
I,SCIENCE
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I, SCIENCE
THE SCIENCE MAGAZINE OF IMPERIAL COLLEGE

FRONT COVER ART:
NANDHIT VASANTH
ORGANIC BOTANIC

BACK COVER ART:
FAYE SAULSBURY
WILDFLOWERS

I, SCIENCE

DEAR READERS,

This year marks 30 years of Science Communication at Imperial College, so it seems right that for our final print issue of the year, we have chosen joy.

Though some may see the pursuit of science as devoid of emotional involvement, students here at Imperial no doubt know that this could not be further from the truth. Science is often a great source of joy and wonder, and scientists count amongst their goals the pursuit of knowledge, health and prosperity. Through collaboration and the appreciation of a shared mathematical language, science is able to connect us with an order that is greater than any single individual.

While it is important to take a positive outlook, articles in this issue also point to examples where science falls short. What is the science behind negative feelings? How can we increase access, equality and liberation in science? Science Communication is and will continue to be fundamental to addressing these issues.

Thank you for supporting *I,Science* this year. We're excited to welcome the incoming team, and know the best is yet to come!

JACKLIN KWAN AND FAYE SAULSBURY
EDITORS-IN-CHIEF 2021 - 2022

We are always looking for new contributors for both the magazine and online. If you would like to get involved as a writer, illustrator or photographer, please get in touch.

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News

JOHN BADER

Imperial College London ranked 6th best university in the world

We can confidently say that 2022 has already been a great year for Imperial!

Imperial College London was ranked as the sixth best university in the world in the QS World University Ranking for 2023. This puts the College one place higher than last year's ranking, as well as third in the UK and top in London. This world-leading ranking is the result of the collective efforts of students and faculty members that were commended and recognised with honourable awards over the past year.

"These results reaffirm that Imperial is one of the best universities in the world. Our success is rooted in our global outlook, our diverse community and the spirit of collaboration that runs through everything we do," said Professor Alice Gast, President of Imperial College London.

Among the numerous awards collected over the past year is the Queen's Anniversary Prize, the highest national honour awarded in UK further and higher education. The award recognises outstanding work that benefits the public and wider world. Imperial College was particularly commended for its exceptional response to the COVID-19 pandemic.

Earlier this year, the College was ranked top in the country for research in the UK's Research Excellence Framework (REF) 2021, an expert panel that assesses research quality and output among UK higher education institutions. Imperial College ranked top in the UK for research output, research environment and research impact among Russell Group universities. The results of the assessment are the highest-ever achieved by the College, showing unceasing improvement and dedication to its academic mission.

"I am very proud of all the incredible people who have helped Imperial to achieve this success through their creativity, ingenuity and perseverance. The ideas they explore and the impact they deliver is at the heart of Imperial's ethos. Their dedication to our academic mission continues to attract students and researchers from around the world," said Professor Ian Walmsley, Provost of Imperial College London, acknowledging the remarkable contributions of Imperial's students and faculty members.

QS World University Ranking takes a wide range of criteria into account, including research output and contributions, as well as diversity and inclusivity. These awards, among multiple others, have resulted in an excellent QS score of 97, putting Imperial College among the world's top leading universities.

Light up Queen's Tower, the celebrations are about to begin... and keep up the great work!

A four-day work week: a dream finally coming true?

Long weekends just got one day longer for over 3,300 employees around the UK in the biggest four-day work week trial ever conducted.

June 7th, 2022 marks the beginning of a four-day work week trial for over 3,300 employees from 70 companies around the UK. This trial, the biggest ever conducted in the world, will assess the impact of reducing a work week from five to four days on various aspects of life, including health, wellbeing and energy levels.

The concept of a four-day work week is based on the commitment model of 100-80-100. This model guarantees that employees get 100 per cent of their pay for 80 per cent of the time they used to work, in return for 100 per cent productivity. The ongoing trial will be testing the applicability of this model, as well as its efficacy and impact on both employees and their work.

The results of the trial, initiated by 4 Day Week Global alongside other organisations, will be assessed by researchers from Cambridge University, Oxford University and Boston College. "We'll be analysing how employees respond to having an extra day off, in terms of stress and burnout, job and life satisfaction, health, sleep, energy use, travel and many other aspects of life," explains economist and sociologist Juliet Schor from Boston College, the project's lead researcher.

As the concept seems to be gaining momentum, 4 Day Week Global will be running a similar trial in Australia and New Zealand later this year. An earlier trial had already been carried out in Iceland but on a smaller scale than the one being currently conducted in the UK, involving around 2,500 employees. The results were promising as they indicated numerous benefits to employees, and no significant drop in productivity.

While employees' wellbeing and work productivity are the main elements of the trial, the environment might be an indirect beneficiary. Research suggests that by reducing work hours we may be able to reduce CO2 emissions, one of the main factors contributing to the ongoing climate change crisis.

"The four-day week is generally considered to be a triple dividend policy – helping employees, companies and the climate," Schor says. "Our research efforts will be digging into all of this."

Just out of curiosity, will Thursday become the new Friday, or will Monday become a chill Sunday? ■

The countdown to Webb's first full-colour images begins

After 25 years of innovation, invention and perseverance, and many milestones along the way, the James Webb Super Telescope is ready to rewrite space history!

"We are on the precipice of an incredibly exciting period of discovery about our universe. The release of Webb's first full-colour images will offer a unique moment for us all to stop and marvel at a view humanity has never seen before," says Eric Smith, Webb program scientist at NASA Headquarters in Washington.

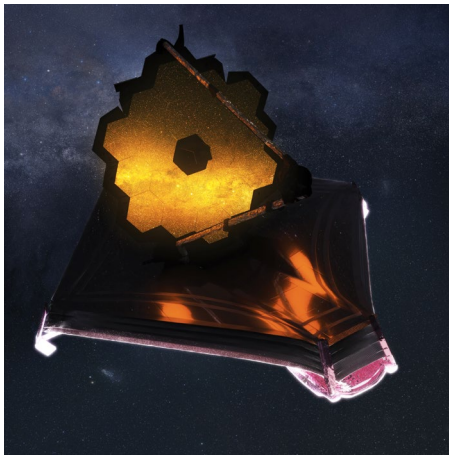
On July 12th, NASA will be releasing the first full-colour images captured by the most powerful telescope ever launched into space. The James Webb Super Telescope, launched on December 25th, 2021, is currently orbiting the Sun at a distance of 1 million miles from Earth. In its aptly assigned orbit, Webb is collecting the faint infrared signatures from the earliest stars and galaxies born after the Big Bang to unravel one of the biggest mysteries of the universe, the origins of life.

In our ever-expanding universe, light from the first exploding stars has been travelling in space since the event that set off the cascade of explosions and formations that lead to our being here today. Due to this expansion, light stretches along the way shifting from short waves of UV light to visible light to longer waves of infrared light. This phenomenon, known as cosmological redshift, will allow Webb to detect the invisible infrared light emitted by the most distant stars and galaxies billions of years ago.

The deeper Webb gazes into space, the further back in time we will be able to see. With its advanced unprecedented instruments, the telescope is off on a promising mission. From the moment it detached from its launch rocket, technicians and astronomers have been orchestrating a well-rehearsed series of deployments that will take the telescope from its folded position to becoming the biggest human-invention in space.

In order to fulfil its mission, Webb is equipped with a 21-foot-wide mirror, which is made of 18 hexagonal smaller mirrors that can be remotely adjusted to achieve the sharpest focus possible. It is also shielded from the heat of the Sun, Earth and Moon by a five-layer sunshield the size of a tennis court. This sunshield is key to keeping Webb at -266 degrees Celsius for optimal performance. Otherwise, the heat of the telescope or other nearby objects will mask the infrared light reaching from the early beginnings of the universe.

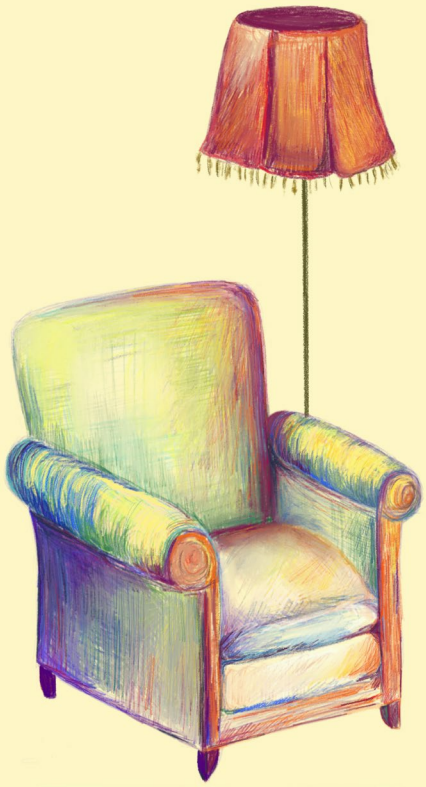
Six months into its mission, Webb has already gone through numerous milestones, from launching on a million-mile journey to its orbit, to unfolding into its fully deployed position, yet its journey back in time has just started. The telescope is expected to operate for 10 years, during which it will capture images of infant stars and galaxies and rewrite the story of our existence.



