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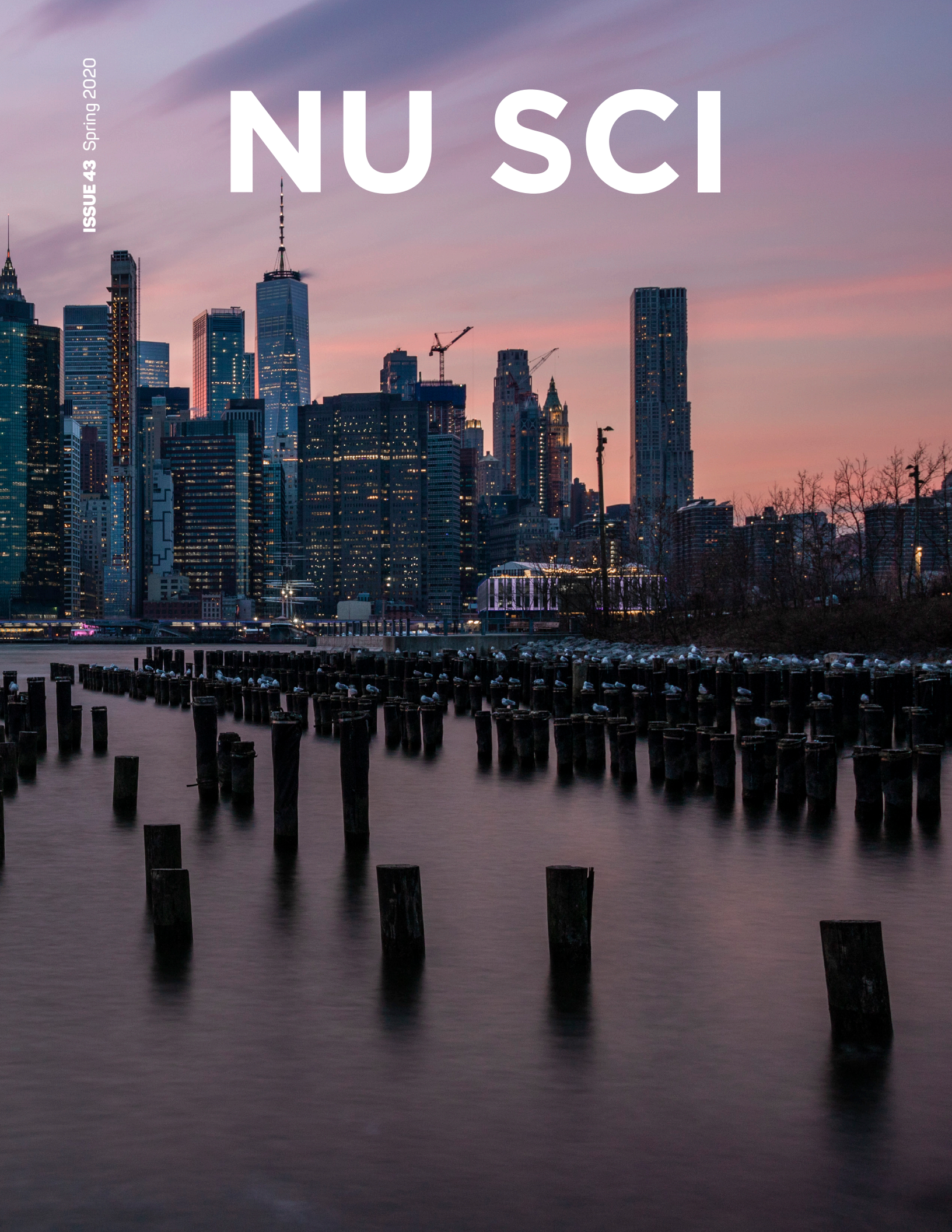

STRUCTURE

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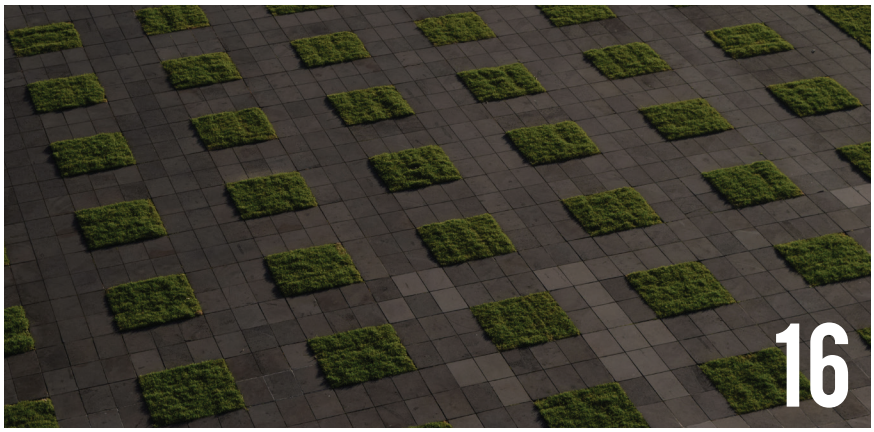

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Northeastern University
College of Science

LETTER FROM THE EDITOR

Standing atop Rockefeller Center in Midtown Manhattan, one sees an essentially limitless skyline. Tens of thousands of structures of varying shapes, sizes, and styles standing uncomfortably close to one another—at times even on top of each other—flanked by parks of green grass and heavy boughs and populated by individuals originating from as many countries as the stone, steel, and precious metals that surround them.

Surveying this concrete expanse from above helps inspire an idea many naturally absorb at some point along the curve of their youth: that a city is more than the physical buildings that shape its streets and skylines. A city, rather, is a living conglomeration of physical, biological, chemical, linguistic, and cultural attributes, which, when viewed as a whole, create *uniquity.*

In other words, a metropolis like Manhattan is just as much its steel-in-a-grid pattern as it is the smell of the azaleas in Central Park, the various neighborhoods in which English is a second language, and the diversity of genetic material walking down Fifth Avenue. So while it's easy to get lost on the observation that cities are made up of many individual structures, it's important to realize the *structure* of a city arises from many other individual factors.

Much the same as our magazine. Welcome to the 43rd issue of NU Sci: *Structure.*

This issue our writers surpassed our expectations; not simply by tackling what structure means in the straightforward, urban sense, such as explaining fractal cities and green buildings, and covering how cities like Boston are using architecture to combat climate change. Our team also got clever and took liberties with the word: investigating topics like the genetic structure of RNA and the chemical structure of stars.

Inside this issue, you'll find stories of fungal architecture, the near future of 3D organ printing, and the structure of hummingbird feathers, among many others.

And be sure to check out our website, nuscimag.com, where you can find more content from this issue, including more original articles and photography.

Lastly, I'd like to once again highlight the work of our design and photography team—while you leaf through these pages, take a minute to appreciate the work of these talented individuals who seem, somehow, to be getting only more brilliant each issue.

Lucas Principe
Editor-in-Chief

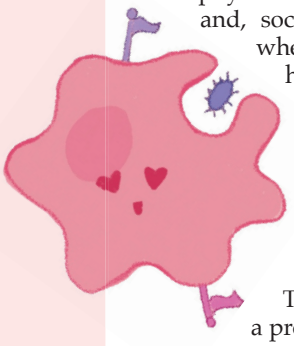
STAFF

Cover Photo by Gus Mueller

A MATCH MADE IN MHC

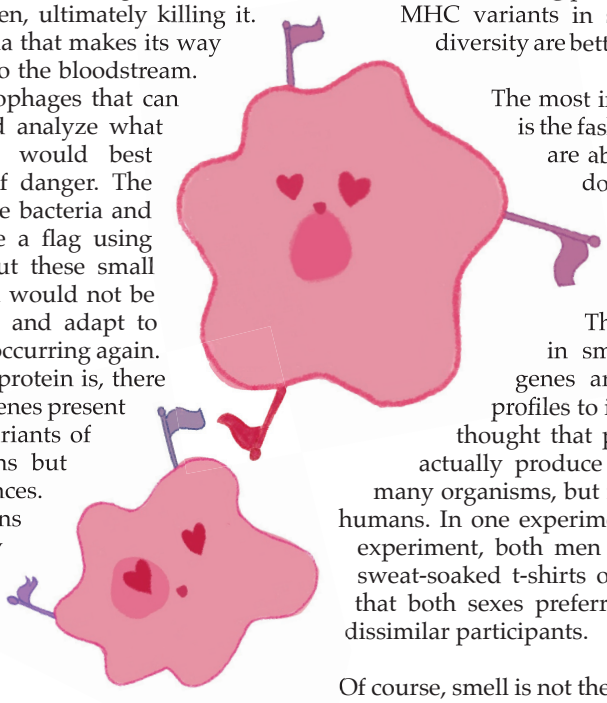
How marine animals quench their thirst

BY THEODORE FISHER, BEHAVIORAL NEUROSCIENCE, 2020
DESIGN BY SOPHIA HITT, BIOLOGY, 2023



As humans, we have a complex selection process when it comes to mating. Innately, we favor certain physical characteristics, intelligence, and personality, and, societally, tend to consider power and wealth when choosing a partner. But recent evidence has shown that there is more to the story: we may be selecting our significant others based on subtle characteristics of our immune system. Scientific research has uncovered an evolutionary mechanism that better prepares our offspring to fight whatever disease or infection may come their way.

The details lie in a small set of genes that encode a protein complex present on the surface of certain immune cells, known as a major histocompatibility complex (MHC). This group of proteins forms a small messenger structure that can present a unique molecular identifier of an incoming threat or an antigen. Then, once this antigen is recognized by a T cell responsible for attacking dangerous cells, a cascade of signals can be cast against this dangerous pathogen, ultimately killing it. For example, envision a bacteria that makes its way past many walls of defense into the bloodstream. We have cells known as macrophages that can eat or engulf this bacteria and analyze what components of the bacteria would best notify the rest of the body of danger. The macrophage ultimately kills the bacteria and sticks this component out like a flag using the structure of MHC. Without these small structures, the immune system would not be able to sense foreign material and adapt to prevent an infection from ever occurring again. Interestingly, as simple as this protein is, there are many different variants of genes present in our genomic pool. These variants of genes produce similar proteins but with minute structural differences. It is speculated that combinations of these different variants may enhance an individual's ability to fight certain infections or even a vast array of pathogens they encounter.



So far, in many species of animals, from Atlantic Salmon to Swedish Sand Lizards, there is prominent evidence of disassortative mating. This means that many of these species prefer MHC-dissimilar partners or mates with different variants. The functional implication of this selection pressure is that having multiple variants of MHC increases an organism's ability to fight novel pathogens they encounter. This heterogeneity in MHC can then be passed along generations to increase survival.

Under the laws of evolution and subsequent natural selection, the best fit variants of genes for survival should become prominent over generations as they are passed along to offspring. It follows that selecting a mate who can better survive is favorable but, if needs of survival are not met, slowly organisms with unfavorable characteristics will die off. Therefore, it's very possible that MHC-similar selected mates and their offspring were not fit enough to survive, giving us a predominant selection.

Recently, human studies are beginning to show a similar pattern. In most populations, the patterns of MHC preference are similar to that of other animals as humans prefer mates with dissimilar subtypes. Particularly Europeans and Americans show strong correlation. But new information is surfacing that shows this isn't true for couples in South Amerindian tribes and some African demographics. This raises an interesting possibility; it may be that homogenous MHC variants in some areas with lower pathogen diversity are better equipped to respond to infection.

The most intriguing part of this phenomenon is the fashion in which we and other animals are able to select mates. As humans, we do not often go around examining our crush's immune system under a microscope. So how else could we determine immunocompatibility?

The first prominent theory lies in smell. Some data show that MHC genes are associated with creating smell profiles to identify other individuals. It is also thought that proteins in the MHC complex can actually produce odor. This has been exhibited in many organisms, but it is still somewhat questionable in humans. In one experiment known as the "sweaty t-shirt" experiment, both men and women were asked to smell sweat-soaked t-shirts of other participants. It was found that both sexes preferred the smell produced by MHC-dissimilar participants.

Of course, smell is not the only consideration we make when we look for a mate. Given the robust link between the immune and nervous systems, it is possible that our personalities and thought processes are of significant influence as well. Overall, this innate mechanism is more than a correlation; it helps us not only in dating, but in fighting the immune challenges we encounter every day.

Psychoneuroendocrinology (2009). DOI: 10.1016/j.psyneuen.2008.10.007
PNAS (1999). DOI: 10.1073/pnas.96.4.1522
PLOS (2008). DOI: 10.1371/journal.pgen.1000184
The Royal Society (2008). DOI: 10.1371/journal.pgen.1000184

Night of the living parasites

BY JOSEPH VALENTI, BIOLOGY, 2023

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

The knowledge of the existence of the "Zombie Snail" has become commonplace in the past couple of years. These snails are infected with a parasite which enters the snail through ingestion of bird feces. Once ingested, the parasite begins to grow in the antenna of the snail, as well as branching out throughout the body. The most distinguishing feature of this parasite is that it transforms the snail antenna into a pulsating colorful new shape that moves similar to a caterpillar. The interesting case about this parasite is that rather than feed off the host, it instead changes the behavior of the host. Behavior changes in the snail include: staying out later in the daylight, moving to higher branches, and an inability to reproduce. These behaviors leave the snail vulnerable to bird attack, which are attracted to the parasite's appearance in the antenna. The birds will eat the antenna of the snail along with the parasite where the parasite runs through the digestive tract of the bird and lays its eggs which exit through bird feces to once again be ingested by a snail.

The mechanisms of this behavioral change which help the parasite thrive in its life cycle are certainly interesting, but its mechanisms are still unexplored and typically attributed to physical barriers rather than mind culture. The physical barriers proposed include the blockage of antenna which heavily reduce sight, causing the snail to stay out later as well as travel higher in order to sea the light, as well as the branching of the parasite physically blocking the snail's reproductive sights causing it to focus more on preservation of the parasite.

While the "Zombie Snail's" behavioral symptoms are less of mind control and more of compensation of physical barriers, parasites are still known to cause shifts in the central nervous system of a much closer to home host: the human. While the brain is one of the most protected parts of the human body, some parasites are able to maneuver their way into the brain. Typically, a brain parasite will enter the body and take root in another organ, lay its eggs, and its eggs can use the body's own cells or vessels to travel to the brain, though many of these mechanisms are not fully understood. The parasite then can take hold in the brain.

> "While the brain is one of the most protected parts of the human body, some parasites are able to maneuver their way into the brain."

Once in, the parasite will interact with the brain and use the organs resources in order to best suit its survival. For example, Schistosoma spp. will form parasitaemia which are masses which induce TH2 responses that favor parasite persistence. It also synthesizes biogenic amines that allow better establishment of the parasite and helps regulate metabolic activity. This can cause major distress on hosts. A parasite called Plasmodium spp. also creates parasitaemia that decreases immune response as well as drives up neuroinflammation.

Some parasites in human hosts have even been shown to cause behavioral changes. One parasite, Toxoplasma gondii, has been show to increase DA release in infected cells, which interferes with locomotion, cognition, memory, and mood. Some studies have also shown that mental disorders such as schizophrenia, depression, and anxiety are more common among those inflicted with the parasite. In animal models, the parasite even caused rats to have a full shift of behavior becoming attracted to the scent of cats, which would help increase the likelihood of production of Toxoplasma gondii as cats are a main host that the parasite thrives in. Scientists theorize that Toxoplasma gondii may increase extrovert, aggressive, and risk-taking behavior, but there is still much research to be done. One study, however, showed that infected dendritic cells typically secreted the neurotransmitter GABA. GABA is typically associated with the inhibition of fear and anxiety which could explain the infected mice strange behavior around cats. Changes in GABA levels has also been associated with certain mental disorders which again could explain the increased levels of mental disorders among infected humans.

While the zombies may remain a part of science fiction, parasites that influence the behavior of hosts are being studied more every day, and the affects these pathogens have on humans are quite terrifying.

PLoS Pathogens (2018). DOI: 10.1371/journal.ppat.1003051

PHOTO BY WIKI COMMONS AND FLICKR

FROM SHROOMS TO STRUCTURES

BY ANUSHKA BISWAS, CELL AND MOLECULAR BIOLOGY, 2023

DESIGN BY YECHAN YANG, BIOLOGY AND PSYCHOLOGY, 2022

Mycelium (noun): the vegetative part of a fungus consisting of a network of fine white filaments, better known as the future of sustainable architecture.

With the state of our environment rapidly declining, experts across fields are searching for alternative methods and resources to fortify a greener Earth. After all, growing populations need growing opportunities for housing, but the concrete jungle simply cannot be sustained. Portland cement, a key component of concrete, emits about one ton of carbon dioxide and greenhouse gases for each ton produced. Instead, some architects and civil engineers have diverted their efforts to manufacturing with mushrooms.

Mycelium is the medium through which mushrooms are able to absorb nutrients. But, how can the common, feeble fungus contribute to the next Burj Khalifa?

The future lies in biomimetics, a field dedicated to the production of materials modeled on naturally-occurring biological processes, and mycelium is the vessel to success. In nature, mycelium binds natural particles together, essentially functioning like biological glue. Unlike certain species of fungi, mycelium is multicellular and able to form macro-structures commonly categorized as mushrooms. With human intervention and the proper temperature, humidity, and carbon dioxide conditions, mycelium growth can be controlled to form predictable, desired structures. When the fungus digests organic substrate sourced from agricultural waste, a solid mass is produced. Within one week, a 432 square inch fibrous mycelium sheet is ready to be used for construction, art, or insulation.

These fungi features are not only fashionable but functional. Weighing only *43 kg/m³*, mycelium bricks can support up to 30 psi. The low-density specifications of mycelium make it astoundingly useful in regions of low support. Despite being comparatively weaker than the 4000-psi-withstanding strength of concrete, on a pound-by-pound basis mycelium reigns superior. Unlike concrete, mycelium can also double as a fire-resistant insulator. Relative to synthetic insulation formed from natural gas, mycelium has increased thermal stability. Mycelium tissue can retain more heat than fiberglass insulation while also being partially-resistant to mold and water. The flesh of the mushroom is also termite-deterring in nature, furthering its application as a practical multipurpose construction tool.

Companies such as Ecoactive, MycoWorks, and Biohm specialize in refining this modern commercial building material. These companies place the mycelium bricks through an accelerated aging process, condensing three years of wind, rain, and humidity exposure into a three-week period. If unweathered and untreated, the inside of the brick will remain strong and intact, but intense weather conditions will speed up the mycelium's natural decaying process. Properly cared-for bricks have a lifespan of about 20 years in stable conditions. Also, placing two living mycelium bricks side-by-side promotes the spreading of mycelium between the individual units as a form of self-bonding; the building practically assembles itself.

If you wish to see a fungi funhouse in person, the Museum of Modern Art in New York features a 40-foot cylindrical tower made by David Benjamin. But if you're wondering where the future of industrial mycelium lies, look no further than your local supermarket. Experts are currently prototyping which strain of mushroom has the most durable, favorable conditions for commercialization. Shiitake mycelium forms a thick, protective, leather-like exterior. Meanwhile, oyster mushroom mycelium is even less dense by-the-brick. With an abundance of tutorials and techniques to form mycelium-molding material online, you can grab a pack of portabella and easily join architects in the quest for an eco-friendly alternative.

As a natural colonizer of soil, mycelium is abundantly found in nature, can be returned with zero-waste, and is 100 percent biodegradable. It is imperative that goals of sustainability and reducing our carbon footprint guide future projects or else our structures shall have nowhere left to stand.

