressure drop, the lifted dust amount increases. That led researchers to believe that in order to pick up dust, vortices must have a minimum wind speed of 15 meters per second or a central pressure below 0.0026% of Earth's atmospheric pressure.

Mars' lower atmosphere is heavily susceptible to turbulence due to its thinness and inability to maintain consistent temperatures. This turbulence causes fluctuations in atmospheric pressure and wind speeds, and further fluctuations in temperature, as noted by Perseverance's MEDA. However, the opposite phenomenon occurs at night when the atmosphere undergoes radiative cooling and, consequently, conditions stabilize, minimizing turbulence and atmospheric shifts. Using Perseverance's observations, researchers at the Jet Propulsion Laboratory discerned that because of low atmospheric pressure and the prevalence of CO_2 in the atmosphere, the speed of sound varies depending on the pitch: Higher-pitch sounds travel faster than lower-pitch sounds. Additionally, the Jet Propulsion Laboratory researchers were astounded by the atmosphere's ability to significantly diminish the intensity of sound waves as they propagate.

Perseverance's odyssey remains far from complete; however, the scientific advances it has brought to light so far have been unparalleled by the efforts before it. Thanks to the rover, researchers are able to chip away at the ambiguity that surrounds the nature of the universe and all things beyond Earth.



Science Advances (2022). DOI: 10.1126/sciadv.abn3783
Nature (2022). DOI:10.1038/s41586-022-04679-0

The Mars Odyssey

Secrets of the red planet

PHOTO BY DANIELE COLUCCI

BY REBECCA SCOTT, BEHAVIORAL NEUROSCIENCE, 2024

DESIGN BY CARINA HALCOMB, EXPERIENCE DESIGN, 2024

In a world of climate crises and fears of societal collapse, planetary relocation has become much more than just a supernormal topic discussed in sci-fi novels, with increasing fields of research being devoted to space discovery and exploration. The advanced research tools used by organizations such as NASA and SpaceX allow for the determination of planet composition and, in turn, habitability. Recent efforts have focused on investigating the current state and astronomical origin of Mars.

In October 2001, the Odyssey Orbiter was launched with a course set to Mars. The orbiter contained three different instruments: the Gamma Ray Spectrometer, the Thermal Emission Imaging System, and the Mars Radiation Environment Experiment. Gamma-ray spectrometry provides details about planets on the elemental level and essentially allows NASA to create a map of the elements and minerals present on Mars. The Gamma Ray Spectrometer consists of the gamma subsystem, neutron spectrometer, and high-energy neutron detector, which all work in tandem to collect information regarding elemental composition. Data is generated by measuring gamma rays emitted by various elements along with recording changes in neutron behavior.

When cosmic rays from the sun impact atoms embedded in a surface, they release neutrons along with energy in the form of gamma rays. All elements emit unique gamma-ray spectra, allowing a spectrometer to identify the elemental components of specific regions of Mars' surface based on the shape of the energy spectrum. In addition, gamma rays also indicate the relative abundance of specific elements based on the intensity of the spectrum. This information can be pieced together to create a highly specific "map" of the composition of Mars with data on elements up to 13 inches below the surface.

The spectrometer has made several notable discoveries since its initial launch in 2001. In 2002, frozen water was confirmed as present on Mars, after an extremely large amount of gamma rays emitted from hydrogen were collected. This further propelled the possibility of life on another planet. After the initial evidence of water on Mars, in 2008, evidence suggested that the red planet used to have oceans up to 20 times the size of the Mediterranean Sea, or double the size of North America, due to the uncharacteristic distribution of potassium, thorium, and iron sediments. The possibility that water existed on Mars in previous times is monumental in the field of planetary research and relocation.

Along with evidence of water on Mars, the Gamma Ray Spectrometer has also allowed for further geoscience investigation on topics such as weather processes, mantle composition, and volcanism. Mars is known to be covered in high amounts of dust, with elemental analysis indicating it may be due to mantle flooding. Scientists have also established that Mars was once a largely active volcanic planet, and with further data collection, the variations in the composition of volcanic remnants could be found. From a physics standpoint, the Gamma Ray Spectrometer provides an excellent method to not only analyze elemental gamma rays on Mars but also the causes of space phenomena such as gamma-ray bursts and extragalactic gamma-ray background. The causes of these gamma-ray incidents are a mystery to many astrophysicists and could potentially relate to the origins of the universe.

Launching the Mars Odyssey itself was an incredible feat, though no one could have predicted what would follow. The devices onboard the orbiter have not only brought about groundbreaking discoveries in geoscience and astronomy but have also sparked hope for the preservation of the species. Space exploration as we know it has only just begun, but the curiosity of humans will never cease in propelling the discovery of the unknown.