ARTIST'S CONCEPTION OF THE JAMES WEBB SPACE TELESCOPE

"These images will be the culmination of decades of dedication, talent, and dreams – but they will also be just the beginning," – Eric Smith, Webb program scientist at NASA Headquarters in Washington. ■

John Bader is an MSc Science Media Production student, and is the News Editor for *I,Science*.



Why I write

FAYE SAULSBURY

As we prepare this issue of *I,Science* — the 52nd in its history and my last as Co-Editor — I find myself thinking hard about communication. Over the year, I have been lucky to meet a number of former Editors-in-Chief. It strikes me that in our conversations, what keeps coming up is not the layouts we designed or the topics we covered, but the joy we found in the connections we made.

I leave *I,Science* feeling that communication is, at its root, about joy. But that is not where I began.

This year marks the 30th anniversary of Science Communication at Imperial. The course here is about practical skills – interviewing, filming, exhibition design – but it is also about reflecting upon what it means to communicate. Why do we communicate? Who do we communicate for? How do we communicate well?

At the start of the year, we were asked to define 'communication.' The first image that came to my mind was a blue text bubble swooshing from my phone to someone else's. It was an easy way to visualise the movement of information from one person to another. It told me that communication is about transmission. We do it because it is practical: people who know more swoosh information off to people who know less, and everyone benefits from more people having more knowledge.

But that idea was not wholly satisfying. Not least because it implied a hierarchy which suggested that communication could only go one way. It did not fit with the conversations I had had with *I,Science* editors, who remembered making friends, not transactions. When we send a text, we hope for a reply, not just for our message to be received. Communication must somehow continue after we hit send.

And there was something else that needed to be accounted for, something emotional and unquantifiable. The transmission metaphor did not answer questions like: why does being lost for words make me feel so restless? What is it about finding them that brings me calm? Why have I been scribbling stories down on paper since before I was in primary school? Certainly, at that age, nobody told me to.

> "...we have a duty to communicate, because knowledge is most valuable when it is shared"

Communication, then, must have been about more than passing information to other people.

There was a joy in sharing stories about my imaginary friends, giving them voices and drawing them to life in the margins. And although it has been a long time since Twizzles the turquoise monkey or Wavey the dolphin have gone on any adventures, there remains a joy in sharing stories and expressing ideas – parts of me – with other people. That is why it is so frustrating to be unable to articulate how I feel. It is why former editors remember most fondly the friendships they made, not the magazines. It is why I write.

Transmitting information is practical, but it is not where we find joy. For me, joy exists in the formation of the message, not the message itself. It can be found in the knowledge we gain from connecting ideas and in the people we ask to help us. Virginia Woolf said it best: *it is the writing, not the being read, that excites me.*

Back in the Science Communication department, each of us is trying our hand at different forms of communication. Although we come from varied backgrounds and each have our preferred media, we are all here because we want to learn how to express ourselves and our ideas: to be communicative. I am sure the first Science Communication students, 30 years ago, would understand.

In a democracy, we are all free to communicate. In fact, I am tempted to go further, to say that we all should communicate, because knowledge is most valuable when it is shared. Of course, in a democracy, we can never guarantee that anyone will listen. But that is only part of the goal. We communicate to create connections for ourselves, as much as for others. ■

Faye Saulsbury is studying MSc Science Communication. She is also *I,Science* Co-Editor-in-Chief.

INGRID ESPINOSA
SERENDIPITY

Science at play
The neuroscience of improvisation

INGRID ESPINOSA

PHOTOGRAPHY BY **INGRID ESPINOSA**

Dr Allyn Lomboy is on the six-hour trip from Manila back to Dagupan, Pangasinan, a city in the north of the Philippines. The "MD" sticker at the back of his car shows he is a doctor – a gastroenterologist to be precise – and such specialists are often few and far between outside of Manila. However, he is not driving home from his clinic.

Instead, he is rushing home from his weekly journey to Ortigas, where he has just been pretending to be an astronaut fighting off an alien invasion, armed with marshmallow machine guns. Dr Lomboy is a weekly student of improv theatre.

Dr Lomboy is one of millions of students of improv, whose day jobs include scientists, engineers, corporate managers, entrepreneurs, healthcare professionals, teachers, musicians, and of course, actors. Improv is one of those things everyone has heard of, has been dragged to see an amateur production of, or dazzled by an actual good Show. Many esteemed actors include improv in their long list of skills, and any film buff can give you at least five movie scenes that are famously off-script and improvised.

But what is it about improv that pulls people in? How does gifting your friend an elephant in a jewellery box from an infinite chest make any sense? How does it make you happy, and perhaps, even help you at work?

As always, cheeky scientists try to come up with an answer. Researchers Charles Limb and Allen Braun designed some magnet-proof keyboards, hired a jazz quartet, and used fMRI scans to look at the brain during jazz improvisation. The patterns that researchers found showed decreased activity in the dorsolateral prefrontal cortex, considered our "inner critic" as it manages inhibition, planning, and cognitive and emotional regulation and control. Improvisation also increases activity in the medial prefrontal cortex, thought to be part of the brain that learns associations and adaptive, particularly emotional, responses. That is, it's in charge of making creative connections and finding different ways to respond. In short, jazz musicians seemed to be more creative when they were improvising. Braun later followed up the study with freestyle rappers and saw similar results. Braun's fMRI technicians must be either very pleased or annoyed with the unique concerts they've been attending in the lab, depending on their music taste!

Another study saw a decrease of activity in parts of the brain among improvising musicians - a similar pattern seen during "goal-directed behavior". This can be interpreted as what some might call a "flow state", where one is totally focused on what they're doing that everything else fades away. Think of Joe the jazz saxophonist and the glow around everyone "in the zone" with their passions in the Pixar movie *Soul*. Or even just the last time you lost track of time doing something you love. Improv might just help you do get into that state of mind.

"Dr Lomboy is one of millions of students of improv, whose day jobs include scientists, engineers, corporate managers..."

More recent studies have also looked into improv to help adolescents deal with developmental trauma and improve the brain's ability to adapt and make meaningful connections with others. How's that for a recommendation from your counselor?

"Improv," he says, "is venturing into the unknown... [it] isn't about mastery, but exploration, with more and more tools along the way. Like science!"

Improvising in creative fields is an obvious win — but how did doctors, engineers and businessmen get into it?

Perhaps not to the level of a Hugh Dennis or James Acasterat the watercooler, improv has been associated with increased creativity, openness, and coping — which makes it prime material for organizational development. Some go so far as to consider companies as a big improv theater, with the techniques being used to solve corporate challenges. Beyond the cubicle, improv has also been deployed in preparing for disaster scenarios, and in training healthcare professionals and educators. Besides, where else might a hitherto incredible situation like say, a global pandemic, come up? Especially at a light enough setting for play and not panic?

Scientists, with their rigorous tests and standard methods, are no exception. Aree Witolelar is an Indonesian neuroscientist at the University of Oslo; and if that isn't impressive enough, he's also been doing improv for 15 years and founded Impro Neuf International, an improv community of more than 1,000 players. His two loves have their differences, but they also have their similarities. "Science needs logical steps, whereas improv is jumping around," Witolelar says. "However, both are all about finding patterns. Improv is making associations we didn't see before, which can be either funny, surprising, or even reflective." Though his interest started with the popular show *Whose Line Is It Anyway?*, he's continually "jumped in" and explored different lands of improv – from comedy, musical, and now cultural representation improv. "Improv," he says, "is venturing into the unknown...[it] isn't about mastery, but exploration, with more and more tools along the way. Like science!" ■

Ingrid Espinosa is studying MSc Science Communication. She is also sub-editor for *I,Science*

Schadenfreude

AARON KHEMCHANDANI

FAYE SAULSBURY
SHADOW PLAY

With an irritated sigh, I glanced up at the clock mounted high on the eggshell-painted wall. I'd come to the Starbucks on Tottenham Court Road, where a friend and I would meet regularly for coffee and a chat, but he was 15 minutes late. Although he was a nice guy, I would always harbour a slight resentment towards him. He seemed to have it easy; he would often clue me in on his latest bonus, next exotic holiday or recent gift from his girlfriend. Meanwhile, I was unemployed, single and stuck in the rut of student living. I was undoubtedly a little jealous (though I'd sooner eat the coffee cup than admit that to myself).

Ah, I'd spotted him – though he walked without his usual confidence, a grim expression written on his sunken face. This was certainly a change from the status quo.

Once we'd sat down, he informed me of his ordeal: his girlfriend had broken up with him the night before. Upon hearing this, I felt sorry for him, but that pity was mixed with a hint of something else. I couldn't help but feel a warmth slowly spreading across my chest. The corners of my mouth tilted ever-so-slightly upward. "That'll bring you back down to reality," a tiny part of me thought.

It was unexplainable, but I felt a sense of joy as my friend detailed how upset he was. You may think this makes me a terrible person, but there's an explanation for this, hear me out!

Experiencing happiness as a result of another's lack of it is common in all aspects of life. Like when a rival football team loses and their fans shed tears of despair, or when a rich, stuck-up celebrity has their mansion robbed, for example. The universal nature of this sensation is reflected in the range of languages that have an expression for it: joie maligne in French, or leedvermaak in Dutch. In Hebrew, it is simcha la-ed and xìng-zāi-lè-huò in Mandarin. In early civilization, the Greeks described it with the term epichairekakia.