PHOTOS BY PIXABAY

The biting truth about venomous snakes

BY BINH DANG, ECOLOGY AND EVOLUTIONARY BIOLOGY, 2022

DESIGN BY KYLA VIGDOR, DESIGN, 2021

When I tell someone I spent a summer catching snakes for research, I often get one of two reactions: an exclamation of fascination or an audible gasp and look of horror. Usually it's the latter. The typical question that follows after both is "Are they poisonous/venomous?" This question is the first indicator of misconceptions about snakes. Often, people ask if a snake is poisonous when they actually mean venomous. The difference lies in how the toxin is delivered; poisonous animals release their toxins if they're ingested or touched — think poison dart frog or pufferfish. Venomous animals release their toxins via biting or stinging; this includes bees, sea jellies and, of course, some snakes. However, there is one known species of snake that's both venomous and poisonous: the Asian tiger snake, a venomous snake that builds a reserve of poison from preying on poisonous toads.

Even if you know the difference between poisonous and venomous, there are still misconceptions about venomous snakes. Plenty of sources cite ways to identify venomous snakes — common identifiers include: triangular heads, a certain coloration or pattern, or facial pits. While some of these features apply to certain species or families of venomous snakes, there are countless exceptions. However, there is some truth to these heuristics.

> "Even if you know the difference between poisonous and venomous, there are still misconceptions about venomous snakes."

Triangular heads are almost always an indicator of venomous snakes. Typically, these wider heads host venom glands on the sides of the snake's head. The Viperidae family of snakes — which includes rattlesnakes, copperheads, and cottonmouths — is known for this distinctive head shape. Nearly all venomous snakes in North America are pit vipers, so this is a good indicator of danger in the region.

This characteristic is less helpful in other parts of the world. For instance, the Elapidae family of snakes, which contains cobras, mambas, and coral snakes, does not have triangular heads and includes some of the most venomous snakes in the world. The inland taipan of Australia has a fairly smooth transition between head and body with no prominent side protrusions and is considered the most venomous snake in the world; a single bite has enough venom to kill 100 full-grown adults. Conversely, some subspecies of garter snakes have triangular heads but are non-venomous.

Garter snakes aren't the only non-venomous species that have evolved to mimic the telltale signs of venomous snakes. Many non-venomous snake species practice this form of mimicry, Batesian mimicry, in which a harmless species resembles a dangerous one by copying their behavior or appearance. A well-known example of Batesian mimicry in the animal kingdom is the case of the coral snake (the other type of venomous snake in North America) and the scarlet snake. Both have a distinct red, black, and yellow band pattern, but the coral snake is highly venomous while the scarlet snake isn't. Even if you could distinguish between those two species, both the scarlet kingsnake and the milk snake also mimic the coral snake, yet neither are venomous.

There are a plethora of other alleged identifiers of venomous snakes, including the aforementioned facial pits — used for infrared sensing and thermoregulation, elliptical pupils, or a single row of ventral tail scales. Unsurprisingly, these characteristics are true in some, even most, cases. However, equally unsurprisingly, there are a multitude of exceptions that invalidate them as perfect indicators.

Snake physiology is incredibly diverse, despite all of them filling the same serpentine form. Across families and species, there are plenty of varied and conserved traits. From a cobra's hood to a hognose snake's pointed nose to a rattlesnake's tail, snakes have unique characteristics that make them as hard to categorize as they are to catch. If you ever find yourself in the wild and come across an unidentified serpent, look out for the common identifiers, but don't assume you're safe if you can't recognize the species. The only way to identify a venomous snake with absolute certainty is to familiarize yourself with the native and invasive snakes in your area. However, the single best advice for encountering a snake is the same as with any wild animal: let it be.

Biota Neotropica (2012). DOI: 10.1590/S1676-06032012000300031

HORMONAL TROJAN HORSES:

How the chemical industry subverts consumer health

BY BRETON WORTHINGTON, PREMED, 2021

Maintaining health is hard enough even without considering the industrial chemicals that wind up in our bodies. In industry, consumers must be informed, even after they're misled, about toxicity. While still not banned, the global community has largely condemned the widespread use of the chemical Bisphenol A (BPA), pointing to numerous adverse physiological effects in humans and wildlife, including endocrine disruption, cardiovascular disease, fat accumulation, and DNA damage. At last, the demand has dictated the supply; "BPA Free" products abound in the market, but are these substitutes much better? Early research says no. Bisphenol F and S are likely as bad as their predecessor. The secret to why lies in their chemical structure.

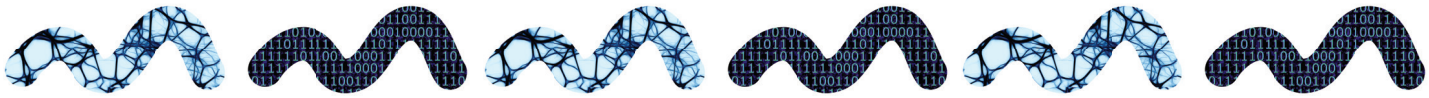
What exactly are Bisphenols? Bisphenols A, F, and S are used in polycarbonates such as plastic bottles, Tupperware, and medical equipment, as well as epoxy resins found in water pipes, sales receipts, electronics, and food or beverage cans. Their unique chemical properties provide durability, pliability, optical transparency, adhesion, and more — making them irreplaceable to the structure of our modern society.

Chemically, BPF and BPS are quite similar to BPA. All three share structural features that allow them to bind with estrogen receptors in the body and, like Trojan horses, access the DNA. Doing so initiates pathways normally regulated by an endogenous estrogen known as 17β-estradiol. Results can be devastating. In one study, zebrafish exposed to BPS exhibited skewed sex ratios, decreased sperm and egg counts, increased estradiol levels, and decreased testosterone levels in males. Because zebrafish have a similar genetic structure to humans, scientists have predicted that these results are applicable to humans as well.

Are you exposed? The quick answer is yes. According to a recent study, BPA is detected in 95.7 percent of urine samples while BPS and BPF are on the rise at 89.4 and 66.5 percent, respectively, which indicates almost constant environmental exposure for Americans. Estimates suggest that 90 percent of this exposure comes from food and beverages. The good news is that limiting your exposure, especially through food choices, can significantly reduce concentrations in your body.

While "BPA Free" may sound healthy, the truth is we've exchanged apples for apples—that is if those apples were chock-full of potential poison. This has left many to wonder: how much longer will the chemical industry play chicken with our health?

ACS Omega (2018). DOI: 10.1021/acsomega.8b00824
Aquatic Toxicology (2014). DOI: 10.1016/j.aquatox.2014.01.009
Food and Chemical Toxicology (2012). DOI: 10.1016/j.fct.2012.07.059
Dose Response (2015). DOI: 10.1177/1559325815610582



C. ELEGANS, A TOY STORY: One Small Step for *Connectomes*, One Giant Leap for *Artificial Intelligence*

BY SPURTI VEMURI, BEHAVIORAL NEUROSCIENCE, 2021

Since the advent of computers, and the consequential fascination of "networks" within the sciences, researchers all over the world have embarked on the Race to the Connectome. The "Connectome" is a comprehensive map of an organism's nervous system, including all the individual neurons and neuronal circuits that it is composed of. Although the Human Connectome Project—which is funded by the National Institutes of Health—is far from being able to reconstruct the entire human brain, some animal models of connectomes have successfully been built from well-studied organisms. One such organism is Caenorhabditis elegans (C. elegans), a tiny, 1-millimeter long nematode. This worm has an extensively studied nervous system, as its entire body is composed of only 1000 cells—302 of which are neurons.

It is thought that once the mystery of the connectome is solved and researchers are able to pinpoint the location and circuitry of every single neuron in an organism's nervous system, it is possible to use only this connectome to reverse engineer the same organism. This is exactly what Timothy Busbice set out to do in conjunction with the Connectome Project. Using the C. elegans connectome, which has been mapped out for decades, Busbice developed a computer program to emulate the worm's neural network and control the robot's body. He managed to create an "organism" with a LEGO robot body and a nematode mind.

C. elegans was the perfect model for Busbice not only at the cellular level but also with respect to the complex behaviors it exhibits in a novel environment. Upon exposure to olfactory and tactile stimuli this nematode can perform immediate reactions—such as backing up when presented with an aversive smell or sensing a physical barrier. This LEGO set came alive through Busbice's code, and footage of this nematode-robot cyborg can be found on his YouTube channel.

Some scientists have responded warily to this progression in connectomes and artificial intelligence—as this could mean we are one step closer in creating artificial life that can think for itself. Right now, this robot with a mechanical body and a worm brain can only do as programmed by Busbice. But can we use this merger between connectomes and computer science to create a program for human consciousness? What would this mean for the advancement of artificial intelligence? Would these robots with "uploaded" brains truly be sentient? Will the fictional dystopias pictured in films like Terminator and Transcendence become our reality?

Frontiers in Computational Neuroscience (2012). DOI:10.3389/fncom.2012.00010

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

The story behind the strange hands of a strange animal

BY DHRITI AIYLAM, PSYCHOLOGY, 2023
DESIGN BY KYLA VIGDOR, DESIGN, 2021

If one were to ask what the strangest animal out there was, the aye-aye is a strong contender. These unique little lemurs, found only on the island of Madagascar, have large yellow eyes, gigantic ears, and extremely long appendages—especially their middle finger. These fingers, which would be nine inches if they are scaled up to human size, seem to be their distinctive trait. So one can't help but wonder: why exactly are their fingers so long?

The aye-aye's especially long middle finger primarily helps it to find food. Aye-ayes hunt at night and rely on echolocation while using a technique called tap foraging. Here, they will tap the dead and rotting wood of trees and listen for hollows, which indicate insect tunnels intersecting under the bark. Once detected, they bite down and rip the bark open, creating a hole. Then, they will use their elongated third digit, which swivels on a ball-and-socket joint, to fish out grubs and bugs.

Although this is certainly handy, there are caveats to having such a long finger. If the aye-aye were to use this finger for traveling, it would snap under the animal's weight. In addition, aye-ayes have also lost the ability to grasp objects with it. That's where their sixth digit, a "pseudo-thumb" comes in. The pseudo-thumb is a feature that was only recently discovered, as a result of all of the fascination surrounding their other fingers.

Aye-ayes and humans alike both have a muscle called the abductor pollicis longus, running down the length of the forearm and giving us the ability to stick out our thumbs. While following the aye-aye muscle, Dr. Adam Hartstone-Rose, an anatomist and lemur expert from NCSU, found that tiny tendons branched off to the aye-aye palm below the thumb and connected to a small bone called the radial sesamoid. Humans do not have a sesamoid bone on the thumb side of their hands (although we do have one on the pinkie edge of our hand). This nubby "pseudo-thumb". made up of bone and cartilage, is manipulated by three muscles that allow it to move in three directions—and it even has its own fingerprint!

But what is the purpose of this extra appendage? Generally, when it comes to most species, scientists don't know what role false digits play. Here, however, the pseudo-thumb seems to have a greater evolutionary significance than the famous middle finger—and this is because the thumb allows them to grasp objects and branches.

What makes the sixth digit so interesting on the aye-aye is the context in which it evolved. Firstly, the aye-aye is the only primate that naturally has a pseudo-thumb. In addition, aye-ayes developed the extra appendage because their fingers became *more* specialized—unlike other species who evolved pseudo-thumbs for the opposite reason. For example, in giant pandas, whose five fingers are arranged in a neat and unopposed row in order to allow them to walk, the transformation of their sesamoid bones into pseudo-thumbs arose due to the animal's need to grasp bamboo shoots.

> "Aye-ayes developed the extra appendage because their fingers became more specialized—unlike other species who evolved pseudo-thumbs for the opposite reason."

An aye-aye's hand is just one of their many incredible features—they also have mammary glands between their legs and white hairs that bristle when they're agitated. In addition, they have the largest brains relative to their body size out of all lemurs. This gives them extraordinary brain power that allows them to create mental maps of the hollow spaces within the tree trunks where they find their food. That's why it's disheartening to know that aye-ayes are currently endangered, and that their population is only continuing to diminish. We should strive to support conservation efforts so that, in the future, we can continue to learn more about this fascinating little creature.

Physical Anthropology (2019). DOI: 10.1002/ajpa.23936

PHOTOS BY FREE SVG AND FLICKR

A NEW LEVEL OF PLANNING

How cities are adapting to rising sea level

BY KELLY THOMAS, JOURNALISM, 2023

DESIGN BY KATIE GREEN, BIOENGINEERING, 2021

In the wake of sea level rise, which threatens to inundate hundreds of cities worldwide in the coming years, coastal cities have begun to adapt their infrastructure. Many at-risk cities have issued climate adaptation reports that detail their plans to prepare for the coming threat, with some already experimenting with innovative infrastructure ideas.

According to NASA, the global sea level is currently rising at a rate of 3.3 mm, or approximately 0.13 inches, per year. This rise can be attributed to two main factors: thermal expansion and melting ice sheets and glaciers. Thermal expansion occurs as the earth's rising temperature causes water to heat and expand, pushing sea level upward. Melting ice is also a result of increasing mean global temperature. With a higher sea level, storms become even more dangerous. "Storm surge," an increased sea level caused by storms, in combination with a standard sea level that is higher than in the past, creates elevated risks of coastal flooding.

> "Creative strategies have sprung up to fight against current and future flooding."

Creative strategies have sprung up to fight against current and future flooding. Coastal cities are utilizing green or gray infrastructure, or a combination of the two. Gray infrastructure traditionally takes the form of concrete barriers or seawalls, in addition to piped drainage and water treatment systems. These structures block cities from flood water, diverting it elsewhere. Coastal cities have typically employed this method of stormwater management in the past. As they plan for the future, many cities are looking toward green infrastructure. This method entails the construction of natural habitats along the coast like mangroves, reefs, and wetlands that buffer storm surge and erosion, as well as urban spaces such as parks and green roofs that are permeable and capture runoff during storms. While gray infrastructure is impervious and prevents the absorption of storm water, green infrastructure is centered around absorbing, filtering, and storing water.

The city of Rotterdam in the Netherlands, divided by a river and located near the coast, aims to be "climate proof" by 2025. Rotterdam's plan is a melding of multiple strategies; its initiatives include making adaptations to their existing gray infrastructure like storm surge barriers and dikes, as well as creating more green space in the form of gardens and public parks. Additionally, the city plans to create public spaces called "water squares" that serve as rainwater storage pools in the event of flooding. Rotterdam hopes to implement social value into these adaptations, such as through their proposed "tidal park" that not only buffers storm surge, but also provides recreational space for citizens and increases overall biodiversity.

Boston's climate response is still in the works, though the city has released a comprehensive plan of how it is seeking to address the issue. Its climate vulnerability assessment report states that in the future, flooding from high tides could result in monthly flooding for "low-lying neighborhoods along the waterfront." Boston has drafted a slew of initiatives to address the problem, some of which the city has already started implementing, such as updating local flood maps and creating designs for green infrastructure. A unique aspect of Boston's plan is its initiative to provide living wages to workers involved in their projects and to "prioritize use of minority- and women-owned businesses," according to the report. The plan features eight "focus areas," which are neighborhoods that are particularly vulnerable to flooding risks and most imminently require resources and action.

The city of Miami, Florida, similarly vulnerable in its coastal location, has also developed a multi-faceted approach to the problem. Miami has already been installing pump stations that drain water from urban areas, along with tidal control valves that prevent water from surging from pipes onto the streets during high tide. The city also plans to use green infrastructure and is currently restoring living shorelines along the coast.

While some at-risk cities have been proactive in putting forth organized efforts in how they plan to adapt to climate change's effects - specifically sea level rise - not all have done so. Additionally, some places, particularly island nations, face such a dire risk that they may have no choice but to leave their land and migrate elsewhere. Indonesia, for example, has already announced plans to relocate its capital from Jakarta to the island of Borneo, motivated by regular and damaging flooding that will continue to worsen. However coastal cities decide to adapt, it is inevitable that they do so; the development and execution of innovative strategies, including those that utilize green infrastructure, will be crucial in the coming years.

ACID OCEAN:

HOW CARBON IS DESTROYING THE SHELLS OF MARINE ANIMALS

BY KELLY VALENTINI, BIOENGINEERING, 2024
PHOTOS AND DESIGN BY IAN PROULX, BIOENGINEERING, 2022

The effects of carbon pollution from the burning of fossil fuels have long been studied and debated by scientists around the world. Its atmospheric influence is usually the focal point of discussion as greenhouse gases contribute heavily to global warming and climate change. However, carbon emissions do not only remain in the atmosphere. They also greatly influence the ocean, including the shells of several animals that inhabit these waters.

Approximately one third of all human-sourced carbon emissions are absorbed by the ocean, making it one of the Earth's largest carbon sinks. Studies demonstrate that in the past two decades, carbon dioxide in seawater has paralleled the substantially increasing rate of atmospheric carbon dioxide.

When emissions are absorbed by the ocean, some of this atmospheric carbon dioxide will remain as a dissolved gas. However, the majority reacts with water to form carbonic acid. This carbonic acid dissociates into hydrogen ions and hydrogen carbonate. The free-floating hydrogen ions lower the pH of the ocean, but they also bond with carbonate ions to form bicarbonate ions.

Carbonate ions are crucial for calcification, or the accumulation of calcium salts to harden tissues. Marine organisms use carbonate ions to form calcium carbonate, a critical component to many shells and exoskeletons. The bonding of hydrogen ions with carbonate ions reduces the amount of free carbonate ions available for calcification. Calcification is integral to a number of marine animals. In many species of mollusks, calcium carbonate is the main component of their shells. Corals form their exoskeleton through calcification. Many species of foraminifera, coccolithophores, crustaceans, and echinoderms also rely on the presence of carbonate ions in seawater.

> "Observable impacts can already be seen among the wild-born populations of ocean species — something that was not predicted to happen until much later."

Extensive research demonstrates that these biocalcification processes are vulnerable to environmental change. Most, if not all, organisms require a greater energy expenditure to calcify in high carbon dioxide conditions, thus putting more environmental pressure on the organisms and reducing their likelihood to survive.

While the negative effects of high acidity have long been studied in labs, observable impacts are prematurely seen among the wild-born populations of ocean species. The National Oceanic and Atmospheric Administration recently funded a study of the larval Dungeness crab population off the U.S. West Coast. Lead author Nina Bednarsek observed the first natural evidence of shell dissolution in crustaceans as a result of ocean acidification. The study found an 8.3 percent increase in shell dissolving, as well as decreased size of the crab larva. The acidic pH also damaged mechanoreceptors, which are small structures, similar to a cat's whiskers, that the crabs use to navigate. These changes will have disastrous impacts on the population in the long term; the crabs are predicted to experience difficulties with swimming, floating, avoiding predators, and foraging.

Though the Dungeness crab study is the first observation of ocean acidification affecting a wild crustacean population, the authors implore that other ocean species may soon feel the consequences. As Bednarsek told CNN, "if the crabs are affected already, we really need to make sure we pay much more attention to various components of the food chain before it is too late." In oceanic locations of naturally acidic pH, such as near hydrothermal vents, species like corals, sea urchins, and shelled mollusks do not exist. The energy cost is too high. As climate change progresses, the rest of the ocean may begin to resemble these zones.

With unchecked carbon emissions, more and more anthropomorphic carbon will end up absorbed by the ocean, increasing the acidity and decreasing the amount of carbonate ions available for calcification. The resulting structural change, while seemingly small, can have a catastrophic impact on the ocean's ecosystems.