Space Science Reviews (2003). DOI: 10.1023/B:SPAC.0000021007.76126.15
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FIRST ROCKETS, NOW POLITICS

How the Artemis Accords are tackling space governance

BY KYLE KIRSHEN, BIOCHEMISTRY, 2025
DESIGN BY CARINA HALCOMB, DESIGN, 2024

With trillions of stars and unknown planets alike, space has always been an endless void of possibilities and resources. And, as humans continue to ravage the Earth, we have begun to look towards space as an alternative supply of opportunities. But, without international law, what will prevent another misuse and overuse of resources? Meet the Artemis Accords: thirteen provisions that look to create international collaboration in the way space is explored and utilized.

Led by NASA, the 2020 Accords look toward the next step in human evolution and the colonization of other planets. While space law, such as the Outer Space Treaty, is not new, the Accords hope to become the first governing body of space outside just a set of rules. This governing body will be accomplished through state and commercial partner facilitation through "international cooperation in the field of scientific investigation." As of now, only eight nations have signed onto the Artemis Accords, due to a lack of trust and understanding between countries that have not always seen eye to eye. For example, China and Russia are having difficulty agreeing to anything with the belief that the development of a governing body would put the United States in control and help them gain a significant advantage in obtaining specifically the moon's natural resources. There are also others that raise eyebrows about the legitimacy of the Accords in the context of international law and whether or not signing would really mean anything. The hope is that, as the Accords continue to be reassessed with the goal of mutual boundaries, more nations will sign. As of right now, eight signatures carry little weight and do not have the traction NASA was looking for. Nonetheless, NASA has made it clear that its intentions are not self-oriented and are instead on the side of scientific exploration.

More than that, NASA believes that the Artemis Accords are a new form of space law. Implemented as a "building block" method of governance, the hope is to stage outer space activities. One of the first steps of the Accords is to implement rules on the number of organizations and what states can be registered to operate in outer space. The purpose of this is to ensure that international organizations are held accountable for their actions. The second main provision is the removal and mitigation of space debris, caused by dysfunctional satellites being left in the Earth's orbit and causing a threat to further space exploration. By registering activities amongst members, the hope is to build a layer of trust "regarding location and nature of their activities and create a 'safety zone' to avoid potential harmful interference." Through the creation of safety zones, the ultimate goal of scientific discovery and proper utilization of resources will be not only accomplished but also monitored to hold everyone accountable.

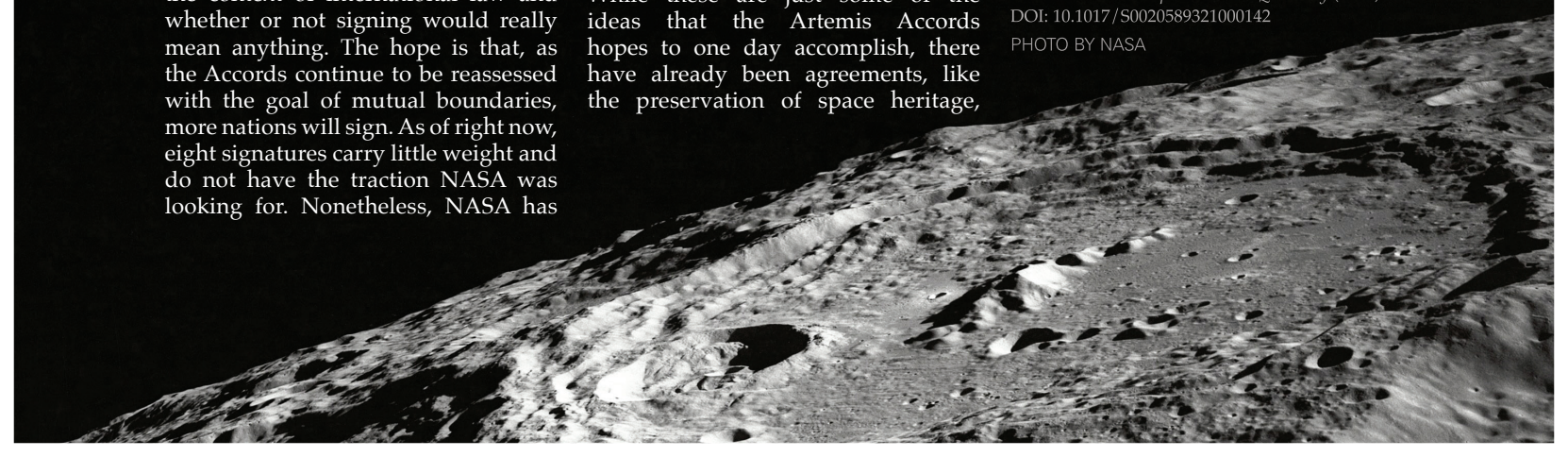
"While space law, such as the Outer Space Treaty, is not new, the Accords hope to become the first governing body of space outside just a set of rules."