In English, however, no such phrase exists. While laughing at a friend's misery is undoubtedly a part of British culture, it may just be that when we're forced to admit to this sadistic sensation, we avert our gaze in shameful silence, afraid to acknowledge the hypocrisy of it all.

So instead of coining our own term, we adopted a German word: schadenfreude. Literally 'schaden' meaning damage, and 'freude' meaning joy. Joy from damage. It first appeared in an English text in 1852 and its usage gradually increased. Since then, it has also been examined scientifically. In fact, the country from which this term was birthed was also home to one of the most important studies on this topic, though understanding it requires us to delve into the eye-wateringly lucrative and testosterone-fuelled world of men's football.

In 2015, 32 German football fans took part in an experiment that involved attaching electromyography pads to their faces, which would measure their smiles and frowns while they watched a series of penalty kicks from their home country against a major rival: the Netherlands.

Interestingly, researchers observed that when a Dutch player missed a penalty, participants' smiles were broader and appeared more quickly than when a German player scored one. This led the scientists to a chilling conclusion: expressions of schadenfreude and pure joy are, at their core, indistinguishable – but our smiles are wider upon learning of the failures of others compared to our own success.

But why is this the case? Are we all just morally corrupt human beings bent on basking in the misery of those around us? Well, no. Not exactly, anyway.

In reality, as prominent neuroscientists have pointed out, schadenfreude is the result of millions of years of human evolution and is deeply ingrained in our psychology. We humans are extremely social animals, perpetually aware of other people and our relationships with them. However, we're also aware of our social status and our place within the inevitable social hierarchies constructed around us. This is a key aspect of schadenfreude because we like to be liked, and raising our social status is a subconscious motivator for many of our actions.

"We humans are extremely social animals, perpetually aware of other people and our relationships with them."

"Understanding [schadenfreude] requires us to delve into the eye-wateringly lucrative and testosterone-fuelled world of men's football."

Whether we achieve it through a promotion at work, moving to a bigger house or receiving an award, it makes us feel good. Studies have shown that it activates reward pathways in our brain that improve our mood. However, the reverse is also true in that low social status can be demoralising and hurtful – but the relative nature of societal hierarchies means that your status depends on those of others. This means that one way for your own social standing to be raised is for someone else of a higher status to lower theirs.

When my ever-confident friend went through his breakup, it caused him to temporarily lose face. It irrationally made me feel like more because he felt like less. Schadenfreude is a fascinating cocktail of joy and envy that has its roots at the core of human psychology, and further understanding it may just be the key to unlocking an entirely new arm of social science.

It unites us as we laugh in unison at the exposing of corrupt politicians and the downfall of spoiled celebrities, and divides us as we allow animosity to manifest in our minds. It's also a way to justify making fun of your friends: an obvious bonus. ■

Aaron Khemchandani is studying MSc Science Communication.

Lifelong learning
Curiosity, vision and joy in STEM

EMMA SOH

"Did you hear Grandma finished her computing course?" my sister mentioned over dinner one day. From lessons on using a smartphone to polishing her jelly-making skills, my grandmother seemed to be having a much more interesting time than I was at school.

The lessons she was going to were often well-attended by elderly folk in the area, and "lifelong learning" became a buzz word associated with posters featuring beaming participants on local notice boards.

I long thought of "lifelong learning" as a term synonymous with lessons for retirees, used to kill time after retirement or to keep up with the fast-paced world that whizzed past them. But lifelong learning is much more than a simple pastime. The European Commission has described lifelong learning as the ongoing process of growing and renewing knowledge, skills, and attitudes towards learning, setting it apart from traditional examinations which focus more on the acquisition of knowledge. When viewed through this lens, lifelong learning can include a wide range of pathways and opportunities, from adult education and training courses at work to library and museum visits. Lifelong learning could include any institution, formal or informal, which acts as an accessible platform to acquire knowledge and skills.

"Lifelong learning in STEM would shift from sitting in classrooms with stacks of notes and rigorous proofs, to more curious and critical minds engaging in dialogue and thinking independently."

But why is lifelong learning so important? The benefits of taking a lifelong approach go beyond the economic incentives of building a skilled economy or a fashionable trend to revamp education systems around. The Alzheimer's Association in the US has stated that keeping mentally active can decrease the risk of developing Alzheimer's (this has perhaps contributed to the perception that lifelong learning is only for the elderly).

But beyond the cognitive benefits, this flexible picture of learning encourages a sense of self-fulfillment and curiosity, teaching people to remain open-minded and adaptable in a changing world, whilst also improving themselves. Lifelong learning is a constant process, as much about knowledge as about attitudes and skills that will remain transferable and applicable as you continue to engage and learn from the world.

For all this talk about lifelong learning, perhaps the more interesting question is: what would lifelong learning look like for Science, Technology, Engineering and Mathematics (STEM)?

Family and friends, whose days studying STEM are but a distant school memory, all expressed the idea that STEM is inaccessible. To quote one of them: "I feel like most people tend to go into the humanities later in life, rather than STEM."

But this view perhaps takes only knowledge, not attitudes, into account. Basic science literacy is important to make informed decisions in daily life, and advancements in science and technology mean that knowledge needs to be continually renewed. From the COVID-19 pandemic to climate change, it is clear to see why remaining aware of some scientific knowledge is beneficial. Acquiring knowledge for the purpose of self-enrichment and pursuing truth is, of itself, a joyful pursuit for many scientists. To quote the physicist Max Planck, "A scientist is happy, not in resting on his attainments but in the steady acquisition of fresh knowledge."

However, viewing STEM purely as an insurmountable body of knowledge to be conquered through learning misses the importance of thinking paradigms and skills, such as thinking logically and critically, that are also useful, whether in STEM or beyond. STEM permeates our lives and STEM education can go far beyond the unidirectional transfer of knowledge from teacher to student in brick-and-mortar classrooms. Learning can take place in different capacities and contexts: in the halls of a science museum, walking along the Jurassic Coast in Dorset, or on Twitter where scientists post the latest updates from space. Lifelong learning in STEM would shift from sitting in classrooms with stacks of notes and rigorous proofs, to more curious and critical minds engaging in dialogue and thinking independently.

Studying STEM develops a unique set of skills and habits, whether inculcating reason to solve problems, the spirit of trial and experimentation, or the importance of skepticism and curiosity. In a culture awash with information, being able to not only know, but also to know how to apply relevant knowledge is increasingly important. Whether it is to find and understand the science behind arthritis for your ailing grandparent, or to question the latest sensationalist clickbait headline about COVID-19, it is in everyday occurrences that the skills and habits learned in STEM become most relevant. Perhaps our vision of STEM education needs to shift from just the acquisition of knowledge, to increasing our focus on cultivating curious and engaged learners who can find joy in interacting with science and the world around them.

Of course, this is by no means an exhaustive vision of lifelong learning in STEM, but it hopefully presents a fresh outlook on STEM education. Far from being solely a pursuit of knowledge, it might be more helpful to develop our scientific attitudes and continue to stay engaged and interested in STEM throughout our lives. So maybe those posters of elderly learners smiling aren't that far off from what joyful, lifelong learners might look like after all! ■

Emma Soh is studying MSc Science Communication. She is also Social Media Manager for *I,Science*.

MAYA PICO
BLUE CELL

Monochromatic blue light seem
chill and ghostly, and makes skin
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I exist in this moment on this planet

**the probability that I exist, source Dr Ali Binazir*

The power of a smile

WILLIAM HORNBROOK

"Smile, though your heart is aching
Smile, even though it's breaking"

Written by Geoffrey Parsons and John Turner, sung by Nat King Cole in his 1954 song *Smile*, these words seem prescient today as many people across the world are facing hardship both physically and mentally. But while smiling alone cannot solve the global crises of the modern world, science seem to suggest that the simple contraction of the zygomatic major muscles, which lift the corners of the mouth into a smile, may hold secrets to the happiness we all crave.

For many of us, the name Charles Darwin conjures thoughts of voyages on the HMS Beagle, finches' beaks and the theory of natural selection. But his work has also played a significant role in the scientific understanding of emotions and how we express them. In his 1872 book, *The Expression of Emotions in Man and Animals*, Darwin suggested that "the free expression by outward signs of an emotion intensifies it. On the other hand, the repression, as far as this is possible, of all outward signs softens our emotions." In other words, if you're feeling happy and you smile, the act of smiling will itself make you even happier. Or if you're feeling angry and you frown, your frown may lead you to have a full-on strop!

"Our attempts to understand the brain's inner workings often raise more questions than they answer."

Although William James, a contemporary of Darwin's, voiced a similar theory, it took almost a century for scientists to develop these ideas into what is now known as the 'facial feedback hypothesis'.

Early studies of facial feedback measured emotional reactions to comedic cartoons when participants were smiling or frowning. Critics of this research argued that the fact that the volunteers knew which emotion they were expressing meant the results were biased. To overcome this issue, a 1988 study, led by German psychologist Fritz Strack, asked participants to hold a pen in their mouth, either gripped between their teeth (which forced their mouths into a smiling position) or between their lips (which stopped them from smiling). Participants reported experiencing a more intense humour response when 'smiling' with the pen between their teeth than when the pen was between their lips. This study proved to be highly influential, not only for subsequent scientific investigations, but also for the widespread acceptance of facial feedback as a legitimate phenomenon.