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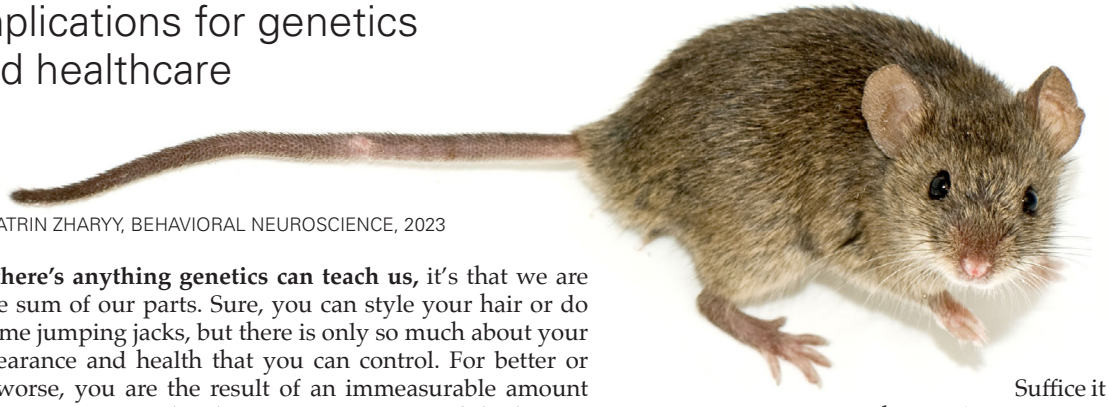
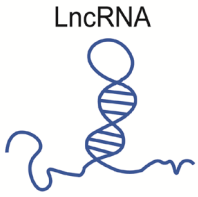
The elusive *Braveheart* RNA structure:

Implications for genetics and healthcare





BY CATRIN ZHARYY, BEHAVIORAL NEUROSCIENCE, 2023

If there's anything genetics can teach us, it's that we are the sum of our parts. Sure, you can style your hair or do some jumping jacks, but there is only so much about your appearance and health that you can control. For better or for worse, you are the result of an immeasurable amount of microscopic molecular interactions. So if biologists, researchers, and healthcare professionals have any hope of understanding the human body, must they crawl around inside our cells with flashlights strapped to their heads to figure out what exactly is going on in there? In short, no. Instead scientists are continuously coming up with new experimental methods and technologies to try and map every stage of human development, from how an embryo becomes a crying machine to what our cells do in old age.

In the past seven years, a particular string of RNA—which is similar to DNA except that it's single-stranded and much less stable—has come under close inspection for its potential role in the development of the cardiovascular system. Our genome is packed tightly into chromosomes in the form of deoxyribonucleic acid (DNA). Replace that "D" with an "R" and you get ribonucleic acid (RNA), best known for being the product of transcription wherein one strand of DNA is used as a template for single-stranded messenger RNA (mRNA). In turn, it can then be used as a template for protein assembly. Proteins are responsible for many, many functions within an organism, but only one to two percent of the mammalian genome codes for proteins. And it doesn't stop there: most of the human genome is transcribed into RNA. So what does all the other RNA that doesn't code for proteins do?

> "This was a huge advancement in the search for the function of lncRNAs and the study of the development of the cardiovascular system."

There are some types of non-protein-coding RNA whose function we understand pretty well; they either aid in translation (making proteins from mRNA) or regulation of gene expression. The least understood class of RNA sequences is called long non-coding RNA (lncRNA). In 2013, Klattenhoff et al. identified a particular lncRNA on the 18th chromosome of mice that was expressed in heart tissue more than any other tissue examined; they dubbed it "Braveheart" — or Bvht in shorthand. Through further analysis, they discovered that this approximately 590-nucleotide-long lncRNA is essential to the activation of a gene regulatory network involved in the differentiation of heart cells from stem cells. Disruption of this network leads to congenital heart disease. Suffice it to say, this was a huge advancement in the search for the function of lncRNAs and the study of the development of the cardiovascular system.

Three years later, another group of researchers determined the secondary structure of Bvht by examining the base-pair interactions between sections of the molecule that cause loops, folds, and bulges in its conformation- these geometries are essential to determining the RNA's function. One of the loops identified was an "asymmetric G-rich internal loop" (AGIL), whose function was pinpointed by cutting it out of the mouse genome using CRISPR-Cas9. Their experiment revealed that AGIL is necessary for binding to cellular nucleic acid binding protein (CNBP), which is a regulatory protein key for the differentiation of cardiomyocytes—the cells that make up cardiac muscle.

The most recent development in the Braveheart saga happened in January 2020 at the Los Alamos National Laboratory in New Mexico, where for the first time, scientists mapped the 3D structures of the Braveheart molecule as well as the Bvht-CNBP complex. They used small angle X-ray scattering (SAXS), machine learning, and high performance computing to develop atomistic models, which elucidate the behavior of complex systems by considering its smallest pieces.

This finding, along with all the other research conducted on Braveheart, has incredible significance for the fields of genetics and medicine. It has laid the groundwork for future structural studies of lncRNA, explorations into lncRNA binding activity, and using Bvht to derive cardiomyocytes in vitro. Unfortunately, although cardiovascular disease is one of the most common causes of death, mammals' hearts do not easily regenerate tissue. If creating heart tissue in the lab were possible with the help of Braveheart, that could open the door to regenerative and transplantation therapy for those with cardiac disorders. The way things are going, enriched scientific minds and healthy hearts await us on the horizon.

Genome Biology (2004). DOI: 10.1186/gb-2004-5-4-105
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DESIGN BY KYLA VIGDOR, DESIGN, 2021
PHOTOS BY FLICKR AND MDPI

3D PRINTING A FUTURE IN MEDICINE

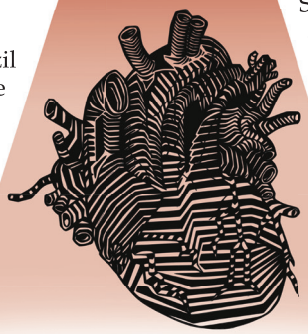
BY EMILY CHEN, DATA SCIENCE AND BIOCHEMISTRY, 2023

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

Our bodies are made up of complex organs connected by networks of blood vessels. Recreating the complexity of each organ is hard to imagine. But, with the advent of 3D printing, scientists in Texas, Cambridge, and Brazil have proven otherwise.

The idea of artificially grown organs isn't new. Synthetic skin has been used on burn patients for decades; however, the concept of creating organs more complex than skin is revolutionizing the field of modern medicine. In March 2019, for instance, a 3D-printed kidney was used for the first time in a life-saving surgery in Texas.

Just this winter, in December 2019, scientists in Brazil printed "mini-livers" that can perform the same functions as a natural liver: building proteins, storing vitamins, and secreting bile. Days later, an Israeli research team printed a heart the size of a cherry, fit with the ability to pump blood. At Rice University, in Houston, Texas, scientists discovered that Yellow No. 5 food dye allows the appropriate vascular networks to mimic the body's passageways and deliver oxygen to surrounding blood vessels. Volumetric Bio, a biotechnology company, is funding a variety of research projects developing 3D printing technology, creating an open-source project and accelerating progress in the field.



In the United States there are currently more than 100,000 individuals waiting for life-saving organ transplants. Additionally, the patients who do undergo an organ transplant face a lifetime of immunosuppressant drugs. If we only rely on organ donors, this constant demand for transplants will never fade. Every day in the United States, 13 people die waiting for a kidney transplant, and with this advancing technology, these deaths have greater potential to be avoided. The central idea of these 3D-printed organs is that cells from the patient themselves are used to make them. This decreases the probability of rejection and reduces the need for immunosuppressant drugs, increasing the longevity and quality of life. The progress of developing 3D printing technology is exponential, and a future using life-sized livers and hearts in transplant surgeries is closer than you think.

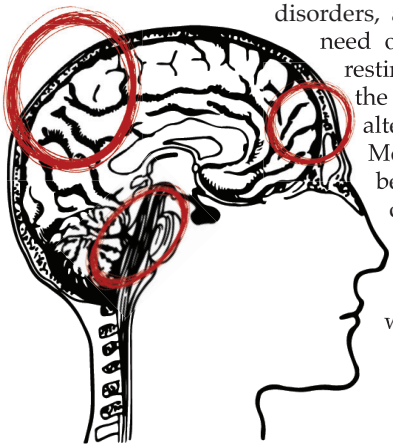
Northeastern researchers discover biomarkers to predict mental illness

BY LILY WEBER, BIOLOGY AND ENGLISH, 2023

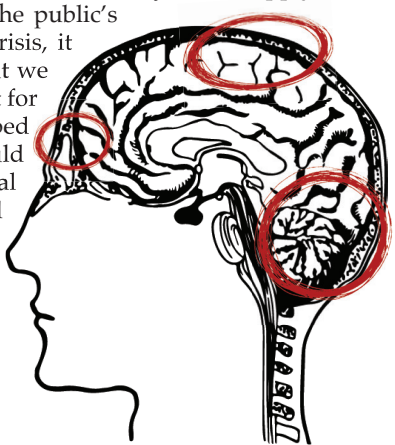
DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

Imagine a world in which mental illness can be identified at an early age; where appropriate treatment can be initiated sooner, thus giving a better chance of recovery to those afflicted. This may one day become a reality, thanks to the efforts of researchers from Northeastern's Department of Psychology, among others.

Researcher's from various collaborating institutions have conducted a study that has yielded a promising lead to groundbreaking results. Conducted by Whitfield-Gabrieli et al. in 2019, data was analyzed from a longitudinal brain development study which followed children from age seven to eleven. It found that functional magnetic resonance imaging, or fMRI, can help to identify children who are at risk for certain psychiatric disorders, and thus pinpoint who may be in need of preventative treatments. Certain resting-state connectivity patterns in the brain were able to predict later alterations in psychiatric symptoms. More specifically, weaker connectivity between the dorsolateral prefrontal cortex and medial prefrontal cortex (regions involved with switching attention and decision making) predicted attentional symptoms, whereas weaker connectivity between the dorsolateral prefrontal cortex and the subgenual anterior cingulate cortex (a region responsible for empathy and emotion) predicted more internalized symptoms such as anxiety and depression. The authors concluded that such metrics obtained from resting state MRIs are promising biomarkers for both major depressive disorder and attention deficit/hyperactivity disorder.



With rising rates of mental illness and a lack of available mental health professionals to compensate, mental health is rapidly becoming a crisis in America. In fact, according to the Journal of the American Medical Association, nearly one in five people in America have a mental health condition. However, according to the National Council for Behavioral Health, by 2025, supply for psychiatrists will fall short of the public's demand. Due to this burgeoning crisis, it is becoming all the more urgent that we develop novel methods of treatment for mental health. The model described in this study, in which people could be screened early on for mental illness biomarkers and then treated appropriately, has the potential to greatly improve the state of mental healthcare in the United States.



Hox genes:

Architects of the body

BY YASMINE MYFTIJA, BIOLOGY, 2021
DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

Have you ever wondered how the human body assembles itself from a simple ball of cells? Or why nearly everyone is born with a similar, universally accepted body structure? How the body knows where *not* to place an extra eye? Or what a human could possibly have in common with its fellow vertebrate, the zebrafish? It seems miraculous that the human body puts itself together as easily as a child puts together Legos, but in reality, this fundamental process is driven by a group of regulatory genes named homeotic genes.

Homeotic genes, which are found in all vertebrates, regulate and direct the development of the many structures in a vertebrate's body. They were first discovered in *Drosophila melanogaster*, commonly known as the fruit fly, in 1978. Hox genes, which are a subset of the broader homeotic genes, are highly conserved evolutionarily and can be found in any animal from a zebrafish to a monkey. In fact, the sequences of many homeotic genes have remained nearly unchanged over millions of years, despite incredible evolutionary changes and distinctions between species. These genes encode for proteins which set off transcription by binding to homeoboxes, parts of the DNA sequence. The homeoboxes then begin a signaling pathway which eventually leads to the formation of a hyper-specific segment of the body by turning on the expression of the genes associated with that segment. For example, in the human embryo, HOX5, HOX6, HOX9, HOX10, and HOX11 create distinctions in the spinal cord which will become the cervical, thoracic, lumbar, sacral, and caudal portions. Humans have 39 known Hox genes that determine which end of the body the head begins to form on, as well as which segments legs or arms sprout from; they play an essential role in left-right and front-back axis symmetry.

When a homeotic gene is impaired by a mutation in its genetic sequence, it can have drastic effects on the development of the animal in which it is found. Take *Drosophila melanogaster* for example. A simple change in its genetic sequence called the antennapedia mutation causes the growth of a leg where the fly's antenna would usually grow during normal development. The antennapedia mutation occurs when the gene which regulates the formation of the posterior segments containing a pair of legs is expressed in an anterior section, thoroughly altering the structure of the fly. However, mutations like these may have other dire effects. Flies with this mutation are often less likely to survive to adulthood, although if they do, they have no antennae. This is quite a disadvantage, as the antennae of species in the *Drosophila* genus are often part of their peripheral nervous system and function as an auditory organ.

PHOTO BY PIXABAY

Mutations in Hox genes also occur in humans and can be quite harmful. If a Hox gene mutation occurs in the cells which produce offspring, it can be passed on and can cause some serious disorders. HOXA1 is a hox gene in which mutations have been found to disrupt proper body formation and cause two rare but distinct disorders: Bosley-Salih-Alorainy syndrome (BSAS) and Athabascan brainstem dysgenesis syndrome (ABDS). BSAS can result in auditory abnormalities, such as deformities within the inner ear which impact hearing, and vision issues as a result of the impaired development of some cranial nerves, artery malformations, and other markedly different facial and limb features. ABDS, the latter of the two diseases, is far more threatening. Among its many symptoms are seizure disorders, auditory issues, intellectual disabilities, and weakness of the facial bones, all of which can impact the quality of life for someone diagnosed with ABDS.

“When a homeotic gene is impaired by a mutation in its genetic sequence, it can have drastic effects on the development of the animal in which it is found.”

While scientists have been studying Hox genes since their discovery, much remains unknown. For example, while scientists are aware that Hox genes often play a role in stem cell development, the link between Hox genes and irregular stem cell growth which may cause cancer is still not understood completely. Only with continuing research into these regulatory genes can scientists fully grasp the complexity and importance of their functions.

Molecular Genetics and Metabolism (2014) DOI: 10.1016/j.ymgme.2013.10.012
Stem Cells Int. (2018) DOI: 10.1155/2018/3569493

The ubiquity of Fibonacci

BY SAGE KUMAR, BIOLOGY, 2023
DESIGN BY NICHOLAS BERRY, MECHANICAL ENGINEERING, 2024

1, 1, 2, 3, 5, 8, 13, 21… It's a list of numbers that most are likely well-acquainted with but haven't seen since your first exposure to algebra: the Fibonacci sequence. This somewhat mystical pattern is more relevant to daily life than Algebra 1 had us believe. The reverberations of Leonardo of Pisa's genius echo throughout math, music, and nature.

Leonardo of Pisa, who is posthumously referred to as Fibonacci, laid the groundwork for his namesake sequence in his 1202 book Liber abaci. The work educated the mathematical community on a new alternative to Roman numerals (the Hindu-Arabic numerals we use today), applied them to many economical and practical situations, and presented questions through speculative mathematics. The catalyst for the generation of the Fibonacci sequence was one of these questions: "A certain man put a pair of rabbits in a place surrounded on all sides by a wall. How many pairs of rabbits can be produced from that pair in a year if it is supposed that every month each pair begets a new pair from which the second month on becomes productive?" The total number of pairs present in each generation of rabbits and the order in which they are generated corresponds exactly to the function $fn = fn\text{-}1 + fn\text{-}2$.

In both nature and history, the Fibonacci sequence is mysteriously omnipresent. In the beginnings of Euclidean geometry, it pops up through its manifestation of the "Golden Mean" of Euclid and Aristotle. As the sequence progresses, the number produced by dividing fn+1 by fn grows infinitely close to this golden number, phi: 1.618034. If we jump forward in time and observe the work of Leonardo da Vinci, we can find this Fibonacci derivative in the form of his Golden Ratio and its many appearances in his art and inventions.

The sequence and its derivatives crop up even more frequently in the natural world around us. Phi famously appears when observing the ratios and rate of expansion between the outside point of any spiral of a nautilus shell, the first inside spiral at one full rotation from the first given point, and the second inside spiral found 900 degrees from point one. This rotation pattern also yields fractals that align to form rectangles with areas that can be simplified to the numeric sequence of 1,1,2,3,5,8,13. The numbers found in the Fibonacci sequence are also frequently featured in plants. Sunflower seeds fan out in 55 clockwise spirals and 89 counterclockwise spirals. Pine cone seeds tend to fan out in eight clockwise spirals and 13 counterclockwise spirals, with the number of seeds in each spiral corresponding to another Fibonacci number. Petal arrangements in daisies, lilies, buttercups, and roses also follow a similar pattern but to a lesser scale.

The numbers of the Fibonacci sequence also transcend scale.

> "The Fibonacci Sequence is mysteriously omnipresent. If we jump back in time to the beginnings of Euclidean geometry, it pops up through its manifestation of the "Golden Mean" of Euclid and Aristotle."

The microtubules of mammalian cells that lend structural support and form the routes for other organelles to travel upon are comprised of either 13 or 21 columns of protein. Zoom out, and mammalian forelimbs are comprised of a series of bones following the sequence of 1, 2, and then three sets of 5 from the humerus to the phalanges (minus the thumb).

But why are this sequence and its associated ratios so prevalent? We have yet to come to a conclusive answer. Aesthetics, structural integrity, and intelligent design have all been offered as potential explanations to Fibonacci's ubiquity but have yet to be verified. So for now, we're left to simply enjoy and marvel at its products.

PHOTO BY BRIANNA WATTS

BIOPHILIC ARCHITECTURE:

Why your succulent collection is more than just *trendy*

BY LOUISE HOLWAY,
CIVIL ENGINEERING
AND ARCHITECTURE, 2022

PHOTO BY SELINA BANERJEE,
CHEMICAL ENGINEERING, 2022

DESIGN BY MARISSA KEESEY,
ELECTRICAL ENGINEERING, 2022

Journal of Affective Disorders (2012). DOI: 10.1016/j.jad.2012.03.012

Building and Environment (2018). DOI: 10.1016/j.buildenv.2018.01.006

As city dwellers, it is safe to say that we spend the vast majority of our time in the built environment. While a weekend ski day, summer camping trip, or even a walk through the Boston Common might make us feel one with nature, we could all do with a little more outdoors. Biophilic architecture focuses on connecting nature to the built environment, particularly emphasizing aspects that contribute to human life and our fundamental need to connect with nature. The goal is to create a habitat that parallels a natural environment and mimics an ecosystem. Not only can this result in beautiful and inviting designs, it can also have a positive impact on mental health and productivity.

In order to influence a space, biophilic design requires multiple strategies including natural light, air flow, presence of water, plants, views of nature, and natural materials and color. While any one of these strategies may result in a beautiful design, true biophilic design uses an intelligent combination of them.

By using these strategies, designers can make their audience feel a deeper connection to their origins, which is an experience with numerous benefits.

One of the benefits is the effect on mental health. Numerous studies have shown the positive impact nature has on our moods. A 2012 study from *Journal of Affective Disorders* found that a 50-minute walk in a natural setting boosts mood and short-term memory. Another study from *Building and Environment* in 2018 had participants experience five minutes of virtual reality featuring biophilic design elements. As a result, the participants experienced lower blood pressure, a decrease in negative emotions, and an increase in positive emotions compared to those experiencing a traditional indoor environment. In addition, experts found that participants experiencing the virtual reality environment reacted similarly to individuals who were actually outside. These results indicate that exposure to nature—even short-term—can have a lasting impact on mood, stress, and memory.