While these are just some of the ideas that the Artemis Accords hopes to one day accomplish, there have already been agreements, like the preservation of space heritage, which has never been seen before. Defined as "historically significant human or robotic landing site, artifact, spacecraft, and other evidence of activity on celestial bodies," all parties have agreed that many of the collective achievements thus far deserve to be preserved to maintain their history and significance. This preservation will be done by creating safety zones and deconfliction zones with the goal of preventing harm from any sites of significant value. Specific examples of some of the artifacts to keep intact are the American flag left from the 1969 Apollo 11 mission and the Chinese flag from the 2020 Chang'e 5 mission. As of right now, the Accords limit the preservation of these physical artifacts and will take deliberation between states and partners to see how that definition changes or is expanded.

The biggest aspect that the Artemis Accords have going against them is time. While the blueprints they have laid out have the potential to be one of the most innovative projects of the future, it needs time to become a fully-fledged governing body. But, where does that start? Well for starters, the Accords plan for continued development of a treaty and expectations in "the basis of international cooperation in the field." Nonetheless, it provides an excellent foundation for the future of politics as we look toward the endless possibilities of outer space. And maybe, through continued growth, policies, and streamlining, it will provide a new era in politics.

International & Comparative Law Quarterly (2021). DOI: 10.1017/S0020589321000142

PHOTO BY NASA



NASA'S PLAN TO RETURN TO THE MOON AND LAND ON MARS

ARTICLE AND DESIGN BY ANANYA JAIN, BEHAVIORAL NEUROSCIENCE, 2025

Painted in his chariot ascending towards the light, the Greek god Apollo has long been known to represent archery, prophecy, and above all else, the sun. His twin, Artemis, is most famously the goddess of the hunt, nature, and the moon. Greek mythology follows us wherever we roam, from the constellations over our heads to NASA's exploration projects, commonly named after figures and symbols in ancient lore. Nearly 50 years have passed since Apollo 11 landed three American astronauts on the moon, putting an end to the space race. Next to enter the scene after her brother: Project Artemis.

In 2018, NASA published its plans to fly astronauts to the moon once again, specifically to its south pole. Whereas Apollo was a 17-part mission, Artemis' plan currently consists of merely three launches. The first launch, Artemis I, will be an uncrewed mission to test systems and is scheduled for launch in November of this year. Artemis II, in 2024, will solidify navigation and crew communication and explore farther than humans have ever gone before, into deep space. Artemis III, also scheduled for 2024, will integrate the data collected during the first two launches and bring the first woman and the next man, one of whom will likely be a person of color, onto lunar soil.

There are four major systems to the Artemis missions: Orion, Gateway, Human Landing System (HLS), and Space Launch System (SLS). The Orion spacecraft, bearing the namesake of Artemis' fellow hunter, will carry the astronauts from the Kennedy Space Center in Florida to the Gateway Space Station orbiting the moon. The astronauts will then board the HLS to reach the moon, modeling how the ideal mission to Mars would unfurl. The final piece, tying all previous elements together, is the SLS. Standing at approximately 322 feet, it is currently the most powerful rocket in the world and will launch Orion, the astronauts, and all cargo to the moon at a speed of 24,500 mph.

Space exploration sparks nationwide optimism and worldwide scientific inquiry, but what creates the need to travel back to the moon specifically? By working to establish a permanent presence on the moon, Artemis' astronauts will essentially lay the groundwork and collect the necessary surface data to send humans to Mars as early as the 2030s. Amongst other factors, another advantage of journeying to the moon lies in the speed of radio signals. The time it takes light, or any electromagnetic radiation, to reach the moon from Earth is almost negligible. On Mars, however, the delay in information ranges from 4 to 24 minutes, which can impact emergency communication to astronauts in space. Mars has a considerably less extreme environment as well, making a successful mission to the moon a clear indicator that the red planet is within our reach. To place all this into perspective, the moon is nearly 240,000 miles from Earth, whereas Mars is, on average, 140 million miles away.

Started in 1994, NASA's Mars Exploration Program (MEP) has launched numerous rovers and orbiters designed to detect mineral makeup, signs of past microbial life, and subsurface water. The Mars Perseverance Rover, launched in 2021 and is equipped with a ground-penetrating radar that has collected magma-encased rock possibly transported by water billions of years ago, indicating that Mars' environment is, or at least was, conducive to water. The Mars Curiosity Rover had deciphered that the atmosphere had traces of nitrogen, oxygen, and argon amongst carbon dioxide, which can point to proof of ancient life.