How does facial feedback work? One of the most commonly held theories states that nerve signals between the emotional centres of the brain and the facial muscles travel in both directions. So, it is not just your brain telling your face what to do; your face has a say in your emotions too! Functional Magnetic Resonance Imaging (fMRI), which measures the activity in different regions of the brain, has shown that activity in the amygdala, a part of the brain known to regulate our emotions, increases during facial feedback.

An alternative theory suggests that the muscle movements associated with a particular facial expression changes the way air can move in and out of the body through the nose. An increase or reduction in this nasal airflow changes the temperature of blood flowing through the brain, in turn causing a change in our emotional state. A cooler temperature is associated with more pleasurable feelings, while a warmer temperature is associated with a gloomier mood. If this all sounds a bit mind-boggling, that's because it is! With the brain arguably being the most complex organ in the human body, our attempts to understand its inner workings often raise more questions than they answer.

Given all this knowledge, perhaps the next question is: can we exploit facial feedback to make us happier? Laughter therapy is a relatively recent practice which has shown to improve long-term mental and physical health, at least in part through facial feedback. Established by Indian physician Dr. Madan Kataria, who has since become known as 'the laughter guru', laughter therapy involves combining the physical and breathing exercises of yoga with periods of forced group laughter. As well as increasing overall feelings of happiness, laughter therapy has also been shown to significantly lower levels of the stress hormone cortisol.

"...laughter therapy involves combining the physical and breathing exercises of yoga with periods of forced group laughter"

Moreover, several clinical trials have investigated the manipulation of facial feedback to treat depression. These involved injecting botulinum toxin, more commonly known as Botox, into the facial 'corrugator' muscles. These muscles are located between the eyebrows and are responsible for frowning. When the corrugator muscles of patients suffering from clinical depression were paralysed with Botox, significant improvements in mood were reported. These effects were attributed to reduced facial feedback; less movement of the corrugator muscles meant less signals were sent to the brain which would otherwise have triggered or enhanced a low mood. In combination with other therapies, Botox could prove to be a valuable treatment, particularly in those whose depression has no apparent root cause.

With much evidence to support the benefits of smiling and laughing for our psychological health, maybe Nat King Cole had a point. If a smile has the power to make us feel better, surely it can make us feel more positive about our place in the world, and to help strengthen our relationships with the people around us.

"If you smile through your fear and sorrow
Smile and maybe tomorrow
You'll see the sun come shining through for you." ■

William Hornbrook is studying MSc Science Media Production.

LEFT:
LUCY CHAPMAN
THE PROBABILITY THAT I EXIST

Happiness on a tiny scale

FREYA MASTERS

FAYE SAULSBURY
PLANT DISSECTION

The tiny scale that we are going to focus on is the level of the cell. That's tiny.

From the hungry macrophage to the humble neuron, there are approximately 200 different types of cell in the human body. The smallest cells in the human body are minute neurons in the brain: cerebellar granule cells. Each of these are 4.0 to 4.5 micrometres in length. In plants, vessel elements which comprise the xylem tissue (for transporting water and nutrients) can range between a diameter of 8 to 500 micrometres – that's still tiny!

If an animal or plant is going to survive, each of these crucial building blocks have a part to play. Each tiny intricate cell ticking along is a fundamental part of a vast, complex whole.

What are the processes and reactions which keep cells 'happy' and thus sustain the whole organism?

Let's start with plants.

We all know that image of the grass cells, joyous and beaming at the prospect of life under the microscope. (If you haven't seen it, google 'smiling grass cells' — you won't be disappointed.)

One process which keeps a plant surviving and 'happy' is that of 'transpiration.'

Transpiration is defined as the evaporation of water from plant leaves – specifically from the 'spongy mesophyll cells' – and the loss of water vapour through the stomata, tiny pores in the epidermis (or outer layer of cells). Whilst transpiration is vital to aid the transportation of nutrients throughout the plant, on a particularly hot day, the rate of water loss by transpiration is greater than the amount of water absorbed through the roots.

"Each tiny intricate cell ticking along is a fundamental part of a vast, complex whole. "

As a result, the cells in the plant's leaves and stem become dehydrated, ensuring that the plant starts to wilt. If this occurs over a prolonged period, the plant may die. Aside from dehydration, numerous diseases caused by viruses, bacteria and fungi might kill a plant. In either of these scenarios, it's safe to say the plant wouldn't be happy.

So, what about the reactions which maintain happiness?

Myriad crucial reactions occur in animal and plant cells alike, with such reactions referred to as 'metabolism.'

You might say that the 30 trillion cells in the human body are 'happy' when they are metabolising. For these life-sustaining reactions to occur, the body strives to maintain a stable internal environment.

This 'homeostasis' enables the body to sustain constant temperature, pH and fluid levels. For example, that burn in your throat is an autonomic process you recognise as thirst — a sign that the levels of water in the body are low. There is something quite extraordinary about our physiology and its ability to adapt to a changing environment.

When our cellular community is in harmony, health blooms. But what happens when the balance shifts?

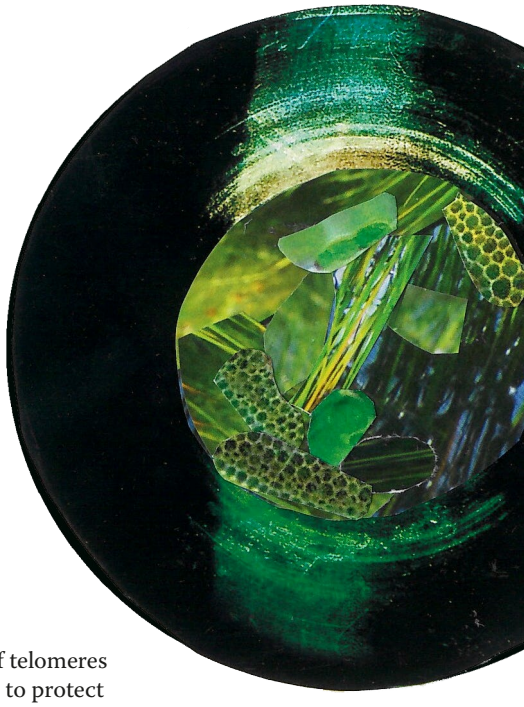
The field of mind-body genomics is concerned with the intrinsic link between our minds, emotional states and our cells (more specifically the DNA within these cells). Essentially, adverse experiences in life (such as cancer diagnosis) are linked to upregulation of inflammation genes in the body's immune cells.

Whilst inflammation is integral to the initial stage of the body's immune response upon encountering a pathogen (such as a virus or bacteria), if it persists, damage can result.

A more favourable scenario would be a decreased inflammatory response. In recent years, multiple studies have found that meditation is one way to achieve this. Strikingly, a calmer mind has been linked to a reduction in the expression of genes which result in a stress response, whereby the process of inflammation is greatly increased.

One protein 'NF-κB' (specifically 'nuclear factor kappa-light-chain-enhancer of activated B cells' – what a mouthful!) has a role in switching on inflammation in the body through stimulating the writing or 'transcription' of certain genes. These genes encode the proteins involved in the process of inflammation, such as cytokines. Meditation may in fact reverse the NF- κB-related transcription of pro-inflammatory proteins.

It is also thought that DNA can be altered structurally (it may undergo 'epigenetic changes') due to meditation. Indeed, meditation has an influence on the end portions of DNA – the telomeres. The role of telomeres is to protect genes; the longer the telomere, the greater the protection for the genes, and the longer the cell can survive.



Whilst chronic stress may in fact shorten telomeres, mediation is linked to longevity in telomere length. It has been suggested that 'DNA methylation' may be the epigenetic mechanism behind this. Indeed, the addition of methyl groups at portions of DNA containing specific genes associated with telomere length has been observed.

What about on the functional level? Meditation has also been found to influence DNA functionally, by altering gene expression (for instance, through increasing the expression of genes regulating cellular energy).

When you think that the human genome has approximately 20, 000 genes, the sheer complexity – the immeasurability – of such interactions becomes clear. We have merely scraped the surface of what 'happiness' means on a tiny cellular (and even tinier) genetic level.

Your cells will thank you if you encourage a calmer mind and emotional state of happiness through meditation. Or, if you are short on time, looking at the image of joyous grass cells and laughing might be a good place to start. ■

Freya Masters is studying MSc Science Communication. She is also Online Features Editor for *I,Science*.


Buttercup
Monkshood
Peony

Reconnecting with nature through botany

CHARLIE DELILKAN

The last two years have been so intense, I feel I've aged at least 10 years. From adapting to living in a pandemic, to white people realising that racism exists, it's been a lot. Finding joy at times when you feel like there's no future is not easy, but it's necessary for our existence. Even better, it's the best type of resistance against the system that is the cause of most modern-day issues: capitalism.

The rise of modern capitalism has seen a rise in urbanisation. Centralising the world's populations means cities are the perfect business environment. People are captured in exploitative labour and dependent on goods and services. Instead of listening to and living with our natural circadian rhythms, living in cities promotes a linear and sped up experience of time.

Just one example of this is our natural sleeping pattern being disrupted by the enormous levels of light pollution in cities. Photoreceptors in our retinas respond to light and communicate with our brain to initiate important biological processes so light is imperative to how our bodies keep track of rhythms. These communications are being disrupted by cities and has been linked to increased depression and anxiety, evident in the rise of mental health diagnoses in the last decade.