The impact of biophilic design also involves increased productivity. A study from the *Journal of Experimental Psychology:* Applied found that workers' well-being increased by 40 percent, and absences decreased, just by adding plants to the office. The average full-time office worker spends 90 percent of the day indoors, and 35 percent spend less than 15 minutes outdoors per day. While building outdoor offices may not be the most practical idea, simply implementing biophilic design elements may result in a more successful and prosperous business.

Although you may not be planning any renovations that include koi ponds or a green roof, there are numerous strategies to effectively incorporate biophilic design into your home. A visual connection with nature may include flowers, plants, or even a fish tank. Non-visual connections can be equally effective, such as with natural air fresheners, open windows, and natural materials like wood and stone. Biophilic design can create a beautiful, inviting space while having a proven impact on mental health.

POWER IN NUMBERS:
UNSINKABLE RAFT MADE OF FIRE ANTS

BY CAILEY DENONCOURT, BIOENGINEERING, 2022

In 2017, Hurricane Harvey flooded southeastern Texas. Accompanying the ensuing high water levels, there were alligators floating through the streets, fish in front yards, and fire ants, *Solenopsis invicta*, gathered on top of the water. After being displaced from their elaborate underground colonies, the thousands of fire ants had no solid ground to reconvene. In order to survive, they gathered together on top of the water, creating a rust-colored mound by biting onto each other.

These flat, round masses, scientifically called conglomerations, can become as large as 18 inches in diameter, and can remain connected for anywhere between 12 hours and 12 days, depending on the conditions. As properly named, fire ants come with a painful, stinging bite if disturbed. Thus, these "fire rafts" posed another hazard amongst the already dangerous floods.

However, this ability for the ants to self-assemble into these large, intricate rafts is quite a scientific feat. Although a singular fire ant fails to stay above water, when accompanied by thousands of other ants, they can create a weave-like structure through their cohesive strength and hydrophobic bodies.

> "In order to stay intertwined together, the fire ants grip onto each other using their mandibles (jaws), tarsal claws (feet), and adhesive pads."

In order to stay intertwined together, the fire ants grip onto each other using their mandibles (jaws), tarsal claws (feet), and adhesive pads. In other words, they use a combination of biting each other and gripping with their feet to keep the raft from falling apart. As measured in a study conducted by the Georgia Institute of Technology in 2010, the amount of force needed to separate two ants was 400 times their body weight, which is quite a feat for an ant but on a human scale is only around 2 grams. This fragile yet powerful force is just enough for the raft to float on top of water.

The majority of the raft is constructed by worker ants, with the queen ant along with some resting worker ants enjoying themselves on top. The raft is not a static structure; the worker ants are in constant motion, so the connections between the ants are constantly changing. They morph and move more like a highly-viscous fluid on top of the water.

Fire ants also contain a hydrophobia cuticle: a strong and flexible skin-like shell. The cuticle allows the ants to hold air against their bodies when submerged underwater; this bubble layer is known as the plastron layer. Most of the larger bubbles of air accumulate on the ventral side between the first two sets of legs and on the propodeum, or the first abdominal segment. The air pockets increase buoyancy, thus allowing the raft to stay afloat for long periods of time. However the plastron layer serves a dual purpose since it also helps the ants breathe when submerged on the underbelly of the raft.

Larvae, specifically the older third to fourth instar larvae, possess an outer bristle-like structure called setae, which helps trap more air bubbles around the worker ants. As shown by the results in a 2011 study conducted at Louisiana State University, the rafts with the larvae held up on top of the water for a longer period of time compared to those without larvae or younger larvae. As the raft grew, the size of the bubbles on the undersurface of the raft could grow to greater than one millimeter in diameter, which were surrounded underwater by submerged worker ants.

When a stress, such as a stick, is applied to the raft, the ants are able to morph and self-heal. In unison, the ants contract their muscles in order to create a more rigid structure to adapt to the applied stress. However, this sacrifices the buoyancy of the raft due to the decrease in air pockets and higher density.

More so than just being scientifically amazing, the structural aspects of the fire ants' raft is currently being examined by researchers and roboticists for applications in man-made floatation devices. These applications include groups of miniature robots to clean up oil spills or modeling biomaterials after interconnected ant rafts for their desirable properties of contraction, stress response, and intricate spatial arrangement. Ants are seemingly small, pesky creatures compared to the human world around them, but when ratioing out their strength and speed, they are incredibly unique.

Proceedings of the National Academy of Sciences (2011). DOI:10.1073/pnas.1016658108/
Journal of Insect Science (2011). DOI: 10.1673/031.011.17101

DESIGN BY YECHAN YANG, BIOLOGY AND PSYCHOLOGY, 2022
PHOTO BY WIKIMEDIA COMMONS

A fleeting glimpse:

The surprising complexity of hummingbird displays

BY RACHEL LINES,
BEHAVIORAL NEUROSCIENCE, 2023

DESIGN BY MARISSA KEESEY,
ELECTRICAL ENGINEERING, 2022

Has a quick flash of color at your bird feeder ever caused you to do a double take? While anyone who has glimpsed the quick movement and fantastic colors of a hummingbird can appreciate their natural beauty, the true marvel of this species comes from their distinct adaptations. The evolution of many bird species is driven by sexual selection, in which the females of the species select mates who demonstrate their strengths and abilities. This process has resulted in many spectacles of nature, such as male birds performing complicated dances or building elaborate nests to impress females. Recently, scientists have evaluated the molecular and structural basis of these hummingbirds displays, and analyzed the role of sexual selection in the evolution of flashy, iridescent colors and pitch production through the movement of feathers on their wings.

The complex coloration of hummingbird feathers can be viewed when the bird moves and changes the angle from which the viewer is observing. From the side perspective, the feathers may appear dull. However, when the bird is turned at a specific angle, the iridescence of the feathers is brightly displayed. Spanning the entire rainbow, hummingbirds have immense color variation between species. Male hummingbirds tend to exhibit large, flashy patches of colors with more prevalence than females.

What makes hummingbirds so distinctly colorful, unlike other bird species? An analysis of hummingbird feathers by researchers at the Field Museum in Chicago revealed that structure has a role to play in the colors. The cells in bird feathers contain melanosomes, or pigment-producing organelles. Human cells also have melanosomes, which produce melanin in hair and skin. After examining the feathers of 35 different hummingbird species using transmission electron microscopy and measuring reflectance spectra, researchers found that hummingbird melanosomes don't merely produce pigment as human melanosomes do. These organelles in hummingbirds are layered and shaped differently in comparison to humans, as well as other bird species. Some bird species have melanosomes that are organized into hollow structures or are completely solid, but hummingbirds have flattened, hexagon-shaped melanosomes containing tiny air bubbles. Through the interactions of light with this complex surface, hummingbirds are able to display brilliant color. Hummingbird color variation can also be explained through evaluation of this structure – the complexity of the structure and traits allows for more phenotypic variation.

Hummingbird feathers are more than just a sight to be seen. Several hummingbird species are also capable of producing sound using only the fast movement of their feathers. Utilizing a phenomenon called aeroelastic flutter, the shape of individual feathers allows hummingbirds to manipulate their flight and oscillate to create attention-grabbing sounds during mating displays. Through differences in feather size, shape, mass, and stiffness, the resonance frequency of the feather changes. Furthermore, hummingbirds can produce multiple sounds from different locations. The Allen's hummingbird, for example, can produce two tail tones and a wing tone simultaneously while performing a diving display.

Scientists have wondered why hummingbirds exhibit these exceptional traits and how they evolved. The appearance of these colors andvabilities in the male individuals of the species suggest that these traits may have adapted due to sexual selection. Hummingbirds have long been a subject of discussions about the relationship between natural and sexual selection. In 1867, G. D. Campbell criticized Charles Darwin's theory of natural selection because he claimed it was not adequate to explain the brilliance of hummingbird coloring. In response, Darwin suggested sexual selection, in which male-to-male aggression and female choice resulted in the expression of different characteristics.

After analyzing the inheritance interactions between different color patches in hummingbird species, Professor Juan Luis Parra of SUNY Stonybrook found that sexual selection does play a role in the emergence of these distinct traits. However, it was also discovered that color patterns are not completely independent of one another. The adaptations that result from natural selection and from sexual selection interact, producing the displayed phenotype. Parra suggests that the overall coloration and species diversity in hummingbirds is affected by sexual selection, but other mechanisms such as natural selection and geographic isolation may also be essential contributors.

Hummingbird feathers are complex in their structure and function, resulting in incredible diversity throughout the species. Beyond a pretty image at your bird feeder, these creatures are specifically evolved to be eye-catching, attracting mates through their elaborate visual and audio displays. In the fleeting moment before they fly away, hummingbirds briefly reveal this beauty to human onlookers, but their true range of attention-grabbing skills remain mysterious, concealed from the average observer.

The season switch-up

Should we redefine seasonal boundaries to match climate change?

BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

It is January 12, 2020, and it is a record-breaking 74 degrees Fahrenheit in Boston. This unusually warm weather brings everyone outdoors. Families gather on picnic blankets in the parks, joggers cut through the paths, and sunbathers lounge on benches — some even sporting shorts.

While the colder weather typical of a New England winter soon returned, these unexpectedly temperate days are not uncommon. A study funded by the Chilean government found that the thermally acceptable growing season has increased by 10.5 days in the last three decades. This means the year warms up more quickly and cools down more slowly.

Some scientists have begun to ponder what weather we should expect in future yearly cycles. As "shorts weather" lengthens, should we reconsider how we classify the seasons?

There are currently two different ways to differentiate winter, spring, summer, and fall. The meteorological method, created in the mid-1900s, is often favored by scientists. It breaks down the seasons into equal groupings of three months. These are based on the temperature cycle and our calendar structure. Summer is the three warmest months: June, July, and August, while winter is the three coldest: December, January, and February. Spring and fall are the "transition seasons" in between.

The astronomical method, on the other hand, is a method that has been around nearly as long as humans have gazed at the stars and planted crops. It is based on the tilt of the earth as it rotates around the sun. This means the seasons are divided by the length of the days. Equinoxes mark the time when the sun passes directly over the equator, where the day-to-night ratio is exactly 12 hours. Because the earth does not travel around the sun in exactly 365 days, the equinoxes and solstices can vary. In the Northern Hemisphere, they usually fall around June 21 (the summer solstice), December 22 (the winter solstice), March 21 (the spring equinox), and September 22 (the autumnal equinox). This is the event you would see marked on your phone calendar as the "First Day of Spring."

A study in 1983 found that the meteorological seasons fit much better with weather patterns in most locations. The astronomical method, on the other hand, really only fits over the Oceanic region of the Southern hemisphere. The lead of the study, Kevin Trenberth, noted in a 2017 interview that after his findings were published, some groups in the United States attempted to switch from the astronomical method to the meteorological method — which would better match the seasonal changes in their region — but were unsuccessful. Today, according to Trenberth, the astronomical definition of seasons persists as the most popular in the U.S.

Scientists estimate that as the globe warms up, the tropics are expanding by 0.1 to 0.2 degrees of latitude every decade. While seemingly small, this means many places with four seasons — regions 30 to 60 degrees North and South of the equator — are instead shifting to two seasons. This results in a dry season and wet season, both of which are hot.

This temperature change brings with it an expansion of extreme weather phenomena. According to the National Oceanic and Atmospheric Administration, the number of extreme weather events is expected to increase in upcoming years. Many locations will have more heat waves, less frequent and more intense precipitation, and an increase in droughts. The weather patterns we expect are predicted to alter drastically.

> "The tropics are expanding by 0.1 to 0.2 degrees of latitude every decade... This means many places with four seasons are instead shifting to two."

This leads to the question: is it time to create another method of dividing the year to better match seasonal patterns? As the temperature stays warmer for longer, should summer be extended to better represent when it is comfortable to wear shorts? We would stop sitting on the edge of our seats for the first snow of winter because winter would still be weeks away. The current definition of seasons is far from an exact science. With the uncertainty of how climate change will impact weather events, the possibility of altering the seasons cannot be ruled out.

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PHOTO BY CHRIS LAWTON ON UNSPLASH

The structure of species:

How organisms are classified

BY MAYA KRAUSE, ENVIRONMENTAL SCIENCE, 2022

DESIGN BY IAN PROULX, BIOENGINEERING, 2022

In 2019, the California Academy of Sciences added 71 new species to the 1.2 million species already classified. The discoveries this year ranged from Cirrhilabrus wakanda, a reef fish found off the coast of Tanzania named for the fictional city from Marvel's Black Panther, to Trembleya altoparaisensis, a Brazilian plant with white flowers that has not been collected in over 100 years. How do scientists know where these organisms fit with the billions of others on Earth?

The process of finding where an organism fits in the structure of the giant family tree of all the discovered species is the scientific field of taxonomy. Taxonomy is based around the structure of the family tree, the hierarchical groupings of organisms based on different biological traits. Each known organism is labeled with a kingdom, phylum, class, order, family, genus, and species, with each subsequent label becoming more and more specific. For example, the kingdom Animalia is comprised of multicellular organisms whose cells are eukaryotes. Within Animalia lie 35 phyla, ranging from Arthropoda (animals with an exoskeleton) to Tardigrada (animals that are segmented four times, also known as water bears) to Chordata (animals that have a backbone), and so on.

For over 2,000 years, scientists have been classifying animals and plants and dividing them by their similarities. Aristotle was the first scientist who attempted to classify all known creatures in his fourth century BC text History of Animals. But the modern process of taxonomy that has become universally accepted and streamlined by the scientific community was invented in 1735 by Carl Linnaeus, a Swedish biologist. Before Linnaeus, biologists had grouped organisms by arbitrary criteria with no hierarchical structure, and often used long Latin names that were not consistent throughout the scientific community. Linnaeus used hierarchical groupings based on shared biological criteria to define organisms' relation to one another. He was also the first biologist to consistently use two names to describe an organism: the genus and the species. Thanks to Linnaeus, the world knows humans as Homo sapiens.

When scientists think they have discovered a new species, they will start by going down through the existing classifications, comparing the traits of the possible new species with the traits of already classified species. For instance, Cirrhilabrus wakanda, commonly called the Vibranium fairy wrasse, shares the features of other wrasses, so this new fish was placed in the family Labridae. However, Cirrhilabrus wakanda has short pelvic fins and bright purple scales covering two-thirds of the body, which distinguish this new species of fish from other wrasses.

Taxonomy starts to get tricky when determining whether an organism's characteristics are part of the diversity of one species, or a distinction between two different species or multiple subspecies. Most scientists consider that if two organisms can mate and produce fertile offspring, they are members of the same species. But with billions of organisms on Earth, there is no way for scientists to track the mating patterns of all individuals to determine their classification. Scientists have also begun to use DNA sequencing to determine the relatedness of organisms, but this is also inconclusive. For instance, humans share almost 99 percent of DNA with chimpanzees, but clearly are different species. Therefore, most scientists continue to base their classifications on characteristics of the organism.

Classification affects conservation both legally and financially. An organism ranked as a species is much more likely to be conserved. If a species is split into two subspecies, one subspecies can lose their protected status, leaving those organisms vulnerable to extinction. Additionally, if two subspecies are reclassified as two separate species, the potential for interbreeding to save the species is diminished. For example, the northern white rhinoceros and the southern white rhinoceros are currently considered two subspecies of rhino. There are only two northern white rhinos left in the world, both female, so some scientists have suggested breeding the northern white rhinos with male southern white rhinos to attempt to save the subspecies. However, if proposals went through to reclassify the northern and southern white rhinos as separate species, interbreeding would no longer be permitted.

Taxonomy is an essential tool used by scientists to describe and organize groups of animals. Without the streamlined process developed by Carl Linnaeus, the structure of the family tree of all known organisms would be convoluted and difficult to interpret. However, this structure can cause problems when determining legal protections of animals, and a new classification could mean the difference between life and death of a species.

PHOTO BY WIKI COMMONS AND FLICKR

UNDERWATER "ROADS"

BY AMANDA BELL, BIOLOGY & DATA SCIENCE, 2023

DESIGN BY KYLA VIGDOR, DESIGN, 2021

Off the coast of the Bahamas lie round, irregularly-shaped stone features, the most famous of which are oriented in a line that has become known as Bimini Road. Since its discovery in the mid-1960s, people have debated whether Bimini Road is man-made or naturally formed over years of sedimentation and erosion. So is Bimini Road the remnants of the legendary city of Atlantis, or is it simply one of the many wonders of geology? Perhaps it would be beneficial to first explore what Bimini Road is and how scientists believe it formed.

Bimini Road is made up of beachrock, a sedimentary rock containing various sized sediments and limestone. Beachrock can contain human artifacts; however, only shells and rock fragments have been found in Bimini Road. Beachrock formation is confined to warm tropical areas like the Bahamas and the intertidal zone where the rock can form from the rise and fall of the tides. Essentially, the constant flood of supersaturated seawater through the sand, along with evaporating seawater and the release of carbon dioxide from the water, helps sediments fuse together just beneath the sand. The formed beachrock remains hidden until the overlying sand is eroded. Once uncovered, beachrock cracks and separates into different-sized slabs as a result of exposure to the sun and water similar to the way concrete roads form. The beachrock is once again submerged when the sea level rises, creating an underwater road.

> "The most popular theory is the idea that Bimini Road was part of the lost city of Atlantis."

Despite the science behind the formation of underwater structures like Bimini Road, there are a growing number of alternative theories regarding their formation. The most popular theory is the idea that Bimini Road was part of the lost city of Atlantis. Ancient harbors in the Mediterranean Sea closely resemble Bimini Road, leading people to connect it to Atlantis; however, the stones are too young to be related to Atlantis. Others say that the stones were arranged by Chinese merchantmen for hauling and repairing their ships following a storm in the 1400s. However, lack of evidence weakens the validity of this theory.