> "To place all this into perspective, the moon is nearly 240,000 miles from Earth, whereas Mars is, on average, 140 million miles away."

Another step in our journey to Mars, Project Artemis has been the product of billions of dollars, thousands of engineers and scientists, generations of progress in both Project Apollo and MEP, and innovative development companies, both US- and international-based. Refining the data and accomplishments since the initial moon landing in 1969, which was actualized merely 11 years after NASA became active, has paved the way for present projects to expand our knowledge of the Milky Way. Following NASA tradition, the constellations and the mythological figures seen in our telescopes and textbooks can provide hope of settlement beyond planet Earth.

PHOTO BY PIXABAY

The science behind the JWST images

BY MILINA TRAN, MECHANICAL ENGINEERING, 2025

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

When you look up at the night sky, how many light-years do you think you'd be able to see into space? 1 million? 2 million? In contrast, the James Webb Space Telescope (JWST) is able to see a whopping 13.6 billion light-years deep. It's NASA's most powerful telescope to date, built to help us understand the history of the universe.

On July 12, 2022, NASA released JWST's first five images of space, observing the Carina Nebula, WASP-96b, the Southern Ring Nebula, Stephen's Quintet, and SMACS J0723.3-7327. These cosmic objects had been observed by JWST's predecessor, the Hubble Space Telescope, but not with such clarity and precision.

JWST uses infrared light, rather than Hubble's optical and ultraviolet, which aids in seeing objects that are farther away due to the concept of "redshifting." As the universe expands, radiation from distant light sources experiences redshifting: an increase in the wavelength of electromagnetic radiation. Redshifting causes the light from these sources to move into the infrared spectrum, right where JWST can detect it. This also allows for "crisper" images, as cosmic dust absorbs visible light, but not infrared light.

But if JWST captures light from the infrared spectrum, how can we even see the images? After all, humans can't actually detect infrared light.

This is where a bit of photo manipulation comes into play. It's not as if NASA "faked" the images — more so that they shifted the radiation into a different wavelength that we can perceive. The shortest infrared wavelengths are translated as blue, while the longest of the wavelengths are assigned as red. Measurement results in a lot of data that needs to be processed, so it can take months for scientists to process an image.

JWST's physical design was also intended to optimize its image-capturing capabilities, with a primary mirror size of 6.5 meters in diameter. This mirror is actually made up of 18 individual hexagonal mirrors organized in a parabolic shape. Each individual mirror, when moved into place, creates an image focused on one object. The unique shape of the JWST mirrors is actually the reason why you can see bright spots with 6 spikes coming out of them — the supports used to hold the mirrors in place cause diffraction spikes. The mirrors themselves are made out of gold-coated beryllium in order to increase the reflection, as well as to reduce reactivity with other materials. Images are collected by taking the light from the original reflected image and bouncing it off another mirror into the telescope's instruments. Then, the telescope feeds the light into a camera, giving us those breathtaking glimpses into the past.

JWST sits almost a million miles away from Earth. In comparison, the Hubble Space Telescope orbits about 340 miles above Earth. According to NASA, JWST is able to stay relatively anchored to a general position with respect to Earth with very minimal use of fuel for orbit corrections because it sits at one of the Earth-moon Lagrange points: "areas where gravity from the sun and Earth balance the orbital motion of a satellite." There are five Lagrange points, and the JWST is placed at Lagrange two (L2). This location has other benefits, such as improving image quality and the effectiveness of light detection. L2 makes it so that JWST can view space without Earth's interference. In addition, its distance from Earth makes it so that it can be kept at the coldest temperature possible. Infrared light is also known as heat radiation, so a colder telescope gives NASA a higher chance of detecting dim objects that are far away.

We know that JWST is able to produce amazing images of space, but there are many implications for the future of space research. Not only will we be able to get a more comprehensive grasp on the scope of our universe, but we'll also be able to understand more complex cosmic phenomena. Thanks to JWST, we'll be able to puzzle together what space really looks like, one snapshot at a time.

PHOTOS BY SHUTTERSTOCK

Supercontinents, superplumes, and the true polar wanderer

BY B. PARAZIN, PHYSICS & MATH, 2023

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Beneath the African continent and the Pacific Ocean; two mantle superplumes, massive areas of the mantle with different seismic wave velocities and different compositions; exist. These large areas are associated with most hot spot volcanoes and large provinces of volcanic rock on the Earth's surface. Their formation is linked to the supercontinent cycle, the cyclical formation and break-up of supercontinents, and true polar wander, the large-scale shifting of Earth's entire crust and mantle as one whole structure relative to the Earth's core and spin axis. These superplumes and the associated reorientation of Earth's axis are evidence of the past supercontinent cycle and the delicate dance of tectonic plates over our planet's surface, slowly enacted over the last 4.5 billion years.