This has been exacerbated by the pandemic. In the first year of COVID-19, global prevalence of anxiety and depression increased by a massive 25 per cent.

"...we've separated ourselves from nature, the world that our bodies and instincts are adapted for."

On top of this, we've separated ourselves from nature, the world that our bodies and instincts are adapted for. Have you ever felt instantly content and happy whenever you escape the concrete jungle and are surrounded by bustling wildlife and luscious green space? That's serotonin and dopamine rushing around in your head. These two neurochemicals are responsible for us feeling good; levels of these hormones have been proven to rise when we exercise or surround ourselves in nature.

So obviously, the key to feeling good is to throw ourselves into nature as often as possible, right? Unfortunately, capitalism has ruined that too. With barely any spare time left after work, connecting with our inner forager isn't at the top of everyone's to-do list. Additionally, the transportation and equipment needed to access outdoor spaces have led to them being primarily occupied by people who can afford them, mainly middle- and upper-class white people.

Black and People of Colour (BPoC) are left with a double effect of this disparity. Not only do we experience less of the benefits from connecting with nature because of access barriers, but we are also the groups within our population who are most at risk of mental health problems.

I have felt this way for most of my life. I never had the finances to escape London until I moved to Sheffield to study, where I had the wonderful Peak District at my doorstep. But even when I managed to head outside with my friends, I felt so out of place being the only visible brown person there that it dampened my enjoyment of the experience.

I have always found joy in science. As someone who has been trained in Western science, I always thought that it was a place of pure objectivity, free from prejudice and discrimination. As I got older, I realised that this was not the case. Unfortunately, Western science has long relied on colonised peoples' knowledge and exploitation, and it still does.

This, coupled with capitalism's talent to destroy natural resources, has repeatedly led to cases of biopiracy – the unlawful commercialisation of biological products without compensation to the people from which they originate. Just one example of biopiracy includes the neem tree which is native to India and many African countries. Thanks to its unique chemical constituents, it is known as the "village pharmacy", having many applications such as contraceptives, laxatives and toothpaste. For centuries, the Western world ignored the neem tree; the practices of Indian peasants and doctors were not deemed worthy of attention by most colonialists.

However, growing opposition to chemical products in the West led to sudden enthusiasm for the properties of neem. The prominent constituent of neem is azadirachtin, a pivotal insecticidal ingredient. It makes insects sterile by interrupting sperm production. In 1985, the US registered a patent for a neem-based pesticide and subsequently sold to multiple private companies for a massive profit. Many Indian associations felt these patents were sequestering ancestral and farmer knowledge, depriving populations of traditional plant material.

"I wasn't sure how to engage with the science I knew without despairing over its history and future."

This is just one example from a long history of colonial exploitation within Western science. I wasn't sure how to engage with the science I knew without despairing over its history and future. I wanted to turn to nature and herbalism through the lens of sustainable traditional knowledge but wasn't sure where to start.

Misery is a collective for queer and trans black and people of colour (QTBPOC) who have organised a year-long programme for BPoC to explore green spaces in London and connect to the earth through traditional knowledge. I have been lucky enough to attend two of these monthly walks, and to have ancestral learning being the core element of a space dedicated to healing, rather than it being dismissed, has made me feel reconnected to my culture. This act of resistance has brought QTBPoCs collective joy in a society where our pain is usually documented and sold. Keep an eye on Misery's social media (@miseryparty) for details on the next walk! ■

Charlie Delilkan is studying MSc Science Communication.

LEFT:
MAYA PICO
HERB KEEPER

Take your brain for a walk

SCARLETT PARR-REID

PHOTOGRAPHY BY **BELLA SPENCER**

With over four million years of history to boot, the human adaptation of bipedalism, or walking on two feet, is something we easily take for granted. From pilgrimages to protests, walking is act of celebration and solidarity as well as a free and simple way to slow down in a world that never seems to.

There are many theories for bipedalism. Standing upright improved balance and posture and enabled our human-like ancestors, Hominins, to watch over tall grasses whilst hunting in the savannah. As grasses grew taller, our ancestors stood straighter. Bipedalism also decreased the surface area of the body exposed to sunlight, helping to beat the heat.

Walking on two feet freed the hands of Hominins to carry food and tools on the go. Whilst the exact origin of bipedalism is disputed, the many benefits of this adaptation have outweighed the challenges such as fallen arches, hernias and lower back pain.

As the French Philosopher Frédéric Gros describes beautifully in his bestselling book *A Philosophy of Walking*, "The pilgrim eventually succeeds the hermit." Recalling the diaries of the Indian saint and pilgrim Swami Ramdas, Gros conveys the essence of the relief of walking: "It is when we renounce everything that everything is given to us." In leaving it all behind, we find our spiritual needs are met in abundance. Ramdas' pilgrimages in the early 1900s spanned hundreds of miles across India from Puri, Dakshineswar, Kashi, Madhura, Brindavan to the Himilayan shrines.

Whether walking is a means of gentle reflection or powerful changemaking, it is not just a physical process of putting one foot in front of the other. Walking also acts on our brains in surprising ways. Professor of Experimental Brain Research at Trinity College Dublin, Shane O'Mara writes in his book *In Praise of Walking* about the cognitive neuroscience of walking. Cognitive neuroscience attempts to map psychological functions onto specific brain networks. When we walk, we engage in spatial navigation, memory and visual recognition, so that we can adapt to where we are and what is happening around us. We often walk from place to place without thinking about the journey at all.

"Neurons that are stimulated when we enter a particular place called 'place cells' are activated in the hippocampus when walking"

ARTWORK BY **SCARLETT PARR-REID**

Walking activates the hub of memory, learning and creativity known as the hippocampus, a seahorse-shaped region in the lower-middle brain. O'Mara describes that as we walk, rhythmic firing of distinct electrical signals known as theta waves arise in the hippocampus that can be measured directly by placing electrodes on the scalp. Theta waves are associated with deep relaxation and learning. Those who experience autopilot driving on motorways have been found to be in theta state, where they report many good ideas come to them. Theta waves might explain why we may return from a walk with a better idea of what we were thinking about prior to it, despite not consciously choosing to.

Our brain helps us to incubate ideas. Neurons that are stimulated when we enter a particular place called 'place cells' are activated in the hippocampus when walking. They signal to us where we are and which direction we are facing: the brain's extensive address book. Walking and aerobic exercise promote blood vessel formation, increasing blood flow to the brain. This in turn triggers the formation of brain-derived neurotrophic factor, a chemical messenger that improves memory and learning through the production of new brain cells, O'Mara writes.

This is despite the longstanding belief that no new brain cells are formed after birth.

Despite research showing the health benefits, as well as humanity's long cultural history, of walking, sedentary lifestyles account for nine percent of premature mortality worldwide, according a Lancet study. "We should be encouraging our populations to regularly and habitually walk in nature, even if they only have access to city parks," O'Mara points out. Walking promotes learning, improves memory and boosts mood, regardless of whether it is taking place in urban green spaces or rural green spaces, he notes.

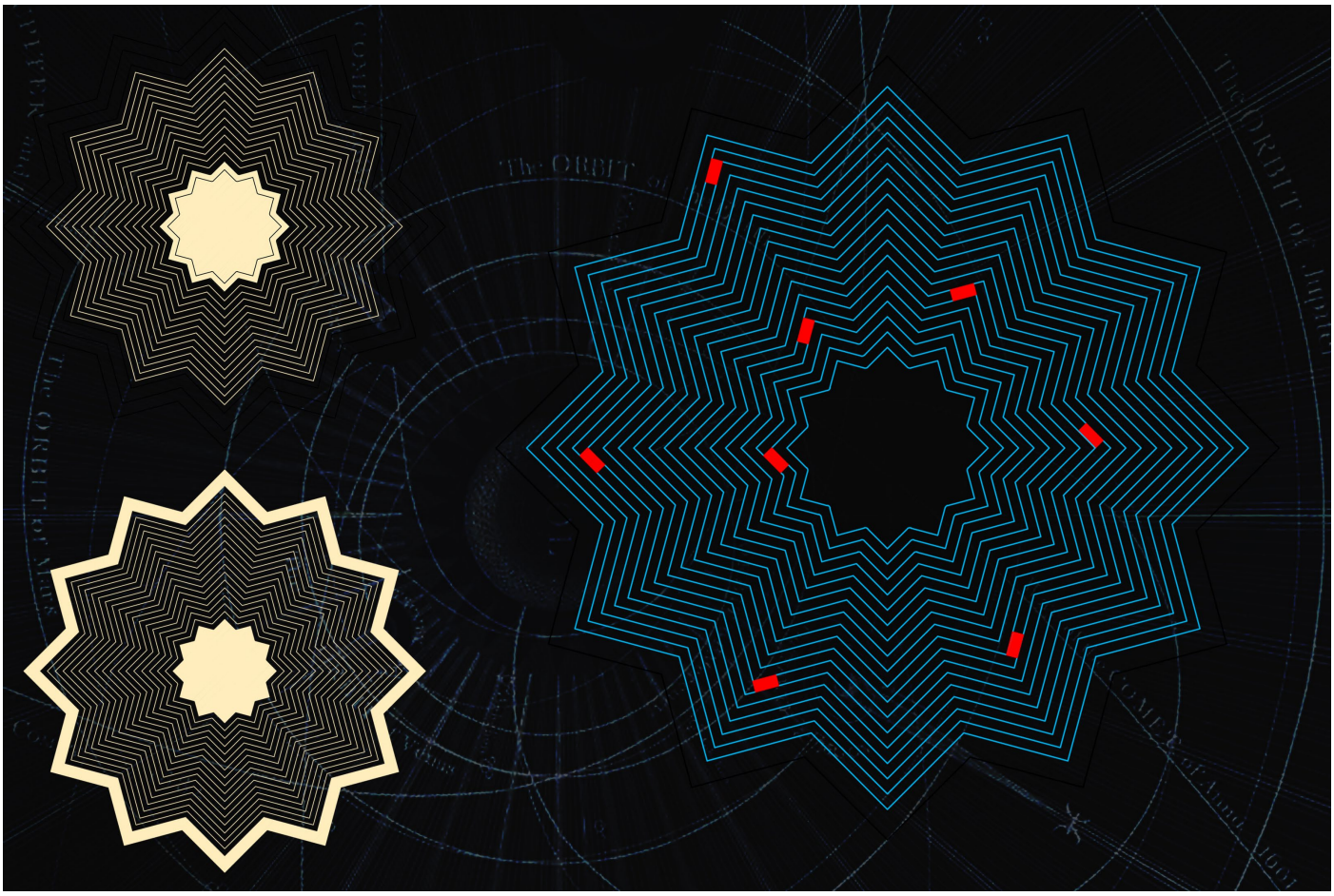
It is unsurprising then that in big cities such as London, 'urban greening' projects are taking place, rehabilitating industrial areas, introducing school allotments and cultivating roof gardens, which protect both the environment and mental health. The link between walking and wellbeing is conceptualised by O'Mara as a positive feedback loop, in which those that walk more show an improved mood, increasing the motivation to walk, thereby improving mood further.