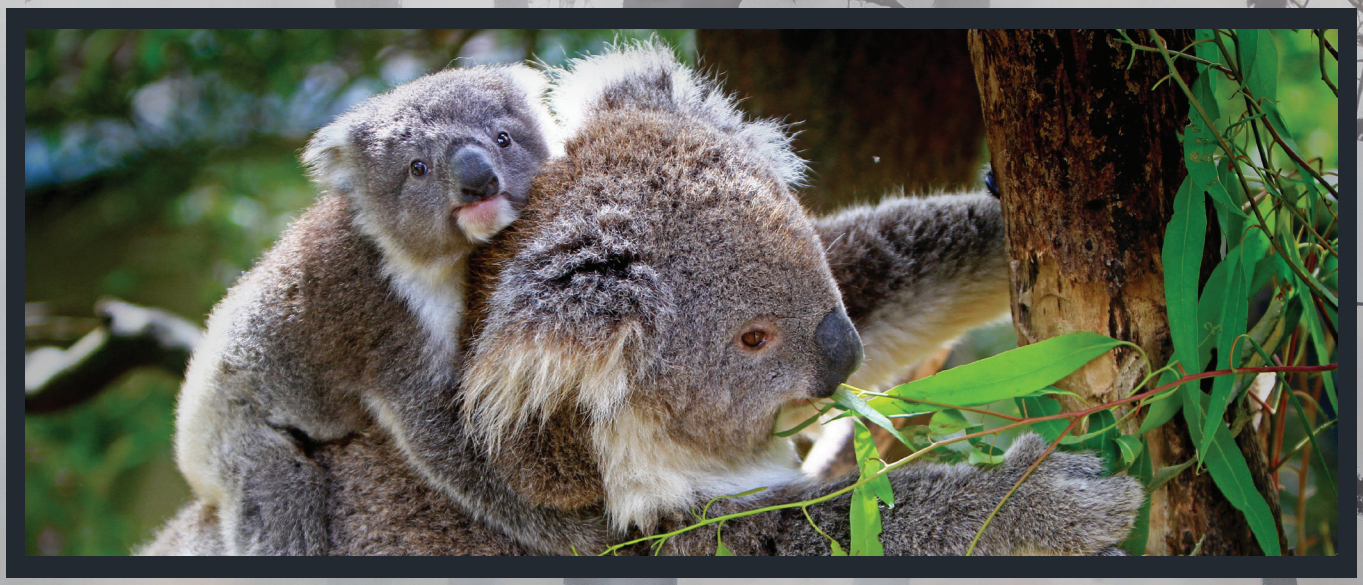
A more plausible theory is that the stones were already there, and people used them to suit their needs. As with the Atlantis theory, believers of this theory use the harbors in the Mediterranean sea as a model for their views at Bimini. Ancient people of the Mediterranean region were part of technical, culturally-rich societies, so structures they built would consist of artifacts such as tools used to build the structures. If the harbors of the Mediterranean were man-made, it would be reasonable to assume that the harbors have artifacts embedded in them. Since there are no artifacts in the Mediterranean harbors or in Bimini Road, they are likely not man-made.

In the past decade, Bimini Road has actually created tension between scientists, most notably Dr. Greg Little and Dr. Eugene Shinn. Little claims that Shinn planted fake artifacts around Bimini Road nearly thirty years ago to spark interest in the area. Even stranger is that Shinn had the support of the United States Geological Service (USGS) and in his actual research, attempted to disprove the theory that Bimini Road is man-made. In 2015, Shinn admitted to planting the fake artifacts, but has faced no consequences since his confession. Is the USGS implying that archaeological forgery is ethical, or that Shinn's fraudulence wasn't significant enough to result in consequences? Does this discredit not only Shinn's research on Bimini Road, but also his research on other topics? This doesn't change the uncertainty regarding the origins of Bimini Road, but it certainly calls into question the authenticity of Bimini Road research.

In short, the mysterious underwater structures around the Bahamas have inspired many theories regarding their origin. Research in the field is questionable since Shinn's admission of planting false artifacts, so it's unlikely that Bimini Road's origin will ever be known. Science disproves many of the anthropogenic-based theories, but that shouldn't diminish the beauty of the rock's structure or the artistry of the theories.

PHOTO BY PIXABAY

AUSTRALIA'S BUSHFIRES: Learning from the burns



BY CHRISTINA MCCONNEY, BIOLOGY, 2021

DESIGN BY KYLA VIGDOR, DESIGN 2021

Australia has been on fire as of late—literally. In case you haven't been following the news, Australians have been battling ferocious bushfires, which have ravished around 1.65 million hectares in the state of New South Wales since January 6th, 2020. Firefighters, both Australian and international, have been risking their lives to attempt to quell the raging fires from destroying much of the continent. Though faced with a frightening situation, these brave individuals at least have a fighting chance to defend themselves from the fires by having a diversity of tools and methods at their disposal (equipping firefighters with mobile water crews, helitacks to aid from the sky, and the knowledge of fire specialists to develop fire safety plans). But there are some individuals who were not privy to such means of protection and instead perished in the blazes: the nearly half a billion mammals, reptiles, and birds in much of the affected areas who lost their lives in their battle against nature. In order to understand how the fires were able to displace so many individuals and animals alike, two questions have to be answered: what pre-existing environmental conditions persisted allowing for such catastrophic burning to take place? And what does this mean for the future of Australia's ecosystems?

Australia's wildfire season spans from November to February (late spring to early summer), with the actual spread of wildfires mandated by four main conditions. First, the fires need fuel covering an expansive range—this allows wildfires not only to burn, but also to travel. Second, the fuel in question needs to be dry enough that the material can actually burn. The third and fourth requirements are an ignition source (whether that be lighting storms or man-made fires) and optimal weather conditions which would allow for the fire to spread. One component of the 2020 wildfires that made this event so devastating, and has caused concern for many within the scientific community, was the fact that the fires in question went outside the expected range of impact. The fires typically need very dry material to burn, such as dry plant biomass; however, areas that were considered to be moist enough to avoid being affected were burnt through. In many cases, these typically "immune" wet areas were rich with flammable organic material, allowing the fires to consume the surrounding plant life.

So, what do these fires mean for Australia's ecosystem? The first thing to consider is the fact that bushfires are an intrinsic part of the continent's natural environment. Much of the plant life found within is prone to burn—residing in areas commonly plagued with drought and dry plant material)—and many others rely upon seasonal bushfires in order to regenerate. These fires are also an important part of the culture, as they're used by indigenous Australians to clear land for agricultural purposes. However, the severity of this season's fires has presented a new cause for concern.

Tall and moist eucalyptus forests, ubiquitously found around the continent, are usually spared from the impact of the fires, but are now starting to be affected more frequently than ever before. In these ecosystems, local wildlife are not only not used to recovering from the effects of wildfire damage, but are now being forced to do so at a much higher rate. Without the chance to properly recover from one burn, the species found within these forests are losing long-term habitats.

Koalas are one of the more popular inhabitants of eucalyptus forests. If they were able to survive the raging fires that devastated their natural habitat, they now face new dangers: predators. The protection that they previously enjoyed from their arboreal homes is now gone, allowing predators easy access to these lovable marsupials. This is a problem faced by many species that are fortunate enough to survive the initial threat of wildfires. The problems don't stop once the fires have ceased, with the aftermath just as harrowing as the ignition.

Australia's wildfires took the news by storm, but once the fires were controlled, the real battle began. Fears that much of the ecosystem is unrecoverable is a problem scientists are now facing—loss of indigenous plant life as well as wildlife could wreak havoc on the now fragile ecosystem left behind.

PHOTOS BY UNSPLASH AND PIXABAY

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Creating a home away from home:

Architectural engineering in outer space

BY ANNABELLE MATHERS, CIVIL ENGINEERING, 2022

DESIGN BY KYLA VIGDOR, DESIGN, 2021

On Earth, structures serve a larger purpose than simply shielding us from the environment; they affect lifestyle patterns, health, psychological response, and adaptability. Those same qualities apply to structures on celestial bodies other than Earth. Not only must architectural engineering in outer space withstand extreme environments, but it must address the new strain on the lifestyle, resources, health, and transportation of astronauts.

The lack of familiar physics and living patterns outside of Earth necessitates that extraterrestrial buildings compensate through enhanced structure tailored toward astronaut lifestyles. These buildings must provide a sense of stability through both practical and self-sufficient design, while allowing flexibility and adaptability within human lives. Unfortunately, there are many limitations on building material and setup, pushing experts to instead stretch the limits of scientific imagination and resourcefulness. Thus, conventional structure and limitations are both redefined in space.

Before the architectural features of extraterrestrial buildings can be discussed, experts face the stringent limitations of another obstacle: material transportation. Launching large amounts of heavy materials is not physically, nor economically, efficient considering current technology. Many experts continue to design buildings formed by on-site 3D printers, which use condensed, fluid materials that are far less difficult to transport than, say, a steel beam. The partially autonomous and self-assembling nature of 3D printing minimizes the need for humans and the bulk of prefabricated structures on weight-sensitive spacecrafts, and during construction.

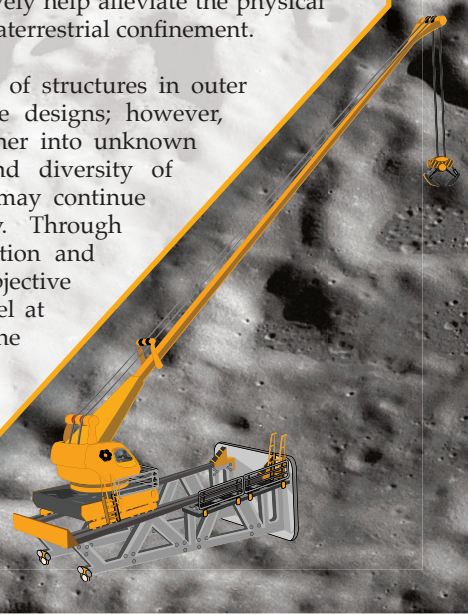
This burden can be further alleviated by utilizing in-situ materials for the 3D printing process from the surrounding environment. In 2004, Dr. Behrokh Khoshnevis of the University of Southern California established Contour Crafting, an accelerated 3D printing technique often tailored toward using Martian dust as printing material. A team at Northwestern University also mimicked Martian soil in a 2015 study, where researchers painstakingly devised a sulfur-based concrete sourced from extraterrestrial sites. By self-sufficiently adapting to the natural resources of celestial bodies, experts seek to reduce the amount of materials in need of transport, and the dependency on Earth's own resources.

The focus on 3D printing using in-situ materials often opposes another popular proposal for extraterrestrial structures: inflatable materials. There are concerns that radiation on other planets with less-protective atmospheres, particularly Mars, may degrade polymers in stretchy materials. However, this issue does not prevent the further pursuit of inflatable solutions. Typically, inflatable designs consist of a thin frame tightly encased in a multilayer, polymer skin, much like an extreme camping tent. This setup maximizes volume of living space while minimizing framing, allowing for more open spaces that are adaptively applicable to many configurations and purposes. A balance of compartmentalized, personal space, and open, airy space is important to the mental health of astronauts. Privacy and spatial focus are just as vital as the avoidance of claustrophobia.

Different compositional additives to the inflatable skin can improve resistance to radiation, as well as provide versatile architecture. For example, a group of European universities developed Self-Deployable Habitats for Extreme Environments (SHEE), which uses robotic self-assembly to combine inflatable material with an inflexible outer shell for increased environmental protection. These small, circular pods are very minimalistic, using multipurpose rooms with specialized wall textures and light emitters to create a practical, but visually stimulating interior. In most designs, specialized LED lighting mimics natural lighting seen on Earth. This mimicry is critical toward fostering a less aesthetically sterile environment in which astronauts can thrive mentally and physically by maintaining a natural circadian rhythm.

A similar multifunctionality, and avoidance of sterility, exists in non-inflatable structures. For example, NASA's 2015 3D-Printed Habitat Challenge notably featured a winner, dubbed the "Ice House," built by teams from Space Exploration Architecture and Clouds Architecture Office. Inspired to use the confirmed existence of water on Mars as their in-situ material, the teams developed an above-ground structure with a semi-translucent ice shell to deflect radiation, facilitate light passage, and allow blended transitions from outdoor to indoor areas. Much like other designs, the architectural curvature creates an illusion of greater interior space. Developers often incorporate hydroponic gardens for oxygen and visual stimulation. Furthermore, multilevel buildings infuse recreation, exercise, and observational research areas that collectively help alleviate the physical and isolative strains of extraterrestrial confinement.

Evidently, the engineering of structures in outer space brings forth diverse designs; however, as mankind ventures further into unknown space, the complexity and diversity of architectural applications may continue to increase exponentially. Through all of this intense adaptation and preparation, the ultimate objective remains true: to simply feel at home as we travel from one celestial speck to another in this vast universe.



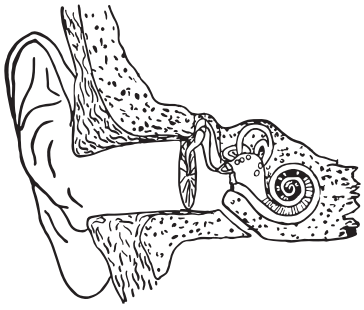
PHOTOS BY UNSPLASH AND PIXABAY

THE SLIP-AND-SLIDE THAT KEEPS YOU STANDING

BY CRISTIAN PIRANEQUE, BIOENGINEERING, 2022

Spider-Man's got nothing on us. If we appreciated our own sense of balance, everyone would be a superhero. It is difficult to fathom the complexity and instantaneous communication that supports balance: visual inputs, sensorimotor (or proprioceptive) receptors laced throughout the body and joints, and, most fascinating of all, the vestibular apparatus. The interactivity of these different systems is often seamless. But anything that disturbs these systems can quickly cause discomfort ranging from simply startling to practically debilitating. Walk out of a spinny ride at Six Flags, and most are aware of how angry the body can get when the brain receives conflicting vestibular, visual and proprioceptive input. Our day-to-day lives are entirely dependent on our ability to continuously remain oriented and aware of where our bodies are in relation to our environment. And while it takes three systems to keep us from falling over, the vestibular apparatus stands out as a uniquely structured system tailored to keep us standing.

Located within the inner ear, this system of tubes and sacs is responsible for the head's spatial awareness. Composed of three semicircular canals and two gravity-sensitive organs—collectively called the otolith organs, and individually the saccule and utricle—the entire apparatus is about the size of a quarter. The canals are oriented in the X, Y and Z directions and are filled with a fluid called endolymph. When the head moves, so does the endolymph, which tickles hair-like cells within the semicircular tubes to alert the brain that the head has moved, and in a particular direction. The two otolith organs work in a similar way, with the saccule responsible for sensing vertical acceleration and the utricle for horizontal motion. Calcium carbonate crystals attached to the ends of more hair-like cells within the organs respond to changes in gravity. If a crystal falls in response to a change in gravitational force, the hair-like cells alert the brain of movement. This causes the feeling of falling or rising in an elevator, even when the brain isn't receiving any visual or significant proprioceptive cues.



> "It is the vestibular apparatus that remains shrouded in mystery."

While the mechanics of this system are often remarkably reliable, they are also extremely sensitive. Say for example, you sit in a chair and begin to spin. Your head begins to move, and with it your semicircular canals. Because of inertia, the endolymph in the tubes resists movement, and so as your head moves to the left, the endolymph pulls the hair-like cells to the right. But after a few moments, the endolymph stabilizes and moves at the same rate as your head. The fluid stops tugging at the hair-like cells, and they straighten out, telling your brain you are no longer moving. But you are! Your visual input says you are whirling around in a chair. This conflict provokes your brain into a tantrum, and you find yourself dizzy and disoriented.

The task of ensuring correct vestibular function is especially important in space. In a microgravity environment, the otolith organs do not function as they do closer to Earth, which causes space motion sickness and hinders the ability of astronauts to perform important tasks. And yet even in the most extreme of environments, the body adapts. In a 2019 report on the human benefits of the International Space Station, NASA describes an ongoing study since 2013 that investigates the effect of weightlessness on vestibular function. So far, this study has shown that there is a dramatic reduction in post-flight symptoms (nausea, dizziness, difficulty tracking objects with eyes) in cosmonauts that have repeatedly been to space over those that have been on prolonged trips for the first time. In collaboration with the Institute of Biomedical Problems at the Russian Academy of Sciences, NASA is using computerized methods—called the *OculoStim-CM*—to track eye movement with virtual reality glasses that can help explain the complexities of the vestibular function for the cosmonauts in space and, to a greater extent, those affected by vestibular disorders here on earth.

Were it not for this complex labyrinth of tubes and sacs, we would be left immobile on the floor. But for those of us fortunate enough to neither be floating around in space or afflicted by a serious vestibular disorder, why not slosh that endolymph around to its fullest potential? Try a handstand, wobble on a slackline, close your eyes and feel those hair-like cells moving. Who knows? There might be a Peter Parker amongst us yet.

Hum Physiol (2017). 10.1134/S0362119717050085
Neuropsychiatr Dis Treat (2014). DOI: 10.2147/NDT.S76747

PHOTO BY BRUCE CHRISTIANSON ON UNSPLASH

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

THE DARK LAYER OF TUCKERMAN RAVINE

BY JASON M. DENONCOURT, CHEMICAL ENGINEERING, 2023
DESIGN BY HEATHER WELCH, ENVIRONMENTAL SCIENCE, 2020

Every spring, thousands trek up the Tuckerman Ravine Trail on Mount Washington in New Hampshire. Trudging through mud with skis and boots precariously strapped to their packs, their destination is Tuckerman Ravine, a glacially carved bowl regarded for some of the most accessible and steep backcountry skiing in the east.

For the majority of these skiers, a spring day on "Tucks" means a good time with friends and family— skiing, building snowmen, or just hanging out by the "lunch rocks" at the base of the bowl. However, for an unlucky few, serious injury caused by accidents and avalanches are a reality.

Though avalanches are far less prevalent in the springtime, extreme caution and attention to warnings posted by the US Forest Service should be taken no matter the season. In fact, most injuries are commonly a result of a lack of backcountry skiing experience and avalanche education.

Through avalanche education, backcountry skiers can identify vulnerable patches of snow to avoid when hiking and skiing on Mt. Washington or any other avalanche prone terrain. Knowing how avalanches form, how avalanches are released, and the different types of avalanches provides a foundation for proper mountaineering safety.

All snow exists in layers, with varying levels of cohesiveness and rigidity. The primary cause of an avalanche is weak snowpack layers. Typically formed of more granular snow and often a result of surface or depth hoar, weak layers fracture under stress—whether a result of new snowfall or an unexpecting skier—and trigger avalanches.

Aspect, or the direction a slope faces, has a profound impact on snowpack. In the northern hemisphere, north–facing slopes receive very little solar heat. Likewise, east–facing slopes receive sunlight primarily in the colder mornings. This cold snowpack is the most attractive to skiers, as this type of snow is often fluffier. However, cold snowpack is also more likely to form weak layers. The popularity among skiers and the increased likelihood for weak layers accounts for why the bulk of avalanches occur on north or east facing slopes.

Anchors also play a crucial role in the formation and release of snow slabs. An anchor is any tree, bush, or rock that protrudes through a slab and holds it in place. The thicker the distribution of anchors and the greater the anchor penetration into the snowpack, the less the risk of avalanches. Likewise, low branching trees, like spruce and fir trees, are far better anchors than trees with few low branches, like aspens and lodgepole pines.

There are two major types of avalanches: slab and loose snow. Slab avalanches are often referred to as the "White Death" or the "Snowy Torrent." As these nicknames suggest, slab avalanches are the most dangerous and account for nearly all avalanche deaths in North America. In a slab avalanche, a cohesive plate of snow slides down the slope. These plates are primarily formed between and released at anchors. As a result, it's very common for a skier to be in the middle of a slab as it gives out and the avalanche forms. These quickly become deadly, as the plate shatters into smaller chunks and gets up to speeds of 80 miles per hour within 6 seconds.

While it's common for slab avalanches to release above a skier, which often proves deadly, loose snow avalanches usually release at a singular point below or at the feet of a skier. For this reason these avalanches are far less dangerous and are frequently referred to as "point releases" and "sluff."

As a skier, getting caught in an avalanche is often just a matter of being in the wrong place at the wrong time. These dangers are inherent to the sport of backcountry skiing. However, the risks of serious injury and death can be minimized with the proper preparation, education, and gear. Technologies like the Recco System—comprised of reflectors installed in clothing and a transceiver—can save valuable minutes in finding people buried in avalanches; statistics show that 93 percent of victims are recovered alive if found within 15 minutes while only 20 percent survive after 45 minutes. In regulated areas, examinations of the snowpack layers are used to determine an avalanche rating, ranging from low to extreme. In many west coast resorts, ski patrol use explosives to trigger avalanches in a controlled environment. On Tuckerman Ravine, avalanche tests are performed daily by the US Forest Service and volunteer group ski patrol are present in the case of any incidents, keeping the skiers, snowmen–builders, and lunch crew safe and smiling.