The science behind how superplumes are created is largely debated. In general, some theorize once formed, a supercontinent shields the mantle below it from heat loss and cold subducting slabs, causing heat to build up into a superplume. Others believe the many tectonic plates subducting beneath the edges of a supercontinent cause mass to accumulate beneath it and form these plumes. Regardless, over the first 20 million to 120 million years of the supercontinent's existence, these large plumes build up deep in the mantle, eventually accumulating petatons of rock, dramatically changing the worldwide distribution of mass and energy. Today, the two extant superplumes represent 6% of the total volume of the Earth alone.

Like any other rotating body, Earth is subject to the laws of physics. These laws dictate that the Earth should spin around an axis where it is most stable. If it is spinning around some other axis, the Earth will slowly rotate the axis it's spinning around until it is in its most stable configuration. This axis of maximum stability is also known as the axis with the greatest moment of inertia. Unlike most rotating objects you'll see in physics class, however, Earth's greatest moment of inertia is always changing as powerful geologic processes reshape its surface and interior. This changing moment of inertia leads to true polar wander as our crust and mantle rotate around the core to try and reach that maximally stable spin axis.

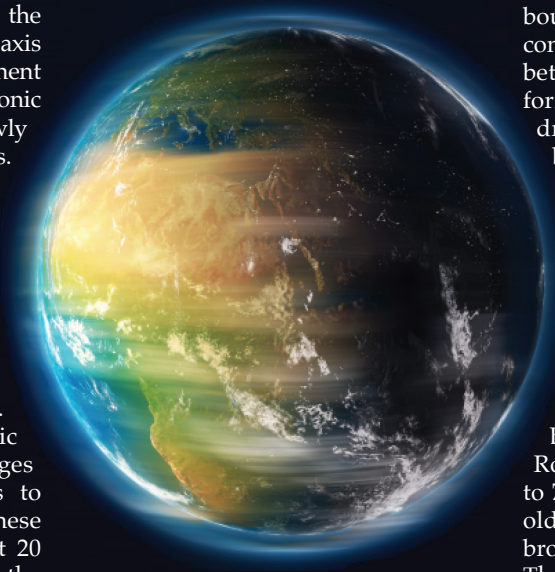


PHOTO BY SHUTTERSTOCK

Though true polar wander can be caused by any shift in mass balance, for the scale of it to be observable, there needs to be an awe-inspiring shift in the planet's mass distribution. The displacement of gigatons of water to the poles during the last ice age caused less than 1 degree of true polar wander, but the formation of these superplumes is more than enough. So, over tens of millions of years, Earth's mantle and crust rotate around the liquid inner core, until the whole supercontinent is centered on the equator, sometimes representing shifts on the order of tens of degrees.

As this whole-Earth rotation is happening, the mantle plume beneath a supercontinent grows in strength, driving the rotation faster and laying the seeds of the destruction of the very supercontinent that allowed it to form. These superplumes drive mantle upwelling, pushing large amounts of magma to the surface and leading to volcanism and the formation of divergent boundaries. These divergent boundaries eventually form into continental rifts and oceans form between the constituent parts of the former supercontinent. The continents drift apart and the superplume beneath them continues to cool until another supercontinent is formed, and the cycle happens once again.

This cycle has happened at least three times in Earth's history. The most recent being the supercontinent Pangea, which formed 320 million years ago and broke up 170 million years ago. Before that, came the supercontinent Rodinia, which lasted from 900 million to 700 million years ago, and the even older supercontinent Columbia, which broke up about 1.3 billion years ago. There are even older supercontinents theorized, but the lack of geologic evidence from that long ago means details about them are scarce. The next supercontinent, Amasia is theorized to form in 200 to 300 million years as the Pacific Ocean slowly closes, uniting America and Eurasia.

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HOW ELECTRIC VEHICLES ARE FUTURIZING THE ELECTRIC GRID

ARTICLE AND PHOTOS BY NOAH HAGGERTY, APPLIED PHYSICS, 2024

DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

Electric vehicles (EVs) currently make up about 1% of the cars in the United States. Economic and technology analysts expect this number to soar up to at least 70% by 2050, drastically increasing the amount of energy Americans are pulling from the electric grid.

Cars in America guzzle 369 million gallons of gas every day. Gasoline stores chemical energy in bonds between atoms, which cars convert into usable energy that rotates their wheels. However, EVs store electrical energy, supplied by the electric grid, in their batteries. Full adoption of EVs would require an added 11% increase in the amount of energy the grid currently produces. Electric grid experts warn that America is nowhere near prepared.