"Whether walking is a means of gentle reflection or powerful changemaking, it is not just a physical process of putting one foot in front of the other."

Whilst it is unclear whether walking is a cause or effect of a better mood – and whether instead being in nature or social groups is driving the benefits – it is clear that walking is a low-risk, free activity engaging the body and mind. Notable benefits can happen in just 20 minutes, O'Mara states. So, walking is to our mood as a lifetime savings account is to our money: you always get out more than you put in.

The act of walking is both a science and an art. Far from simply moving from A to B, it is a vehicle for change and wellbeing and a symbol of spirituality that is embedded in culture. Whether a short stroll in a city park or a long hike though the countryside, walking is a quiet superpower we often forget to appreciate. Next time you go for a walk, you might just find you've taken more journeys than one. ■

Scarlett Parr-Reid is studying MSc Science Communication.



Looking for joy? Find some fear

BOHNI DATTA
I, WRITE COMPETITION WINNER

"You've never watched *The Blair Witch Project*?" my mum asked in avid horror, immediately playing the film. While I may be less cultured in the face of fear, she has spent countless nights watching horror movies until the crack of dawn. On the other hand, my dad's automatic response to any film is to ask, "Is it a horror?" and if it is, a quick goodnight and straight to sleep.

My parents react in this black or white way about riding roller coasters, listening to ghost stories and other scary entertainment. From a young age, I was perplexed as to why they had such contrasting reactions to fear, and finally I understand why they experience it so differently.

Why does fear appeal so much to some people? Extracting pleasure from fear may seem like an absurd paradox but there is a logical explanation for it. Let's take a look back at the prehistoric age: when we were not hunters but the hunted, our survival depended on our ability to anticipate and react to danger from predators and other life-endangering situations.

As humans, we have learned to fear uncertainty. The brain is continuously assessing our circumstances, but it becomes more difficult in unpredictable scenarios where the wrong reaction may prove fatal.

When riding roller coasters, there is no control – every twist and turn creates unpredictability, crafting a fear of the unknown. "I feel a wave of pure emotion – there is no fighting it," confessed my mum during our conversation. This is a primal instinct, with no room for thought or reflection. Our brain simply reverts to our ancestors' learned reactions. Likewise, for horrors, the uncanny face in the mirror and blood trails in houses are linked to unexplainable deaths, causing a flight-or-fight reflex.

Even without being able to predict what might happen, our brains still prepare for danger. The amygdala, the part of the brain that processes fear, senses a threat by uncertainty, attention, change and struggle, always linked to death. It causes our blood flow to change – blood flows away from the heart and into the limbs, making it easier to throw punches and run away.

Levels of glucose in the blood spike, providing a ready store of energy if the need for action arises. The nervous system is alerted

and releases cortisol, a hormone produced in response to stress, which increases blood pressure. Other hormones prepare muscles for violent action, equipping the body for danger.

So why do so many people pay to experience something so frightening? While the amygdala causes these survival mode reflexes, the hippocampus, which controls memory, and the prefrontal cortex, which makes high-level decisions, determine if the fear response is suitable. In the context of fun experiences such as riding roller coasters, the fear response can be dialled back to dampen the amygdala's activity.

We recognise that it isn't a real threat and re-label it as "joy" instead of "fear" due to the similarities in physical reactions, such as pounding heart and butterflies in your stomach. "You can trigger the sympathetic nervous system while cognitively being aware that it's not real," says psychologist and wellbeing consultant, Lee Chambers. Riding a roller coaster or watching a horror movie means we are in a safe controlled environment where there is no real harm, which our brain can understand.

However, exposure to terrifying acts, or even the anticipation of those acts, can still stimulate us in opposing ways. Watching horror simultaneously activates both negative stimulation, such as anxiety, and positive stimulation in the form of excitement. The most intense pleasure is usually experienced at the most fearful moment; a paradox to say the least.

So how can risky activities increase levels of stress and joy at the same time?

I,Write is a science writing competition, held by *I,Science*, for secondary school students across the UK. Students were invited to pitch our editors their article ideas and the top three were selected for one-on-one mentoring. Mentors from the *I,Science* team guided students on how to research, write and edit their pieces. Their final articles were then judged and voted on by the entire *I,Science* team, with the winning entry published in here.

We were impressed with Bohni Datta's ability to integrate strong scientific details with personal, warm anecdotes from her family. The science she delves into is broad-based, ranging from biology to sociology to psychology – giving a holistic macroscopic view of her chosen topic. We think her article about how watching horror movies gives some of us joy is a pleasure for anyone to read.

'Eustress', a term coined by Hans Selye, the founder of stress theory, is translated as 'good stress'. We can feel challenged, focused and energised in stressful situations, leading to fruitful outcomes and encounters. Eustress can occur while cooking a complicated meal, solving a puzzle and, of course, riding roller coasters. The Yerkes-Dodson stress graph shows the relationship between stimulation and efficiency, which is highest at moderate levels of stress.

Another reason thrill-seeking activities are so popular is the heightened social connections. Chambers describes bonding as an integral part of the enjoyment: "When you watch scary entertainment together, and the biochemical rush is peaking, you feel amazing, and think everyone with you is amazing. You think it's due to the people around you rather than the experience."

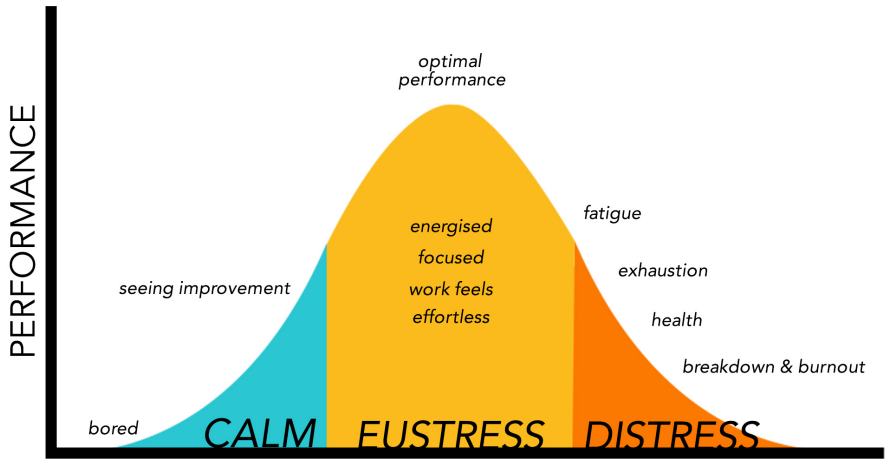
Emotions can be contagious, if your friend laughs you do too. We feel inclined to do the same as others so we can understand how they are feeling. This intensifies our own emotional experiences and strengthens social bonds. Obviously, physical contact enhances these connections – the death grip on your friend's wrist or a quick hug after the movie brings us together.

Lastly, trust in the other is increased with the, albeit fake, idea of keeping them safe. This holds true for my family, because after watching horrors with blankets covering our faces, we make a pact to not leave anyone alone in the dark – a sign of true familial solidarity.

You may still not be convinced that fun in fear is your cup of tea, and that is absolutely fine. Some people remain skeptical when faced with fear, like my father. He often complains that, "the special effects look so fake" and that, "this could never happen in real life." This means the cognitive side of the brain is taking control and eliminating the sense of threat.