PHOTOS BY PIXABAY

NU SCI

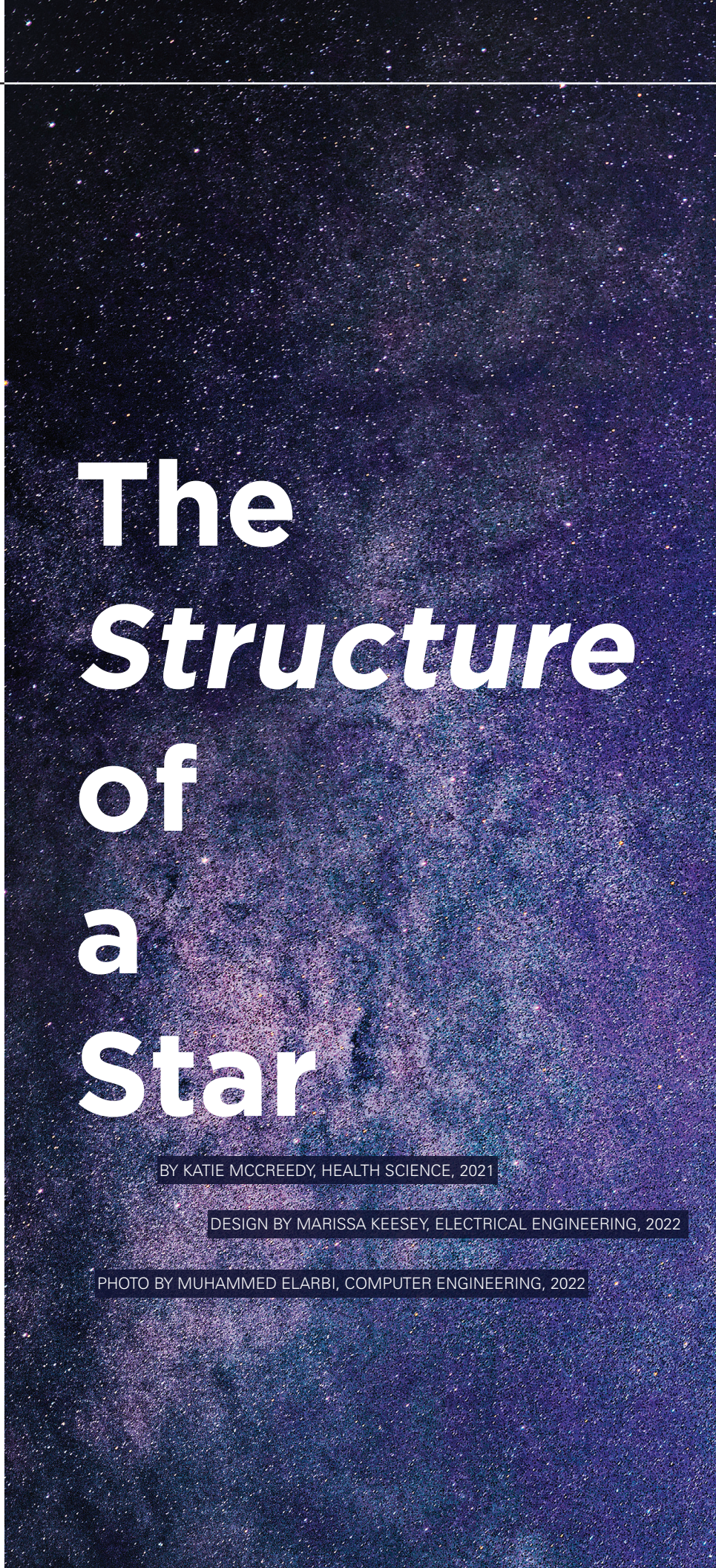
EXPLAINS

The *Structure* of a Star

BY KATIE MCCREEDY, HEALTH SCIENCE, 2021

DESIGN BY MARISSA KEESEY, ELECTRICAL ENGINEERING, 2022

PHOTO BY MUHAMMED ELARBI, COMPUTER ENGINEERING, 2022



There's something intangibly captivating about the vast darkness of the night sky — its stars twinkle and sparkle so distantly that they seem to exist in their own imaginary world. But, over many decades of research, astronomers have developed increasingly in-depth tests and chemical analyses to understand the composition and structure of those elusive stars.

One such technique is emission spectroscopy, which is used to capture the unique pattern in which a star's hot gas molecules emit extra light. These wavelengths are unique to each element, so it is possible to understand what makes up a star by the wavelengths it emits. "What we observe of a star is the light that is emitted by its photosphere. This light is really the light that goes through the layers that are in its atmosphere and ours," explained Alessandra Di Credico, an associate physics and astronomy professor at Northeastern University.

Imagine a star as an onion with distinct, separate layers. In the star's case, each separate layer compresses the others, increasing pressure toward the intensely hot central core.

A star exists in a state of hydrostatic equilibrium — meaning gravity forces these gaseous layers together, while the core exerts its own opposite pressure force outward onto the other layers. These opposing forces keep the star's gaseous layers in its compact, circular form. In general, gaseous hydrogen molecules compose the outermost layer, then there are layers of helium, carbon, neon, oxygen, silicon, and finally a central iron core. These layers vary between stars, although usually heavier metals exist in the inner star core and lighter elements like helium and hydrogen exist in the outer layers.

How these distinct layers develop tells the story of how stars are born. At first, the star is composed of moving hydrogen molecules that form a dense center. As the atmospheric temperature at the center increases, the hydrogen molecules start to move more quickly, increasing the chance that they bump into each other. "They overcome their electrical repulsion and they feel their nuclear strength, which makes them stick to each other. So, at that point they create helium. The moment this starts, that's when the star is born. For the sun, this happened many millions of years ago," said Di Credico.

Because of their beautiful complexity, many myths about the composition of stars and the night sky exist. For one, the common belief that the sky is sprinkled full of visible stars is false. "Only a small portion of the visible sky are actually stars," Di Credico added. This is because other planets emit light similarly to stars, so they also appear as distant white dots in the sky. Only the bright, outstanding dots in the sky actually constitute stars.

Stars also do not twinkle because they are distant flickering fires, but instead they twinkle because of how their light enters Earth's atmosphere. "The reason why they twinkle is due to the fact that the light that comes from the stars is very steady, but when it arrives to us it has to go through our dynamic atmosphere. So the interaction of that light with the atmosphere creates light patterns and that variation creates the twinkling," continued Di Credico.

Despite their intricate layers and powerful gravitational balance, after billions of years stars still inevitably die in spectacular fashion. This happens in particular to very large stars, at least five times the size of the sun, that use up the nuclear fuel burning at their core to fuse the elements of their layers. When this fuel runs out, the star becomes much cooler and its delicate hydrostatic equilibrium fails. The pressure at the center of the star that was holding the gaseous layers together against the force of gravity drops, allowing the gravitational force to collapse the star in as quickly as 15 seconds. This catastrophic explosion is called a supernova. Large-enough supernovas ultimately result in an often fabled aspect of science fiction nightmare with its own mysteries and fascination — the black hole.

Astronomical science ultimately makes that seemingly mythical, distant sky of stars understandable through scientific inquiry. Still, looking up on a clear night bestows no less wonder.

Magnetic skyrmions:
New bits of spin

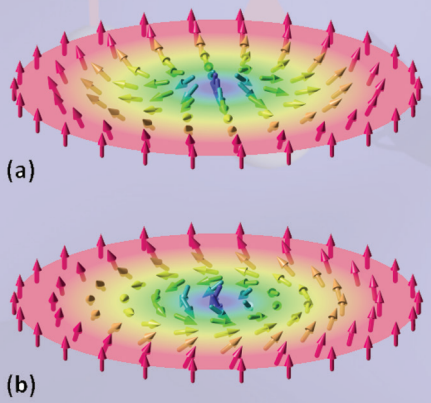
BY JENNIFER GARLAND, APPLIED PHYSICS & MATHEMATICS, 2021

PHOTOS BY WIKIMEDIA COMMONS AND NIST

Electrons have a fundamental property called spin, which can have an orientation value of ½ or -½ — up or down. Figuring out how to induce particular directions allows the spin to represent and carry information, similar to the more familiar zeros and ones of electrical charge in computer logic. The 2007 Nobel Prize in Physics for giant magnetoresistance recognized the significance of harnessing electron spin to read information from a hard disk drive: faster than traditional methods and allows information storage even after a power source is removed. This field of using the electron's spin in addition to its charge to store information is called spintronics.

Research into spintronics has risen alongside the development of nanodevices and the strive for lower power use and physical storage space. Smaller devices and lower-dimensional materials are leading to further study of materials, their quantum behavior, and methods of controlling their behavior.

Some materials can contain magnetic skyrmions — nanometer-sized swirls of spin. These swirls act like a particle and can be created, destroyed, and manipulated with electrical current or voltage for information storage.



(a) Néel- and (b) Bloch-type skyrmion

Skyrmions are special because they are topologically protected, which means that their spin configuration is preserved and resistant to structural imperfections. The center of the skyrmion has a magnetization in the opposite direction as its boundary, and flipping the orientations of many spins is difficult. This stability, arising from an effect called the Dzyaloshinskii–Moriya interaction (DMI), is needed to accurately transmit information and makes them a frontrunning candidate for use as bits among similar quasiparticles such as magnetic bubbles.

The Néel- and Bloch-type skyrmions, each with a different spin configuration, are the most common occurring in multilayer and bulk systems. Though many instances of skyrmions have been observed since their experimental discovery in 2009, there is still a search for the most suitable host systems. In order to use skyrmions for information storage, they need to be written, transmitted, and read. Each of these steps has its challenges: formation must use low energy and create very small skyrmions, transmission through the material must occur rapidly, and reading requires the skyrmions to be electrically detected.

Reading and writing skyrmions can be performed with scanning tunneling microscopy (STM). By using current pulses, defect sites can be created in materials where the skyrmions can nucleate in less than a nanosecond. Quick formation time means that information can be processed more quickly. Though the word "defect" has a negative connotation, defects are often vital to producing desired qualities in materials. Because no perfect crystals exist, the role of further defects and lattice inhomogeneities also needs to be investigated.

> "These swirls act like a particle and can be created, destroyed, and manipulated with electrical current or voltage for information storage."

Even though skyrmions are on the nanometer scale, they need to be especially small, around or under 10 nanometers, to allow for fast information transmission, high density storage, and low energy consumption. More research is needed to understand how to control the size with parameters such as the material, temperature, and magnetic field to consistently reach this goal.

Additionally, for use in devices, skyrmions must be stable at room temperature and under zero or low magnetic fields. For a while, they were only observed at low temperatures and high magnetic fields, but the first instances of skyrmions at room temperature were discovered in magnetic multilayers in 2015 and 2016.

Skyrmions have typically been found in thin films and multilayers of magnetic materials, but thin films are not conducive to actual device integration, partly because of their slow growth techniques. Previous studies have favored ferromagnetic materials, but recent research has shown that ferromagnets have limits for both the size of skyrmions and their transmission speed. Moving forward, ferrimagnetic and antiferromagnetic materials have proven more promising.

The materials development for spintronics is critical, as simpler metals that can be manipulated with less power could replace semiconductors like silicon in current electronics. Memory and logic devices that integrate magnetic storage are important for reducing energy and material consumption in our increasingly information-dense world, and these bits of spin might just be the key.

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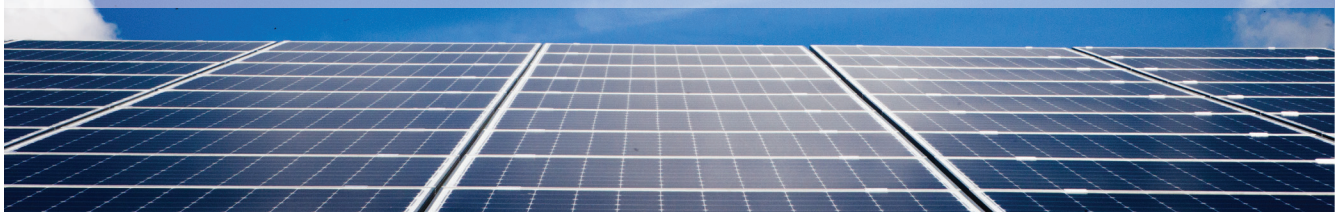
SUNLIGHT AND SEMICONDUCTORS

How quantum mechanics powers solar panels

BY ISABEL KAIN, PHYSICS, 2021

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021



The Earth is constantly awash with energy. During the day, photons literally fall from the sky, pumped out by fusion reactions in the Sun, and power countless processes on Earth. Humans have not evolved photosynthesis (yet), but a technological workaround has been developed. Solar panels now cover the roofs of homes and acres of solar farms, allowing humans to tap into this vast power source. But how do solar panels work? The answer lies in the exploitation of two fascinating phenomena of quantum physics: the photoelectric effect and semiconducting materials.

The 17th and 18th centuries saw the development of quantum theory, a physical model which describes the universe on the smallest scales. Quantum mechanics is based on the hypothesis that energy is emitted as "quanta," discrete packets of energy with a characteristic frequency – meaning that particles behave as both tiny spheres of matter and oscillating waves. Albert Einstein applied this interpretation to explain a previously mysterious phenomena, the photoelectric effect, for which he was awarded the Nobel Prize in Physics in 1921 and which launched the modern field of quantum mechanics.

Einstein's paper sought to explain the photoelectric effect, which had been observed since the mid-1800s. Experiments revealed that when sufficiently intense light strikes a surface, a spray of electrons is ejected from the material, where the intensity of the ejection is proportional to the wavelength of the light. If a voltage was applied across the material while this effect was triggered, an electric current could be induced across the material. Einstein hypothesized that the energy from each quantum of light was being absorbed by the electrons, which would be freed from the material if the absorbed energy was greater than the binding energy holding the electron in place.

> "How solar panels work lies in the exploitation of two fascinating phenomena of quantum physics: the photoelectric effect and semiconducting materials."

This easy generation of electric current had very attractive applications, and physicists set to work trying to create devices which could support this effect. They discovered that this effect was most feasibly created using a special class of materials called semiconductors.

In excellent conductors such as metals, it doesn't take much of a push to induce an electron to jump from a bound state to an unbound one, meaning electrons can flow through the material with ease. This amount of energy needed to zap an electron between states is called the band gap. Insulating materials have a much wider band gap, meaning a large amount of energy is needed for an electron to be excited from its bound state and start moving through the material.

Semiconductors have a unique version of this band gap: while it still takes a certain amount of energy to change its electrons' states, a semiconductor's band gap only allows electrons to flow in one direction. Once one electron starts to move, this single charge is amplified into a much stronger electric current.

The mechanism behind this effect is the p-n junction. Semiconducting materials come in two forms, p-type (where "p" stands for "positive") and n-type (where "n" means "negative"). Semiconductors usually contain a mix of p- and n-types, and when placed close together form a p-n junction (physicists are renowned for their creativity). N-type semiconductors have a slight negative charge because they carry more bound electrons than the material normally does; p-type semiconductors have a slight positive charge because they carry fewer electrons. These absences where electrons should be are called "holes," and act like small positive charges.

So what does the energy conversion process look like in a solar panel? On a sunny day, a photon zips from space and strikes the surface of the semiconducting material in a solar panel. If the photon is sufficiently energetic, an electron gains enough energy to escape its bound state, and begins to diffuse throughout the material. This electron may reach a p-n junction, and the negatively charged electron is accelerated from the negative n-side to the positive p-side. When these electrons are pulled away, they leave behind holes, which other electrons in the surrounding material then move to fill, creating a cascading flow of electrons. The p-n junction serves to amplify a trickle of a few electrons into a rush of electric current, which can then be collected and used.

Solar panels are often hailed as the energy solution of the future. Whether or not this is true – increasing efficiency and declining cost are drawing favor, while concerns about the toxicity of manufacturing are rising – they certainly stand as a testament to humankind's ability to harness the mysterious mechanisms of the world around us.

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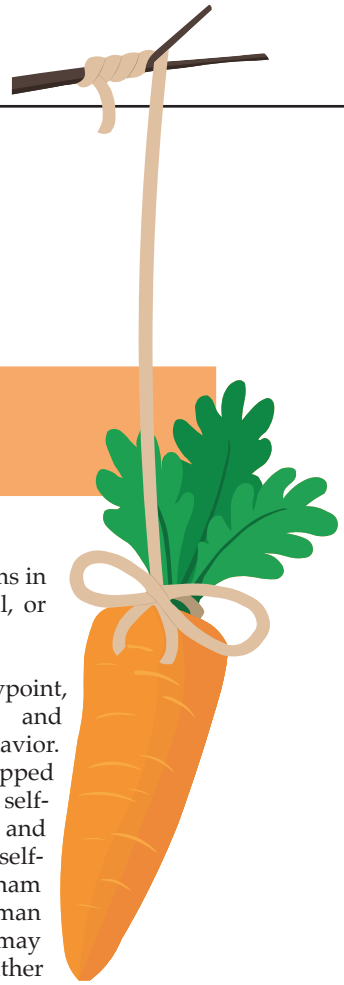
PHOTO BY FLICKR

Structure vs. agency in humans:

How much control do we really have over our behavior?

BY KRISTEN KILGALLEN, PSYCHOLOGY, 2022

DESIGN BY KATIE GREEN, BIOENGINEERING, 2021



Socialization and social institutions are structural agents that have powerful influence over the human psyche. Humans have evolved as a social, tribal species because our cooperation was beneficial for survival. In modern times, we see this play out in the desire for social acceptance and approval.

The debate lingers, however, over the extent of which society, our DNA, and our environment can override human agency. Our psychological interpretation of events gives rise to the behaviors we exhibit (whether we are aware of it or not). Much of clinical psychology focuses on our nervous system's interpretation of our environment and how we can exercise our free will to act more adaptively.

An important distinction to make is the difference between independence and autonomy. Independence implies an ability to distinguish one's self from what is prescribed, expected, or common. Autonomy, on the other hand, pertains to humans ability to self regulate and make determinations isolated from external influence. In theory, someone can be autonomous whilst choosing to be dependent on others.

The structure of society lends itself to certain behaviors, but many argue that humans are still capable of thinking differently and acting autonomously of external "shapers." This term is used by behavioral psychologists to describe processes that reinforce behaviors in subtle ways to reach a target behavior. Although it is true that the human mind is capable of thinking independently from the majority culture and separating one's self from "groupthink," our thoughts and beliefs are intrinsically connected to the experiences we have in the world. The human mind, according to Dr. Dan Siegal, a psychiatrist from UCLA, is "the emergent self-organizing process, both embodied and relational, that regulates energy and information flow within and among us." In other words, we can not separate our thoughts and ourselves from the exchange of information we have with the world around us.

From the framework of a computational model of decision making, Dr. Robert Proctor from Purdue University has ran studies that continuously outline the ways that the brain's output (our decisions and behaviors) are based upon various inputs (stimuli and information we have consciously and subconsciously processed and stored). These inputs are largely a result of our social environment. This makes our past largely influential over the decisions we make in the present, both for the individual, as well as in the broader sense of the way human cultures and societies evolve. Much of our modern understanding of learning systems in the brain is based on this computational, or information-processing model.

Some take a more deterministic viewpoint, suggesting that external influence and structures are the shapers in our behavior. However, humans are highly equipped organisms, with opportunities for self-regulation of our emotions, mindfulness, and introspection. This can lead to a form of self-actualization, which psychologist Abraham Maslov viewed as the highest form of human development. Agency, in this sense, may actually be something we develop, rather than something we are born with, as we unlearn the conditioning, socialized behaviors, and subconscious programming that largely controls human behavior on a daily basis.