In this expansion, operators and planners will have to delicately balance the energy drawn by consumers with the energy produced and stored by the grid. Long-term support of the rapid adoption of EVs will require building out green energy sources, battery storage capabilities, and accessible charging stations that encourage drivers to spread out their electricity demand.

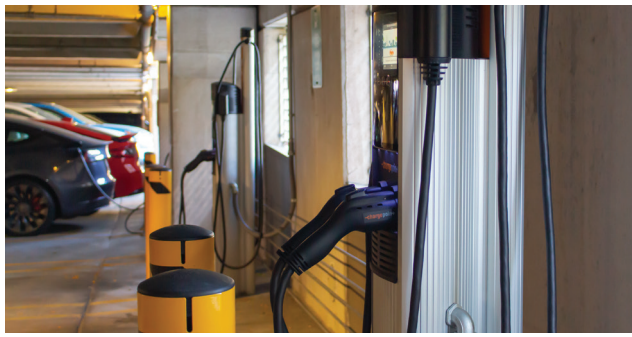
The rise of inequity and electricity demand

The spread of EVs brings a hopeful but complicated vision of the future. As America begins to build its future grid, single-family homeowners can install their own EV chargers, batteries, and even rooftop solar, capitalizing on the new electric grid's full flexibility and financial benefits. Renters and city dwellers are not afforded the same luxury. People living in apartments act solely as energy consumers, unable to sell the energy they produce from solar panels or store in batteries to electricity providers.

The Boston-based activist group Green Energy Consumer Alliance's Drive Green program focuses on increasing EV adoption through informative webinars and EV test drive events. The group works to inform landlords on how to easily install home EV chargers and familiarize renters with public charging stations around them.

The higher sticker price of EVs creates a lot of hesitation in consumers. Right now, "people buying EVs tend to be older and wealthier," said Kelly Shin, an Electric Vehicle Program Associate at the organization

Even so, the price of lithium-ion batteries, the most expensive component of electric vehicles, has plummeted in the past 20 years, faster than many experts predicted. The sticker



price of EVs is expected to drop below that of gas cars by the end of the decade, even without including cost savings from ditching gasoline and lower overall maintenance costs. Paired with a renewed investment from the federal and state governments in transitioning to clean transportation, this has led to recent predictions that EV sales will skyrocket beyond earlier estimates.

The stress EVs will place on the grid is not only due to the amount of energy EVs need, but when they need it. The current grid has almost no capability of storing energy: energy must be used after its production. As the evening sinks in, energy use peaks as people turn on lights and appliances in their homes. This increase in demand already requires controllable energy types — such as fossil fuels, coal, natural gas, and nuclear power plants — to increase their output. Adding everyone charging their EV in the evening after work and a new dependency on daytime solar energy exacerbates the discrepancy between peak demand and peak supply of energy.

Building out battery infrastructure creates flexibility to offset when electricity is generated and when it's used. Batteries can store energy produced by solar in the middle of a warm, sunny day when demand is low and discharge that energy as night falls. But building a nationwide battery infrastructure is costly, and many experts argue that the grid should mainly use battery infrastructure as a safeguard during extreme events and grid failures, not in day-to-day grid balancing.

The public charger

A Stanford University research group performed a case study on how different charging infrastructures would impact the Western U.S. electric grid of 2035. The team found that simply increasing people's access to public and workplace chargers had a more significant effect than scheduled charging.

In a grid balanced with scheduled charging, when someone comes home from work and plugs their EV in, it doesn't immediately charge. The owner would input when they plan on leaving next, and the charger waits until electricity demand — and prices — drop once people turn off the lights and head to bed. It then coordinates with other chargers in the neighborhood to spread out the energy demand. Public superchargers work similarly. Users schedule when they plan to arrive at and depart from a charger with an app, and the charger's computer coordinates these requests to optimize charging times.

In the Stanford team's 2035 electric grid models, public and workplace chargers shifted the energy demand more in line with the midday peak of energy production from new solar. While the computer scheduling method can help distribute the evening demand peak throughout the night, it's only capable of marginal shifts and adjustments. An EV owner may only have their car plugged in for a few hours, so the charging time can only shift between those hours. Conversely, investing in public charging infrastructure can shift nighttime charging demand to midday.

Day charging might not be the answer for every community, especially if they're becoming increasingly dependent on overnight wind or hydropower. Regardless, how communities design charging infrastructure matters, and the Stanford team urges policymakers to begin incentivizing and planning for charging stations that make charging during the peak of energy generation most convenient.