Alternatively, it could indicate a lack of modulation by the cortical brain, resulting in a "too real" experience. For example, children who are younger than six or seven can't separate reality from make-believe, and can experience severe trauma from seeing something frightening. The prefrontal cortex is not fully developed in children, meaning their brain can't discriminate between real and harmless threats. In simple terms, some brains just aren't built for fear and that is absolutely normal.

All in all, it seems that experiencing fake-dangerous situations is either stimulating and fun, or terrifying and uncomfortable. The enjoyment lies not in your hands but in psychology and the chemistry of your brain. My family will remain split on the matter, and honestly that's fascinating. The joy of fear is one you may never know until you try, so go and watch *The Exorcist* and brave The Smiler with your friends – you may well have one of the best experiences of your life, brought by a curious concoction of fear and joy. ■



THE YERKES-DODSON STRESS GRAPH

GOOD NEWS FROM CHEMISTRY

Good news from the world of Chemistry! These two essays were written by students taking the Materials Chemistry module. They look at promising novel research that could one day help make industrial processes cleaner and greener.

Black liquor: from waste to future fuel

ARIELLE RAHARDJO

Graphene quantum dot synthesis could elevate papermaking waste to solar fuel producer.

Some might think that the papermaking industry is in decline due to digitisation and technological advancements, but this is not true. While these factors might reduce the use of graphic paper, demand for packaging, tissue papers, along with pulp for hygiene and textile products continues to grow. As of 2018, 430 million metric tons of paper products is produced annually. This not only consumes around 253 gallons of petrol for every ton of virgin paper but also produces 17 per cent of the total global industrial waste.

Papermaking produces large amounts of waste, with black liquor being the major waste produced in pulp and paper mills. This sticky black substance consists of organic polymers and inorganic compounds used in the kraft pulping process. It is highly toxic and is a hazard for aquatic life.

The pulp making process yields up to 10 tons of black liquor for every ton of pulp produced, which means that up to 4.3 billion metric tons of black liquor are produced annually. Currently, black liquor is treated by evaporating it to reduce its water content before combusting it as low-grade energy stock. The combustion process not only leads to more pollution but also underutilises the carbon-rich biomass contained in black liquor.

However, recent research by Dr Zaiyong Jiang (from Qilu University of Technology, China) and his team explored the viability of using black liquor to synthesise graphene quantum dots. Graphene quantum dots (GQDs) are small, environmentally friendly nanosized graphene structures with unique properties that make them an appealing material for various applications, ranging from bioimaging and biosensors to photovoltaic devices.

Dr Jiang and his team aimed to use these black-liquor-sourced GQDs to enhance the performance of titanium dioxide (TiO2), a widely used photocatalyst – a material which uses light energy to drive chemical reactions. TiO2 is of particular interest because it is often used in solar fuel production and is ideal for research as it has high chemical stability, high reactivity and is environmentally safe. Being a photocatalyst, TiO2 nanosheets absorb ultraviolet light to conduct reactions on its surface. One of these reactions is the reduction of water molecules to hydrogen gas, which can then be used as fuel. GQDs are able to enhance the performance of the TiO2 nanosheets and increase the rate of hydrogen production. Making GQDs out of black liquor would, therefore, transform this presently low-value waste into a versatile, high-value material.

Black liquor is an appealing feedstock for GQD production as it contains lignin residues. Lignin is a carbon-rich compound shown to be a useful stock material for GQD synthesis. For this reason, Dr Jiang has successfully isolated the lignin-rich portion of black liquor and combined separate lignin segments into carbon ring chains similar in structure to graphene.

> "Papermaking produces large amounts of waste, with black liquor being the major waste produced in pulp and paper mills."

Upon testing, there was a significant enhancement of reduction activities for TiO2 with GQDs in comparison to just TiO2 when exposed to ultraviolet/visible light. Dr Jiang observed that the addition of GQDs produces more hydrogen, with the best performing ratio of GQD to TiO2 producing up to 25 times more hydrogen than that of pure TiO2.

Unfortunately, while this method enhances the production of hydrogen, it requires the use of methanol as a sacrificial reagent. These reagents are used to extend the reactivity of the photocatalyst and are consumed during the reaction. As a result, a large supply of methanol would be needed to scale up the process, making this method unsuitable for large scale hydrogen production. Not only would this be hazardous due to the high toxicity of methanol, it would also be very wasteful as methanol itself is a very valuable energy source.

Despite this limitation, Dr Jiang's research has shown the potential of transforming black liquor into a high-value asset. As the global climate crisis continues, the development of clean and renewable energy sources becomes increasingly important. Currently, hydrogen energy conversion systems have a high future potential. Hydrogen gas can be produced by various energy sources and is one of the most available options for storing renewable energy. At the same time, hydrogen fuel cells have the potential to be used in many sectors, such as long-haul transport, iron and steel, and household energy supplies, significantly reducing the carbon footprint of these sectors.

Currently, 95 per cent of hydrogen gas is supplied from natural gas and coal, resulting in high amounts of carbon dioxide emissions. But it is possible to use sustainable and renewable sources to produce hydrogen, as is exemplified by Dr Jiang's research. As this field develops, it is possible to produce green hydrogen at lower costs, allowing us to reduce the use of fossil fuels.

Of course, research to utilise black liquor does not stop here. The global environmental crisis due to pollution has highlighted the importance of a circular material economy, which would ideally minimise industrial waste by recycling and reusing these waste products. ■

This essay was written by Arielle Rahardjo as part of the 'Material Chemistry' module.

Recent 'breakthrough' in separation technologies could help save the planet

JOSEPH BURKE

Recent 'breakthrough' in separation technologies could help save the planet

The separation of chemicals consumes a vast amount of energy in the world today. In the US, around half of all industrial energy consumption can be attributed to chemical separations, which accounts for roughly 10-15 per cent of the nation's total energy usage.

One separation that takes place on a very large scale is that of ethylene and ethane. Ethylene is mostly used to make polymers we use daily such as polyethene (which is the world's most popular plastic) and poly(vinylchloride) (PVC). Polymers are materials made from carbon atoms bonded to each other in very long chains which can have other substituents attached to tailor their properties.

Separating ethylene and ethane is challenging because they have similar boiling points and molecular sizes, making it hard to find a process which will discriminate between the two. Currently, ethylene is separated from ethane by repeated distillation cycles at low temperatures (as low as -160 °C) and high pressures, making this process very energy intensive.

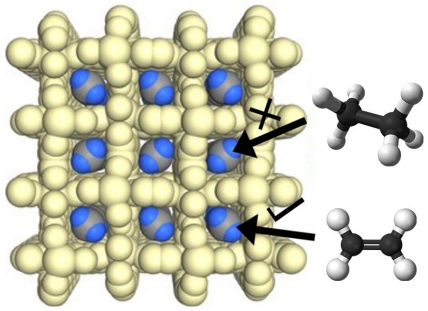
New separation methods are currently being investigated which could save approximately 1.5 GJ per ton of ethylene produced. To put this into context, that would be enough energy to power an average UK house for around 5 months! Given that ethylene production exceeded 150 million tonnes in 2016, the possible energy savings would have a significant impact on the environment and world economy.

One potential solution could be metal organic frameworks (MOFs) that separate gaseous mixtures and save tremendous amounts of energy. One researcher investigating MOFs, Dr Banglin Chen at the University of Texas, said: "Metal-organic frameworks are very promising materials for gas storage and gas separation at a lower energy and economic cost."

But what exactly is a MOF? A MOF is a large molecular structure consisting of metal atoms joined together by organic linkers These are molecules which can bond to multiple different metal atoms at the same time, connecting them to each other. Similar to sponges, these molecules contain tiny pores that have extremely high surface areas – one gram of MOF can have a surface area comparable to a full-size football pitch!

The size of pores and structure of MOFs can be tuned according to application, which is why researchers are excited about applying them in a variety of fields such as gas storage, separation, catalysis, drug delivery and sensing.

In 2019, a research group (consisting of scientists working in the US, China and the Netherlands) designed the MOF [Ca(C4O4)(H2O)], or 'UTSA-280', capable of separating ethylene from ethane. Prior to this study, some members of the team, including Chen, had already investigated the effectiveness of several MOFs for separating mixtures of short hydrocarbons (molecules containing only carbon and hydrogen atoms), including ethylene and ethane. These materials were promising as they were able to perform the separations, however they were not stable in water. This made them unsuitable for industrial usage because water, within the gaseous mixture, would react with the MOFs and cause them to degrade.



UTSA-280 crystal lattice with 1D pores. Ethane molecules (top right) can't fit into the pores but the ethylene molecules (bottom right) can.

One of the researchers, Dr Wei Zou, recognised this, stating that they were "not claiming [their] materials perform so well they can't be improved" but also believed their solution was "worth pursuing further." Therefore, Chen, Zou and other scientists, turned their attention to a different MOF, 'UTSA-280' which could act as a molecular sieve to perform the desired separation.

'UTSA-280' contains one-dimensional channels which are large enough to allow ethylene to enter but not ethane, explaining why this MOF is referred to as a molecular sieve. Bonding in the framework is rigid, ensuring pores do not deform with changes in pressure and temperature. Also, it was possible for the MOF to be regenerated after use, which means that the small molecules inside the pores could be removed without damaging the MOF's structure. This means that it can be used to carry out the separation multiple times before it needs replacing, which would be crucial if it were to be used in industry.