Motivation and learnt behavior can stem from contextual structures, but our awareness of these structures gives humans the opportunity to make such forces obsolete. For example, if you are aware of the tactics used by advertisers in food marketing campaigns, you may find yourself being able to make a more autonomous decision at lunch time rather than unconsciously deciding you want to buy what they're selling. Of course, it is impossible to be aware of every input that has some sort of weight in factoring in our choices--once again limiting the amount of true autonomy one has--but we can work at growing our awareness of the major influences.

Whether classified as autonomous or not, every choice is influenced by either our desire for a certain outcome, or a desire to feel joy and satisfaction. We have all sorts of motivations: introjected motivation regulates our action based on guilt and the desire for social approval, intrinsic motivation comes from the inherent joy you get from a behavior, and integrated motivation comes from the desire to act in alignment with one's values. External motivation implies a lack of autonomy, but action taken from intrinsic and integrated awareness is a way individuals can exercise their autonomy and empower all of us as humans.

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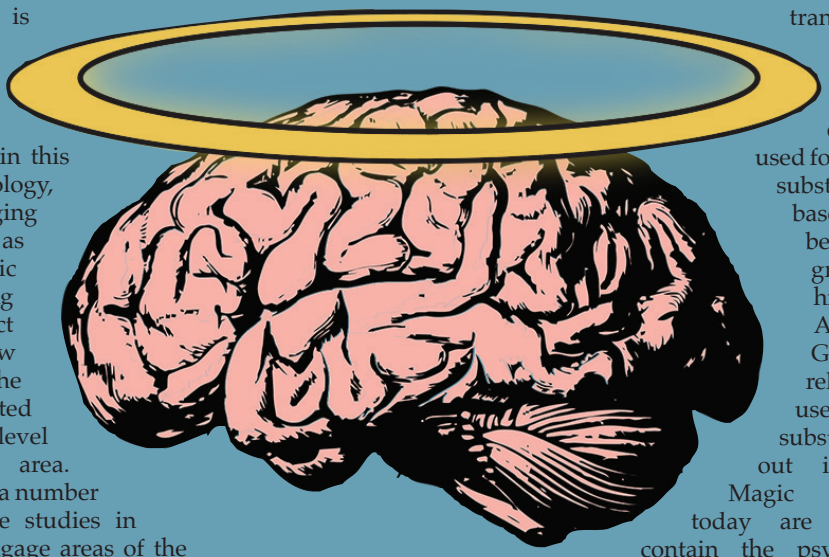
The junction of science and spirituality

BY KRISTINA KLOSOWSKI, BEHAVIORAL NEUROSCIENCE, 2022
DESIGN BY KATIE GREEN, BIOENGINEERING, 2021

Belief in a higher power, supernatural being, or divine force- though different in role and representation, consistently spans across diverse cultures and time periods. Thus, from a sociological standpoint, many have argued that human beings are innately religious. But natural scientists have long been divided over whether there is a biological or neurological basis for faith, and more specifically, religion.

Some scientists have claimed to pinpoint a 'God spot' in the brain - a chief area where religious or spiritual beliefs would be stored. In contrast, other scientists claim that the complex web of thoughts and emotions involved in religious belief is not limited to just one area of the brain. A common thread among neuroscience research in this area is their methodology, which involves imaging techniques, such as functional magnetic resonance imaging (fMRI). fMRIs detect changes in blood flow to different parts of the brain, which is correlated with an elevated level of activity in that area. Researchers have used a number of techniques in these studies in order to activate or engage areas of the brain involved in religious belief. This could be exposure to content that is designed to evoke spiritual thoughts and feelings, or simply asking them to meditate. Interestingly (and maybe somewhat ironically), there is some evidence that religious experiences can activate the same reward circuits in the brain that are activated by behaviors considered to be high-risk or taboo in our culture, such as sex and illicit drug use.



Some other areas of the brain that have been implicated are the amygdala (a part of the brain that plays a key role in processing emotions), temporal lobes (involved in vision, memory, sensory information processing, emotion, and comprehension), the Anterior Cingulate Cortex (involved in processing stimuli and assigning control to other regions of the brain), as well as several other regions. Additionally, one research study observed a decrease in activity in the prefrontal cortex, the part of the brain involved in many executive functions. Due to the complex nature of spiritual thoughts and feelings, it is likely that there are many circuits involved in the interactions between the aforementioned brain regions that are responsible for producing these types of thoughts. Some scientists hypothesize that areas of brain activation may even differ based on the particular religion or belief in question.

This research, coined 'neurotheology,' is part of a broader field of study that examines at many different levels, the relationship between the brain and theological belief. It is worthwhile to note that this area of study is not an attempt to explain away faith with science, but rather an inquiry to better understand the psychological basis of faith, and why it has persisted as part of our human nature for so many years.

An interesting aspect of this field being explored is the chemical induction of spiritual or transcendental states. In fact, there is an entire class of chemical substances called entheogens, which are used for such purposes. These substances, often plant-based, have historically been used by different groups throughout history, such as Native Americans, ancient Greeks, and aztecs, for religious rituals. The use of some of these substances has not died out in modern culture. Magic mushrooms, which today are used recreationally, contain the psychoactive ingredient psilocybin, which produces mind-altering effects when metabolized by the body. These effects can often include "mystical" experiences, which is a broad term that encompasses religious or spiritual experiences or feelings. Mystical experiences induced by hallucinogenic drugs often include feelings of sacredness, oneness with an individual's surroundings, ecstasy or deep positivity, and a transcendence of time and space. Reported experiences of this phenomena during a "high" spans users of all viewpoints, including those who would not normally define themselves as religious. The biochemical underpinnings for these phenomena are not entirely clear, but psilocybin seems to stimulate serotonin receptors, which is a neurotransmitter involved in mood, emotion, and overall happiness.

Regardless of one's religious or spiritual beliefs, it is clear that these spiritual experiences, whether naturally or chemically induced, can have fascinating effects on the human brain. Neurotheology is proving to be a piece of the complex puzzle of understanding why humans think and behave the way they do, and as a budding field that has much more to explore.

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PHOTO BY PIXABAY

THE SCHIZOPHRENIC MIND

BY BEIYU (PAM) LIN, BIOLOGY, 2021

DESIGN BY LILLIE HOFFART, ENVIRONMENTAL SCIENCE, 2022

Maycon told researchers that it started with childhood drug use: gasoline, cocaine, marijuana, and alcohol. By age 12, he began to experience auditory hallucinations, which are perhaps the most famously recognized symptom for schizophrenia. By age 17, the disease had worsened to the point where he firmly believed the voices in his head came from the devil, whispering threats to take him away. And while Maycon, who was soon after checked into urgent mental health services, is just one case study, there is no shortage of similar stories amongst those diagnosed with schizophrenia.

Schizophrenia is a serious mental disorder suffered by approximately 20 million individuals in the United States. The buildup of early symptoms—which include changes in self care, bizarre and disorganized thoughts, and lack of energy—often culminate as dissociation, or a loss of touch with reality; this is often portrayed and recognized by popular culture as a "psychotic break." While in its active state, schizophrenia commonly presents itself as delusions (thoughts or beliefs that don't make sense), hallucinations, confused behavior, and abnormal movements. Presently, there is no cure, but there is ongoing research into more and more effective treatment, which include cognitive enhancement therapy, social skills training, and antipsychotic medication. While there is progress, it's still exceedingly necessary for researchers to learn more about the intricacies of the disease in hopes of better understanding and treating it.

> "By age 12, he began to experience auditory hallucinations."

In 2015, researchers across the globe collaborated to form the ENIGMA Schizophrenia Working Group, launching a project that has proved itself to be a hallmark in schizophrenia research. They decided to tackle it from a neuropsychiatric lens by conducting a study that closely studied abnormal brain structures in patients with schizophrenia. After aggregating data from a whopping 15 study populations, they were met with incredibly consistent results. When compared to healthy individuals, it was found that in the brains of those who suffered from schizophrenia, there was a smaller hippocampus, amygdala, thalamus, nucleus accumbens and intracranial space. In contrast, they had a significantly larger pallidum and lateral ventricle volumes. The power of scientific research had discovered that there were concrete, visible differences in brain anatomy

So, what exactly do all these findings mean? It's still only a starting point to have identified the distinctions between normal and schizophrenic brain structure. The new research isn't sufficient to make any definitive conclusions about these disparities, despite the study having occurred half a decade ago. However, the study *did* show that the independent analyses done across different research labs could be corroborated through this large meta-analysis; this kind of validation lets scientists know that they are moving in the right direction. The next step in schizophrenia research is to test the effects of different treatment options and observe their impact on key regions of the brain. In addition, researchers are also beginning to combine biological and psychological research in an attempt to target novel genes for therapeutic purposes.

Despite an increase in research efforts, the main issue for patients suffering from schizophrenia is the lack of treatment altogether. The median time between the onset of symptoms and finally getting the needed treatment is an alarming 18 months; these months are critical time that could be used to decrease the impact of psychosis. Fortunately, research is already being conducted on how to properly educate the masses on early symptoms, such as through the use of social media.

There are also now a handful of specialized centers, such as CEDAR clinic in Boston, targeted at young individuals who may be experiencing early high-risk symptoms of psychosis. These types of clinics have been conducting mounting research for treatments, while simultaneously breaking down stigma and ignorance about the mental disorder. Learning about the neurobiology of the disorder is clearly beneficial, and the momentum on funding should not be halted. However, the social barriers of schizophrenia treatment are also vital factors to look into with equal curiosity and fervor. Moving forward, there is still much to do in order to adequately treat those suffering from this debilitating illness.

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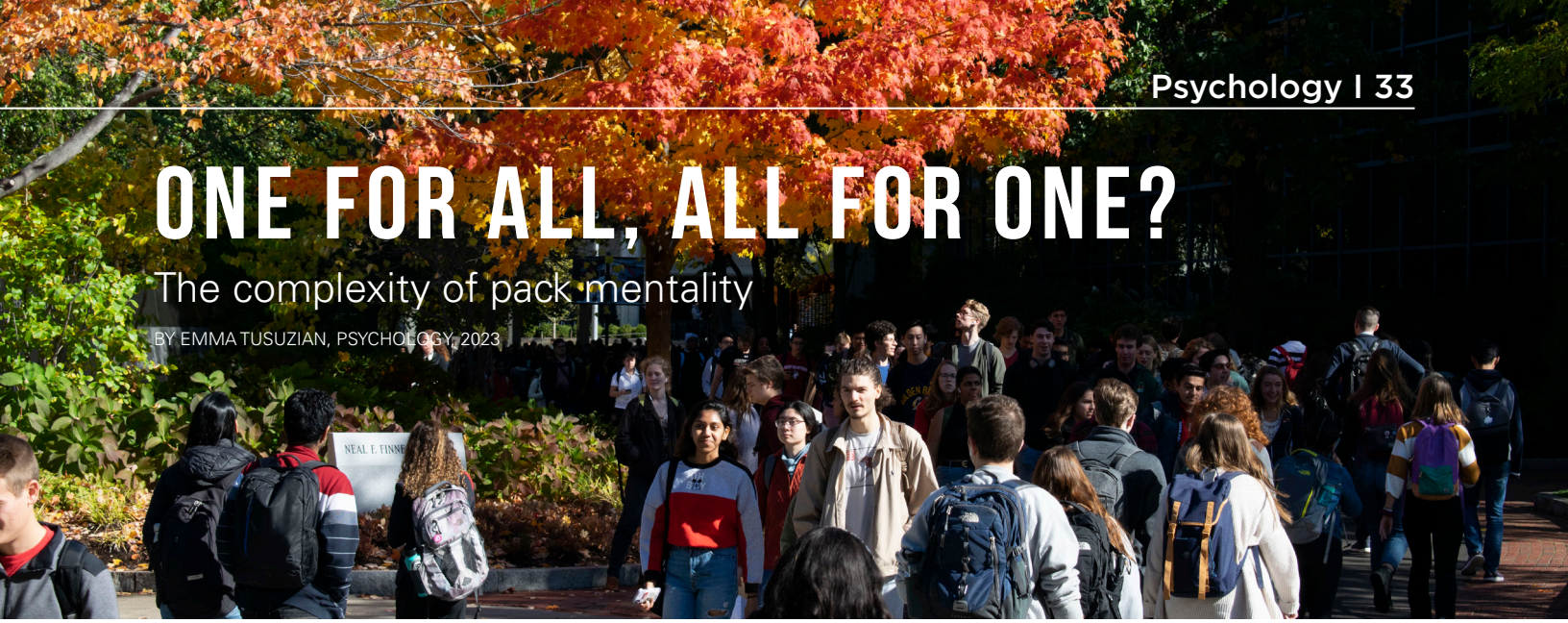
PHOTOS BY FLICKR



ONE FOR ALL, ALL FOR ONE?

The complexity of pack mentality

BY EMMA TUSUZIAN, PSYCHOLOGY, 2023

Many cultures emphasize individuality, yet our desire for social acceptance and community tempts us to conform. The term "groupthink" was initially derived from the novel 1984 by George Orwell, which describes the overwhelming social pressures that warp reality and personal morality, driving us to behave in ways we normally wouldn't on our own. Since its introduction to popular culture, a wide range of disciplines have attempted to explain our motivations for following the "pack," making our potentially dangerous decisions a question of biology, psychology, and morality.

Like splitting a bill, being in a larger group distributes the weight of responsibility among individuals. This leads them to collectively rationalize risky behavior as having fewer consequences. However, this also allows for manipulation of others in favor of the individual. Evolutionary biologist W.D. Hamilton developed the theory of a "selfish herd" to explain why animals travel in close groups. His research describes herds as the result of animals competing to be towards the center of a pack in order to avoid predators, ensuring other members of their species take their unfavorable places. Though this theory is somewhat disputed due to its dismissal of other motivations for grouping, people can also use the comfort of a group as a shield from social dangers. Cliques are potential examples of protective mechanisms for those who hide behind reputation or character of the collective. Individuals rejected from the group parallel the animals who have been left exposed to the danger of navigating alone. Applying the selfish herd theory to humans, people group together in pursuit of their own self-interest. To take on the pack rationality and earn a strong identity within it is to protect oneself from criticism or personal blame. This may ultimately result in more respectable status or other social benefits.

Since groupthink is a complex and multifaceted theory, understanding the social dynamics of a group is fundamental to interpreting each individual's motivations. We not only use groups as social protection through association, but also seek personal benefit through those around us. Pack mentality goes beyond members simply having a common agreement or conforming to certain codes. Every pack member's self-interest will alter their social standing, directly affecting group dynamics. Behaviors performed within or for a group, such as gang initiations, establish new members as those "earning" a right of passage and older members as more respectable. Research also suggests that groupthink in juvenile gang activity stems from members collectively considering their own gang stronger than a rival. Due to this exaggerated perception of their own strength, individuals may create an illusion of success, which ultimately results in real aggression. In addition, social hierarchies, both within a group and between individuals, can motivate members to be seen as more respectable. This causes them to behave in ways their group would deem worthy. Given the psychological pressures of groupthink, can social decision-making be explained by patterns of electrical and chemical signaling? A 2010 study combining literature and experimentation suggests the prefrontal cortex, a brain region critical to social decision-making, has a variety of different functions involved in pack mentality. For example, there is a region involved in valuing abstract rewards such as long-term benefits of cooperation. It also regulates emotional responses that could harm important relationships. The dorsal anterior cingulate cortex, located towards the back of the brain, works as a "social alarm signal" as it reacts to violations of social norms like deviating from group opinion or being outperformed by others. These concepts involving self-interest, group norms, and relationships are foundational to pack mentality. For instance, recognizing violations of social norms could show the strength of an individual's sensitivity or commitment to a group's standards. If neural systems can explain the dangerous decisions incited by groupthink, we may be able to understand the power of packs in a new light.

Subjects of pack mentality can be found everywhere from local gangs to corporate leaders, yet the tendency to conform can be too gradual to recognize within ourselves. Increasing awareness of such temptations could promote confidence, while biology could concretely explain patterns of perpetual conformity. Acknowledging these causes can make signs of groupthink more visible, ultimately allowing us to recognize our own misjudgments as a society.

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DESIGN BY MEGAN LI, COMPUTER SCIENCE & DESIGN, 2023
PHOTO BY ZOË SOMMERS, POLITICAL SCIENCE & JOURNALISM, 2022

THE GENDER GAP:

The most pressing structural engineering problem

BY JULIA HINES, CHEMICAL ENGINEERING, 2021

In 1950, when Mary Pottle and three other women started the Society of Women Engineers chapter of Boston, gender discrimination in engineering was rampant. Mary Pottle herself was told that her application from MIT was denied because "[her] goal in teaching was not sufficient to bump a man from the role." She decided to go to Northeastern University instead and was able to graduate as one of the first few women with a Mechanical Engineering degree. At this point, women accounted for less than one percent of the students in US college engineering programs.

The Chemical Engineering department at Northeastern recently announced that their incoming class was 50 percent female. This huge improvement from Mary Pottle's time reminds us that we have come very far. However, according to the Society of Women Engineers ongoing research, women are still facing disadvantages that prevent them from being equally as successful as their male counterparts.

> "When there are not role models or allies in leading positions, women either lose hope or are not brought into managerial positions."

The US continues to be one of the only developed countries to not mandate paid maternity leave. This in addition to the fact that women often receive a pay decrease when they have a child, whereas a man receives a pay bump, creates a general culture of frustration for all working women. The rate of women joining the workforce across all fields is declining due to these hardships. However, in the male-dominated world of engineering, they have to face even more barriers preventing them from success. In a survey by the Society of Women Engineers, a respondent said that she felt "diversity is not being embraced in a meaningful way". These sentiments are echoed throughout the engineering field where women haven't seen representation progress since 2001. As of 2018, only 13 percent of engineers in the workforce are female .

Structural issues are also a huge barrier to female success. Only 11.5 percent of engineering managerial positions are held by women as of 2019. When there are no role models or allies in leading positions, women either lose hope or are simply not brought into managerial positions. There are multiple ways in which structurally, the system is set up to disadvantage women. Listing just a few: lack of paid maternity leave, lack of affordable child care, a wage gap between men and women in the same roles, and the culture around sexual assault. For progress to be seen in the engineering field, structural changes need to be made.

Fortunately, many initiatives have been started to kickstart this change. Groups like the Society of Women Engineers and IEEE Women in Engineering allow for women to find peers and mentors. In addition, many local STEM initiatives target middle and high school girls, such as Northeastern's student-run organization Bits & Bots and its service-learning robotics Cornerstone of Engineering class. These have seen progress, but it is slow. International programs have also seen success; the UN program STEM and Gender Advancement has provided students worldwide with materials and opportunities to explore science and technology. Despite the great work of these organizations, a stigma and culture favoring men in the engineering sector still exists that can be hard to ignore as a woman starting her career.

Recently, engineering co-op classes at Northeastern have added lessons on microaggressions and bias. These lessons are able to educate new workers entering the workforce on the issue of implicit biases, but there is still a large population of older workers that have kept their ideals and attitudes outdated. Although a hard task, for this gender gap and disctrimination to stop, the structure and culture of the engineering field needs to change completely. With the stagnation of improvement since 2001, the new local and international initiatives will hopefully start making a statistical difference soon.