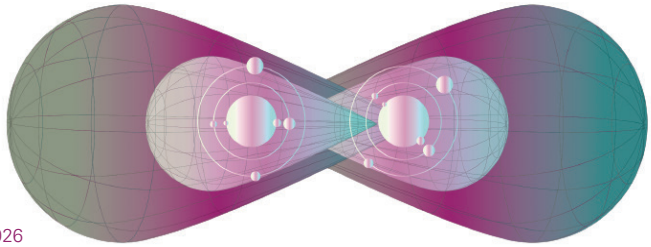
"Charging infrastructure has a really big impact on the grid," said Siobhan Powell, who led the study and recently finished her PhD with the Stanford team. "It totally changes what time drivers are using electricity."

Studies on lower EV adoption levels typically focus on EV owners living in single-family homes. However, as researchers begin to study the high levels of adoption that are likely in the 2030s and beyond, people living in apartments, who previously had little access to EVs, become an increasingly important demographic. Public and workplace charging infrastructure provide universal and equitable access to charging, including for those living in apartments.

"It's a fortunate result that public and workplace charging also happens to be the best option for the grid," Powell said.

Nature Energy (2022). DOI: 10.1038/s41560-022-01105-7

THE RAMIFICATIONS OF QUANTUM ENTROPY



BY PATRICK J. DONNELLY, ELECTRICAL & COMPUTER ENGINEERING, 2026

High school science class has a tendency to boil the universe down into a series of immutable laws. Newton's laws of motion, Kirchhoff's circuit laws, the laws of thermodynamics, etc. — these principles govern the known universe without exception.

Of the aforementioned, one of the most often quoted is the second law of thermodynamics, which is usually given as "entropy always increases," or some variation thereof. But what is entropy, and why must it always increase?

"Entropy," like the second law of thermodynamics, is almost always given in poorly-defined, indefinite terms, like "the disorder of a system." Indeed, Ludwig Boltzmann, one of the progenitors of chaos theory, originally defined entropy as the "amount of chaos" in a closed thermodynamic system. However, he did not stop with such nebulous terminology.

In fact, Boltzmann was the first to quantify entropy with a singular formula, penning the first derivation for its value in 1872. The exact formula (in classical physics) is $S = k*\ln(W)$, generally interpreted as "the number of microstates which have the same prescribed macroscopic properties" for a given closed system.

To translate the above jargon, a system is simply a finite portion of space whose change over time is being studied. A system is closed if and only if there is no transfer of matter or energy from within the system to outside. A macrostate describes the general state of a system, and a microstate describes the combination of all the states of the particles in the system. Multiple microstates, which can describe the specific energies and arrangements of particles, can describe the same macrostate, such as the general distribution of particles and temperature of the system.

Boltzmann's entropy formula, as it came to be known, describes the possible changes to a given microstate with respect to its macroscopic properties; that is, entropy is proportional to the number of microstates for a macrostate of the system.

Herein lies the reason why entropy must always increase. Imagine filling a room with gas. As the gas cylinder empties, the room fills, and the gas itself disperses. The number of microstates — in other words, the possible positions every gas particle can have — is lower for the macrostate of the gas in the cylinder than for the gas filling the entire room. Thus, the entropy of the system increases, and no amount of time or dispersive processes will get the gas back in the cylinder.

It therefore becomes easy to imagine that this must always hold true: that entropy increases continuously without bound. However, this is simply not the case; as usual, these classical laws break down at the quantum level.

Quantum physics is the physics of quanta. Quanta are finite, discrete energy states, usually understood as being "packets" of energy, like photons. At the simplest level, quantum physics is the physics of systems whose energies exist in discrete units. This interpretation of the world is directly at odds with classical physics, in which values like energy exist on a continuum. At current, this model is the most widely accepted.

Quantum physics has several odd (and interesting) ramifications, the most famous of which being superposition. In other words, quanta can exist in several states at once until they are directly "observed," usually by laboratory apparatus.

Though superposition can theoretically manifest on the macroscopic level, the term is usually reserved for much smaller quanta, which can, for instance, exist in several places at once until directly observed, as proved in Thomas Young's double slit experiment.

Superposition can affect not only position but also time. Certain interactions on very small time scales can, in fact, exist in a superposition of moving forward and backward through time simultaneously.

This is not to say, however, that particles can time travel. Time itself can be defined by entropy, with the direction of increasing entropy itself being the direction in which we define time to be moving forward. This is also not to say that we may reverse entropy; the second law of thermodynamics, so far as we know, is constant.

Rubino et al. prove that under very specific circumstances the flow of time may be muddled; that is, it is possible for a particle to be put into a superposition in which the flow of time becomes suspended. However, measuring entropy breaks the superposition and, invariably, time continues forward with the particle carrying along the path of increasing entropy.