Ethylene is commonly produced by cracking heavier hydrocarbon fractions to produce ethane, which is then dehydrogenated, a process that removes molecular hydrogen. The yield of ethylene from this is only 50-60 per cent, so finding an energetically efficient way to separate the gases is needed. In industry, UTSA-280 could carry this out by a process called breakthrough separation. This works by passing a gaseous mixture of ethylene and ethane through a column packed with MOF.

The two gases pass through the column at different speeds, allowing them to be separated. Counter-intuitively, ethane passes through the column faster than ethylene. You might expect that ethylene passes through the column faster because it is able to travel through pores in the MOF, whilst ethane is not. However, when ethylene molecules are inside pores of the MOF they bind to the surface, which slows them down. Conversely, ethane molecules cannot not fit into the pores so pass around the outside of MOF particles. This means that they pass through the column more quickly. Results from breakthrough separation experiments found that clean separation of the gases was achieved under relatively mild conditions.

What's more, 'UTSA-280' is easy to make and is very water stable. Chen noted that this made the MOF "much more feasible for industrial usage" than MOFs made previously for the separation.

The investigation of UTSA-280 as a molecular sieve for ethylene/ethane separation has shown that greener industrial processes are possible. Theoretically, the key principles of this study could be replicated for other separations by adjusting the MOF structure to make pores the appropriate size for the desired separation. However, to make molecular sieves suitable for separations on an industrial scale, membranes would need to have a huge surface area (up to 1 million square metres), which would require advances in manufacturing methods. It is encouraging to see that MOFs starting to be commercialised in recent years in gas storage technologies so hopefully it won't be long before molecular sieves hit the market. ■

This essay was written by Joseph Burke as part of the 'Material Chemistry' module.

PODCAST REVIEW

The Science of Happiness

ANJANA NAIR

I usually tend to avoid self-improvement podcasts. Mostly because I am a bit of a cynic, and partially because I find listening to people rhapsodise about unlocking the secrets of a happy life quite difficult. However, last month I decided to give a few episodes of *The Science of Happiness* a shot. Ranked as the second most popular podcast on Apple's Top Podcasts, this podcast has been a major hit since February 2022.

Summer calls for trying out some new things, including finding ways to better yourself in one way or another. With that in mind, I tuned into not one but six episodes of the podcast. The good thing is that I am glad that I persisted. The bad thing is that I am unsure if it fully equipped me with the capacity to actually improve myself. However, it did offer some perspective.

Most episodes are delightfully short, anywhere between 15 to 20 minutes. The Science of Happiness is concise in this way, each episode structured cleanly. It begins with a brief introduction to the scientific theory of happiness that the episode tackles. Two popular episodes go by the titles *Three Good Things* and *Three Funny Things*.

Next, is an interview from a "guinea pig" who undertakes an experiment on happiness. Basically, these are personal narratives, but not just any narratives. They are told in real-time, and are experimental and contain practical insights. These stories demonstrate how these experiments work and are applicable in our everyday lives. At the end of the episodes, there is a small exploration of the research that supports the value of the exercise.

"[each episode contains] an interview from a "guinea pig" who undertakes an experiment on happiness."

The show in no way appreciates scientific jargon. Everything that we listen to is purely direct and honest. Nobody suggests any kind of mindfulness exercise or meditation, nor is encouraged to think more positively. The doctors and psychiatrists involved in making the show are quite respectful regarding how they talk about happiness, supported by research and evidence.

Human beings are organically happy creatures, or we tend to believe so. But this show attests to the fact that not being happy is not a failure. The underlying theme of the podcast is very cliched in its own way – it confronts the reality that it is okay to not be okay. The podcast serves as a reminder to be gentle and forgiving with oneself.

Dacher Keltner, the host, effectively presents research-based suggestions for the listener. The guests (or the guinea pigs) range from actors to writers to psychiatrists. The audience is broad in that way. Personally speaking, I found Daniel Wu's episode (a leading actor in the Chinese language film industry) about connecting to our body particularly interesting and helpful.

Assuming readers have already listened to some podcasts about happiness and living a better life, it is safe to argue that most of them end up following the same trends, and overall, just end up giving pretty generic advice. *The Science of Happiness* left me with tactical advice or at least something to really ponder and think about after the episode had ended.

"...this show attests to the fact that not being happy is not a failure."

Placing the focus on the science of happiness really changes the approach to this topic, telling listeners why they may be stuck in unhealthy habits and how to change them to make their life more enjoyable and, well... happy. The podcast brings on interesting voices from various backgrounds that help to shift perspectives on how one defines happiness. I would sincerely recommend listening to the very first episode: *Three Good Things*. The premise of this episode is quite simple: it explores the practicality of taking time every single day to make written notes of three good things that happened, in as much detail as you can. It broke through my cynicism quite quickly. It is a frank, clear exploration of how happiness can be found in simple places. One would be surprised to see the outcome of this exercise.

The Science of Happiness hits the right notes, and I am glad I took the time to listen to it and reframe how I saw my place in the world a little bit more clearly. It felt like it was a good place to start working on my happiness. ■

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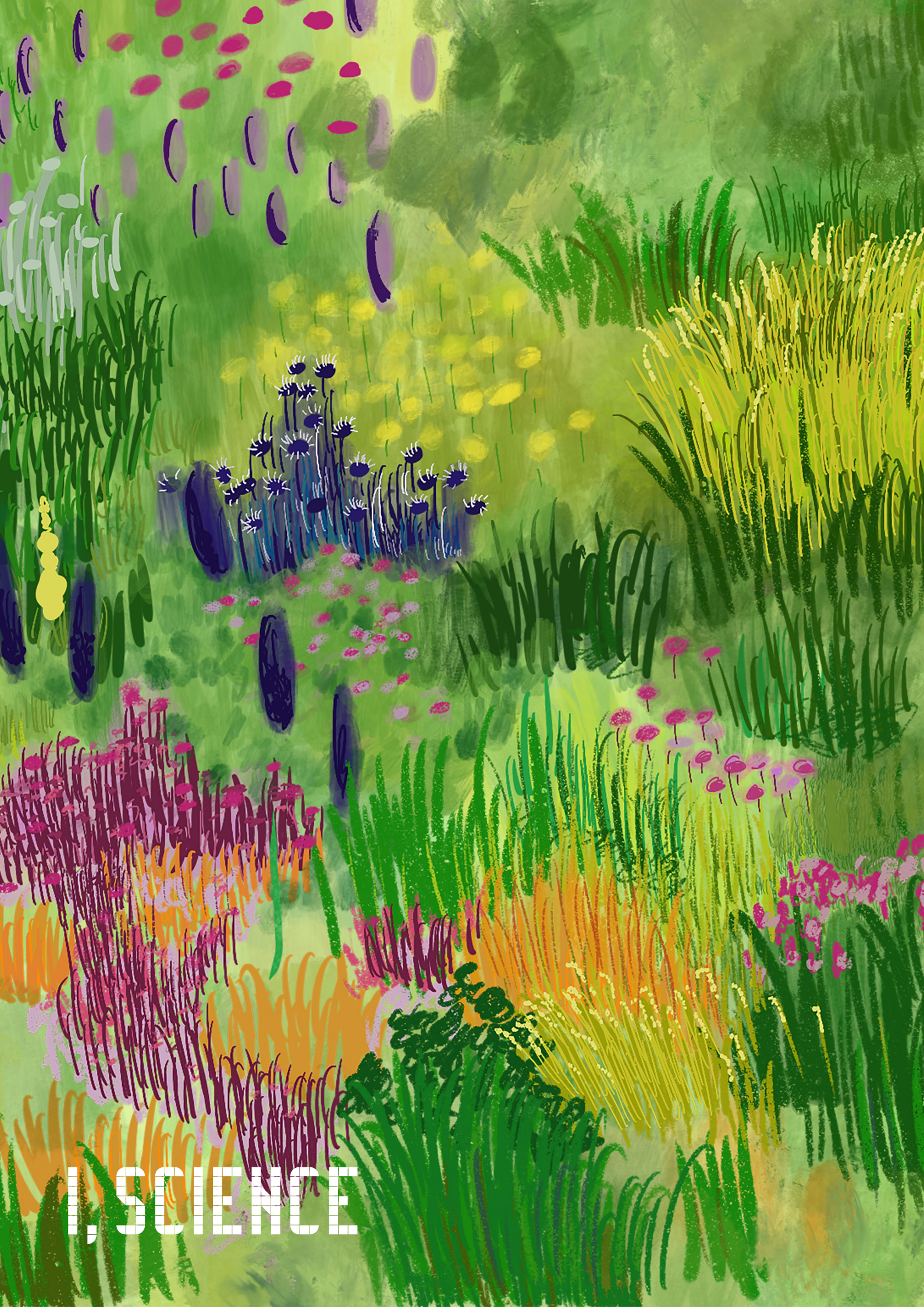
Captivation: An Exploration in Chromatics

Maya Pico

What determines the pigments we see? How does colour affect our reality? From the anatomy of the eye to the occipital lobe a vastly complex yet seemingly effortless process is carried out by the brain. Images and wavelengths of light from the outer world are processed internally; as a result, the perception of colour allows us to discern one subject/object from the next. On a psychological level, colours within a given context maintain the ability to trigger specific emotional states. This piece is an attempt at tracing a thread of chromatic through the psyche-inviting viewers to question the role of colour in relation to their own lived experience.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