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PHOTO BY PIXABAY

The defeat of Olympians

How Olympic venues impact surrounding environments

BY CARA PESCIOTTA, PHYSICS, 2022

As Tokyo prepares to host the 2020 Summer Olympic Games, the city plans to spend $25 billion to accommodate 33 sports and an estimated nine million attendees. Arenas will be filled with national pride, traditional ceremonies, and lifelong achievements—but what happens to the fame and fortune once the Olympic flame is extinguished?

For many veteran host cities, the answer is nothing. Venues costing millions of dollars in design, construction, and maintenance are abandoned—being used just a handful of times. Economic risk, though, is only part of the problem. The process of building an Olympic city can be detrimental to the surrounding environment and community, leaving behind ravaged land and displaced citizens.

With miles upon miles of land to develop, Olympic cities take a huge toll on biodiversity. Habitats are destroyed, food sources decline, and animals are forced to find new homes; landslides and mudflows become more prevalent as well due to the absence of trees to secure soil.

The 2014 Sochi Winter Olympics are among the worst of Olympic past, despite their promise of a "zero waste" Games. Dr. Suren Gazaryan, a zoologist associated with the Environmental Watch of the North Caucasus (EWNC), cites incidents of illegal waste dumping, construction blocking animal migration routes, and limited drinking water access for locals.

Another Olympic tragedy occurred in Rio de Janeiro, where over 50,000 people from local communities were displaced to make room for luxurious venues. From "flash evictions" to withholding information, residents were neglected during construction and often not given proper compensation to make up for losing their homes. This caused many to move into low-income housing in suburbs with little infrastructure, "demonstrating that rather than benefit from urban improvements, those displaced suffer their impacts," according to the Norwegian Refugee Council and International Displacement Monitoring Centre. Due to lack of funding from the Brazilian government, maintenance of the 2016 venue has been put on hold, leaving arenas to rot.

While many cities have dropped the ball on environmental and societal sustainability, some have taken proper care to avoid the downfalls of their counterparts. Cities like Sydney and London implemented green infrastructure during the games, employing free public transit and solar energy, while also planning ahead to ensure a sustainable future.

Sydney's 2000s Olympics led to the creation of "Australia's first large-scale urban water recycling system, which continues to save approximately 850 million litres of drinking water each year," as reported by the Olympics website. In addition to this ongoing project, the city remodeled venues for commercial and residential use.

A little over a decade later, London's Olympic Park was built on once-contaminated industrial land, repurposing an otherwise deteriorating landscape. What could be built as temporary was, and what could not was promised to be offset using other sustainability tactics. After the games, London has transformed its Olympic Park back to greenspace and revitalized the canals and rivers running through it.

For many years, host cities were selected based on who could spend the most money to put on the most elaborate games (hence Sochi's $51 billion bid). As societies begin to value sustainability over flash, Japan is expected to act as a turning point in how the Olympics are run. To eliminate a large portion of monetary and environmental costs, 25 preexisting structures will be utilized, leaving ten temporary and eight permanent venues to be built. Japan also promises to use native plant species in their landscaping and recycling rain and wastewater. In the coming months, it will become evident if Japan can uphold these commitments or if the Tokyo Olympic Park is destined to become yet another abandoned venue.

> "As societies begin to value sustainability over flash, Japan is expected to act as a turning point in how the Olympics are run."

The Olympic Charter states "the goal of the Olympic movement is to contribute to building a peaceful and better world by educating youth through sport practiced without discrimination of any kind and in the Olympic spirit, which requires mutual understanding with a spirit of friendship, solidarity and fair play."

For the Olympics to not only speak with their words but with their actions, a conscious effort must be made to protect environments and communities across the world. This means respect and transparency with a host city's citizens, affordable expectations for governments, and meticulous planning to guarantee minimum ecological impact before, during, and after the games. Over 100 years after the modern-day games' conception, it is time the Olympics fully exhibit the ideals of peace and education they preach.

DESIGN BY MEGAN LI, COMPUTER SCIENCE & DESIGN, 2023
PHOTOS BY PIXABAY

Life: In ruins

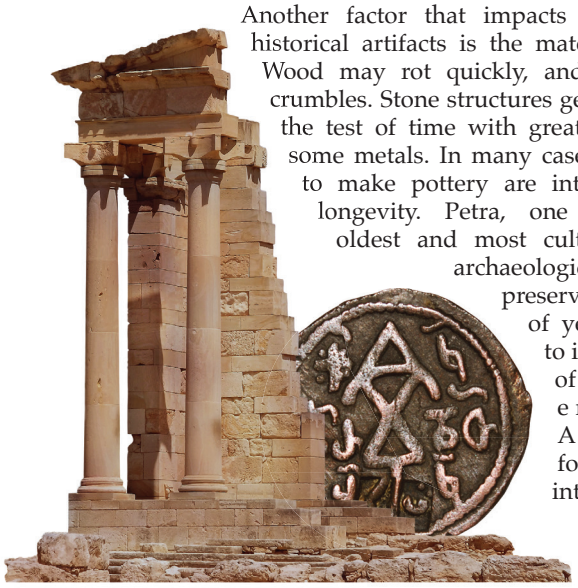
BY HEATHER WELCH, ENVIRONMENTAL SCIENCE, 2020

A skull here, a coin there, the foundations of an ancient home — the study of archaeology reveals to modern societies how their long gone counterparts lived and related. In 2019, a recently discovered site in Idaho inspired a study, which postulated that the first people who arrived on the American continents did so at least 16,000 years ago by boat. But how do artifacts and structures, such as the ones that provided this information, survive hundreds to thousands of years until someone luckily happens upon them?

Remains such as pottery, paintings, buildings, and bones are, in fact, often broken or damaged when discovered by archaeologists. Many natural processes, including sunshine, precipitation, animal interference, and bacterial breakdown, can jeopardize the condition of artifacts. However, some factors can improve the chances of surviving erosion, rust, rot, and warp.

> "Cities and settlements have constantly been abandoned, knocked down, and then covered by new structures."

A few processes, including deposition of sediments from floods or volcanic eruptions, can preserve materials by providing a protective layer. This phenomenon infamously occurred in the Italian city of Pompeii, which was destroyed in A.D. 79, and rediscovered in the mid-18th century. The fine-grained volcanic ash produced by the tremendous volcanic explosion encased the city so tightly that archaeologists have been able to unearth intact glass jars still containing fruit. Pompeii's intricate and colorful interiors were so well preserved that, upon their discovery, their portrayal further inspired the revival of neoclassical art and architecture in Europe.



Another factor that impacts the longevity of historical artifacts is the material composition. Wood may rot quickly, and mudbrick often crumbles. Stone structures generally withstand the test of time with greater success, as do some metals. In many cases, processes used to make pottery are integral to material longevity. Petra, one of the world's oldest and most culturally significant archaeological sites, remained preserved for thousands of years partially due to its structural usage of the Jordanian environment. Archaeologists found Petra carved into the landscape's red sandstone rocks, and surrounded by protective mountains that helped the city remain undiscovered and undisturbed by humans. However, the ancient structures still face threats from ongoing erosion, flash flooding, and tourism.

The environment in which an archaeological site exists also affects the extent to which the site is buried and preserved. The composition and thickness of the topsoil layer, as well as its rate of accumulation, have a large impact on how quickly a site is buried, and what reactions the material may have with biological factors. The Inachos River watershed in Greece was the subject of a study that proposed a statistically significant relationship between surface erosion and artifact distribution. The conductors of the study further postulated that mountainous and semi-arid regions, like the Inachos River watershed, are particularly vulnerable to erosion. Subsequent soil loss affects the elements and processes to which the artifacts and structures are exposed. Soil accumulates quickly on a floodplain as water deposits sediment that gradually settles in the flooded areas. In sand dunes, blowing sands rapidly bury ancient sites. The Great Sphinx, excavated in the early 1900s, required experts to painstakingly uncover the monument from massive amounts of Egyptian sand.

When a new civilizations rises, remains of the old civilization (e.g. foundational structures, family belongings, city waste, etc) may be buried underneath, and protected by the layers conveniently built on top of them. The famous tells of the Middle East, known as artificial mounds of mudbrick and societal refuse reaching up to 30 meters high, formed in this way. The mounds formed when successive generations living in the same area accumulated layers of crumbled mudbrick over thousands of years. Essentially, cities and settlements have constantly been abandoned, knocked down, and then covered by new structures. In the past, the foundations and rubbish of previous civilizations often remained due to the inability to effectively remove it. Thus, cities eventually raised their elevations as new generations built over old.

It remains to be seen what will be built upon this generation when it fades away.

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PHOTOS BY PIXABAY AND WIKIPEDIA

Building towards the future:

Alternatives to climate-killer cement

BY GABRIELLE HERNANDEZ,
BIOCHEMISTRY, 2022
PHOTOS BY PIXABAY

Looking at a map of the United States, one sees a winding path of arteries spreading up the Pacific Coast, through thousands of acres of farmland, and circling cities like Chicago, New York, and Boston. The more than four million miles of highways that span the United States link together a backbone of manufacturing, production, tourism, and commuters that make up the American economy. But the highways that created a streamlined way to move things from California to Maine could very well also be the downfall of the economy.

The impact of climate change will have an irreversible effect on the Earth. But while many focus on cars, planes, and single-use plastic, we forget a large contributor—cement. Surprising to any non-mechanical or material sciences majors, the process that goes into making one of the most popular forms of cement, Portland cement, is high energy and highly emissive. Cement is primarily made up of clinker, a type of carbonate that typically comes in the form of limestone. In the reaction that decomposes these carbonates, significant amounts of heat and carbon dioxide are necessary. In order to create 1000°C of heat needed for the reaction, the fossil fuels burned in the process also contribute to the overall emissions of the reaction. Ultimately, the Center for International Climate Research in Norway concluded that the cement industrial process contributes to approximately 8 percent of human-caused carbon dioxide emissions, which is rising with the growing demand for cement around the world.

Despite this underground climate contributor, scientists across the world are already up to the challenge. One group of scientists from Madrid and Brazil evaluated the use of the expanding agricultural industry to supplement a percentage of the carbon emissions caused by cement. The material they chose to investigate was the burned remains of elephant grass. Elephant grass ash, which can be used to replace 20 percent of the composition of cement, maintains a similar mechanical behavior and texture, creating a partial substitute for the high energy reaction. Another exciting alternative out of India is Ferrock, a "carbon negative" material that could completely replace Portland cement. Made of upcycled iron dust and fly ash, two waste byproducts of the iron and coal industries, this material was substituted for portions of concrete and tested for consistency, compressive strength, and tensile strength. Ultimately, Ferrock stood up to the test and proved to be a possible alternative to concrete.

While cars shift from gasoline to electricity, and electricity shifts from coal to solar and wind, the infrastructure industry will also need to find an environmentally-friendly alternative to cement.

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REDEFINING THE "CONCRETE JUNGLE": The green building revolution

BY SHELLEY SEUNGHYE JEON, PHARMACY, 2025

Amid increased concern over a decaying planet, the oxymoronic idea of a "green building" has been perpetuated by architects, environmentalists, and city-planners alike. According to the World Green Building Council, green buildings can be any structure that reduces environmental damage and promotes the conservation of Earth's climate and natural environment. They can be 'green' in their design, construction, or operation and may possess state-of-the-art technical features such as the efficient use of energy and water, renewable energy, and sustainable materials. Green buildings are also flexible in their architecture and tend to be uniquely aligned to a region's distinct climate, culture, or socioeconomic priorities. Though one may typically associate the monotonous assembly of concrete with building, the new era of green buildings is redefining the process behind building to be fluid, updated, and creative.

For instance, consider the structure of Northeastern's Interdisciplinary Science and Engineering Complex (ISEC), a LEED gold certified building designed to use 78 percent less energy than a standard intensive research building. According to Payette, the Boston-based architecture firm that designed ISEC, the concept for ISEC was Flow and Movement, an appropriate theme that effectively characterizes the building's momentum in both expanding the Northeastern campus and connecting the Roxbury, Fenway, and Back Bay neighborhoods of Boston. From its signature solar veil to the daylight-filled atrium, daylighting controls, and its construction with recycled aluminum materials, the building is simultaneously timeless and cutting-edge, rigidly designed yet fluid to the eye. This two-fold aspect of the structure is appropriate considering the conglomeration of culture and innovation that is concomitant to conducting scientific research in a historical city.

The green building revolution began in the early 1990s and has since proliferated into a global movement for "green districts." The consulting firm McKinsey introduces green districts as an expansion of green buildings that are "small enough to innovate quickly, and big enough to have a meaningful impact" on both economic and environmental terms. However, in order for the transition to green districts to be feasible, a level of coordination beyond that of city-planners and architects is required. The creation of green districts surpasses the structural capacity of a building and contains an inherent pressure for the residents of these structures to live more environmentally conscious lives. Hence, amidst the ingenious structure of many green buildings, including those on Northeastern's campus, therein lies a haven not only for research and innovation, but for global citizens cognizant of their responsibilities to the environment.

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DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

FRACTAL CITIES:

Looking more closely at chaotic design

BY LAUREN MACDONALD, ENVIRONMENTAL SCIENCE AND CHEMISTRY, 2022

DESIGN BY KRISTI BUI, COMPUTER SCIENCE, 2021

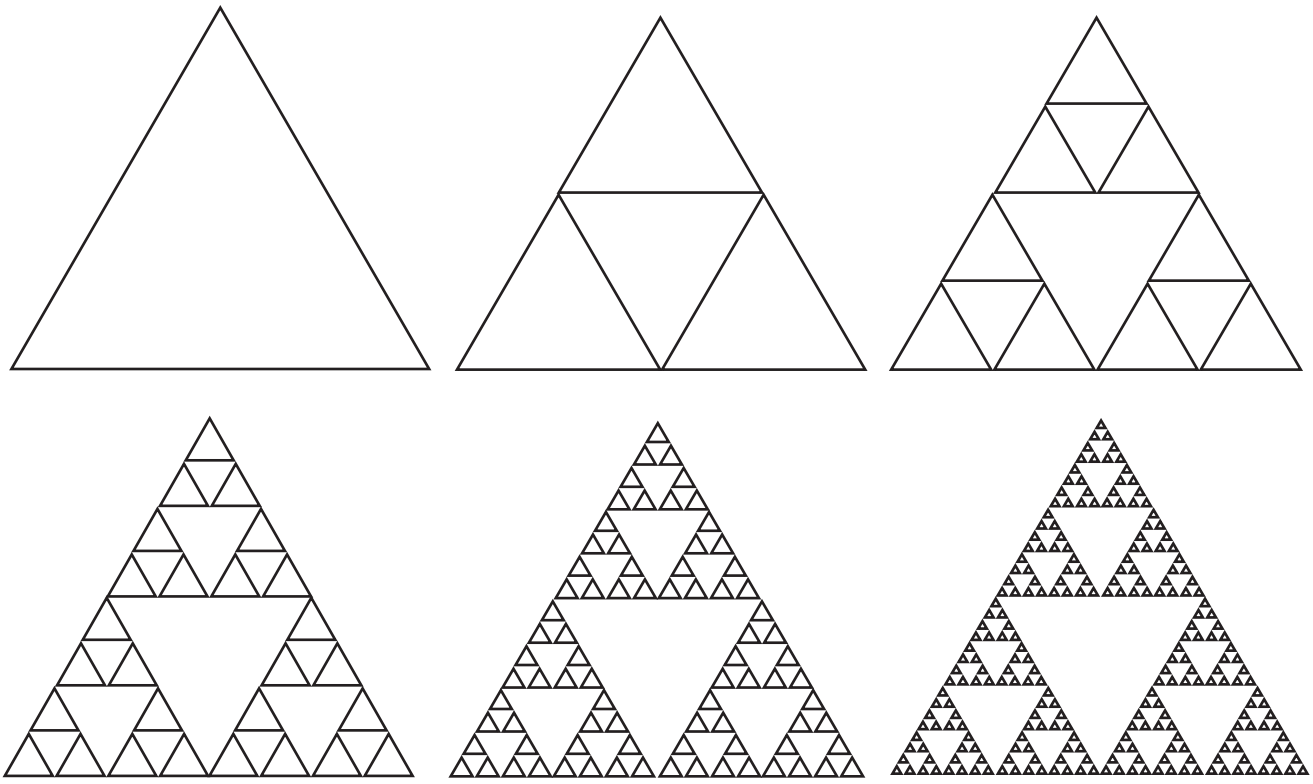
Navigating an older city can be confusing and harrowing, with winding alleyways and impossible shortcuts. But despite their chaotic reputation, cities like London, Paris, and Berlin are actually extremely well-organized when viewed through the lens of fractals.

Fractals are defined as recursive geometric figures that can be modeled mathematically, where each iteration of the fractal is mathematically similar to itself. That is, if you were to zoom in an infinite amount, the fractal would still appear identical. Fractals are present in nature (in snowflakes and conch shells), can be used to predict biological growth, and are frequently used in art by painters such as Jackson Pollock. They are also used in computer modeling systems to create complex computer-generated image (CGI) backgrounds that look realistic, as well as other computational uses.

In order to create a fractal, a model would start with an initiator shape (Image 0). The initiator would then be replaced with an altered version, called a generator shape (Image 1). After the alteration, any part of the image that is mathematically similar to the initiator shape will be replaced by the generator. Repeating this process infinitely will generate a fractal. (The fractal in Image 4 is the well-known Sierpinski's Gasket.)

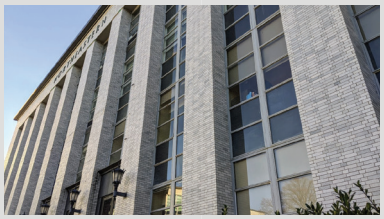
From a macro perspective, fractals can often seem just as chaotic and confusing as older cities. But when you zoom in, you find that there is actually a high degree of order present in the self-similarity. The world's oldest cities—ones that were built without modern urban planning—fit this definition. When cities were first built in medieval times, they were designed with the intention that everyone could easily walk to everything they needed. Housing, shops, bathrooms, recreational facilities, and all other necessities were organized around central hubs. As the city grew, more space was needed. These small modules of all the necessities grew outwards, forming a maze-like city full of tiny alleys interconnected by larger central pathways.

In this way, older cities simulate fractal growth. Stereotypically "structured" cities like New York fail to have the same detailed organization as fractal cities. Today, we are used to navigating and understanding block cities because they make sense on a macro scale, but ancient cities were built on the micro scale when the only mode of transportation was walking. So, counterintuitively in the present day, these chaotic cities can be just as organized and easily understood as New York.



Built in Boston

BY ERICA YEE,
INFORMATION SCIENCE &
JOURNALISM, 2020



Northeastern's evolving architecture

The original master plan for Northeastern University in 1934 aimed to distinguish the university from the look of Harvard buildings, which drew from early American and English traditions. Architects decided on an austere, light gray brick design, as exemplified by the oldest buildings on campus such as **Ell Hall** (1). As Northeastern expanded in the subsequent decades, later architects incorporated elements of neighboring buildings, like the brick and concrete trim combination of **Kariotis Hall** (2), built in 1982. Opened in 2017, the **Interdisciplinary Science & Engineering Complex** (3), aims to symbolize the school's future as a prominent research institution. The building's surrounding pathways also help facilitate walking, biking and mass transit as they connect Boston's Fenway and Roxbury neighborhoods.

This map shows Boston's over **120,000** buildings, based on estimates from city data.

There are **60** colleges and universities within the city proper, all with their own campus layouts and styles.

Sources: Analyze Boston (data.boston.gov), ***AIA Guide to Boston*** *(3rd edition, 2008)*

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