While, on the microscopic level, entropy may become periodically suspended in time, it will eventually resume and continue in the direction of entropy on the macroscopic level, preserving the second law of thermodynamics.

Thus, while not exactly immutable, the second law of thermodynamics still remains as a benchmark for the behavior of macroscopic thermodynamic systems, as, like all "universal laws," it is derived by observation, and matures via experimental study, all in the pursuit of understanding.

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PHOTO BY SHUTTERSTOCK
DESIGN BY JASMIN PATEL, BEHAVIORAL NEUROSCIENCE, 2025

How about Hydrogen

BY LUNA BRUSS, CHEMISTRY, 2025
DESIGN BY THOMAS PAULUS, CELL & MOLECULAR BIOLOGY, 2025

As the most abundant element in our universe and the first one on the periodic table, hydrogen is really nothing new. So, why are so many countries calling it the key to our transition to clean energy? And if hydrogen is so abundant, why are we not already using it? The main issue with hydrogen is that it never exists by itself in nature. Energy expenditure is necessary to isolate it, and most of the time that energy comes from fossil fuels, so it has been hard to call hydrogen sustainable, until now.

The most popular way to isolate hydrogen is through a process called electrolysis: An electrolytic cell uses an electrical current, usually derived from some sort of fossil fuel, to separate hydrogen atoms from oxygen atoms in a water molecule. Basically, a fancy battery that runs electricity through water; then catches gaseous hydrogen and oxygen. But how does all of this relate to clean energy?

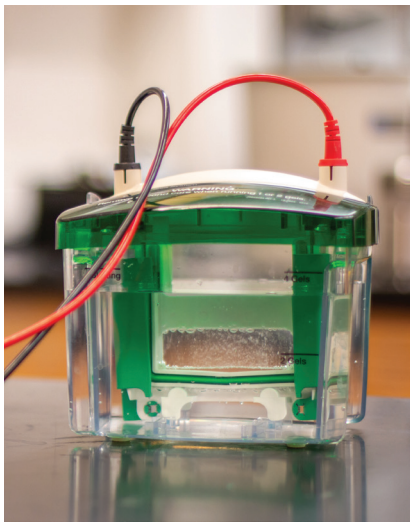
Two of the main issues with renewable energy are the inability to store it and the insufficiency of current energy grids to support excess energy production. If humans only needed energy when the sun is shining and the wind is blowing, there probably would not be any issues with reliability, but unfortunately, natural disasters, cloudy days, and no wind are all factors that have to be accounted for when talking about renewable energy. One could ask why we would have excess renewable energy when not a single country is running 100% on renewables.

PHOTO BY MIMI PEREZ

Trying to catch the T during rush hour and standing alongside other people trying to squeeze into an already overflowing train is a similar experience to an electrical phenomenon called the "bottleneck effect." Imagine the people trying to catch the train are electricity, and the T is an energy grid. This issue could be easily solved by the addition of a few more train cars, but in the same way, the MBTA doesn't have more train cars to offer, many electrical grids simply don't have the capacity to store the electricity referred to as "excess."

Luckily, this is where hydrogen comes in. Nothing about electrolysis is inherently unsustainable. The only issue is where to get the electricity to power this process. What if we used excess renewable energy to power electrolysis when energy is abundant, and then stored it in hydrogen bonds until we need it again? This approach is exactly what several countries in Europe, especially Germany, are calling Power-to-X.

Power-to-X takes advantage of surplus renewable energy to power the process that makes hydrogen. The hydrogen is then stored and considered the "power" to complete the "X." Like in a mathematical equation, X is just a variable that could stand for electricity, fuel, heat, ammonia, chemicals, or anything that can be created by combining hydrogen with something else. To power this process, something called a hydrogen fuel cell is needed. A fuel cell is basically a battery, except that instead of needing chemicals like lithium and cadmium, the fuel cell produces energy by combining hydrogen with available oxygen from its surroundings, producing water as a "waste" product. Sound familiar? A fuel cell is basically the inverse of electrolysis; instead of breaking apart water to make hydrogen and oxygen, it combines hydrogen and oxygen to make water and harnesses the energy released by this reaction.



An anode (red) runs a negative charge through the water that attracts positive hydrogen ions. These atoms charges balance out and hydrogen gas is released.

Another reason hydrogen could be so helpful in the clean energy transition is that it can be transported through preexisting gas pipes with very few modifications to them. In the U.S. especially, the vast natural gas infrastructure could be easily modified to transfer hydrogen. Given all this information, you might be wondering: Why we are not already doing this?

Unfortunately, hydrogen is still fairly expensive, and it can be explosive when stored as a gas and not handled properly. But for countries that have the infrastructure and money, and want to make the transition to clean energy, hydrogen power is certainly a step in the right direction.

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