New Scientist

WEEKLY 18 July 2026

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A dramatic rise in nighttime heat stress

The paradoxical effects of high temperatures on your body

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This week's issue

On the cover

Extreme heat
4 How 'impossible' heatwaves became a reality

4 A dramatic rise in nighttime heat stress

26 The paradoxical effects of high temperatures on your body

Vol 271 No 3604
Cover image: Getty Images

6 Three fertility breakthroughs that could boost IVF success

14 Did Neanderthals and humans share a culture?

13 The man whose algorithm could break the internet

17 Benefits of beetroot
14 Inner lives of bees
40 Is the universe a computer?

4 News

"This is just the start. Things are unfolding in a major way and the long-term effects will be savage"

News

9 Maths' little helper
Formalising Fermat's last theorem is progressing quickly thanks to AI help

10 Reshaping bonds
Special relativity seen warping a chemical bond

11 Seeing the light
Resuscitated retinas respond to light

Views

16 Heating up
What a spell in a heat chamber taught Alec Luhn about his resilience to high temperatures

17 Purple patch
Alice Klein on the benefits of beetroot for exercise

18 Aperture
Photos from Shackleton's expedition to Antarctica

20 Culture interview
Why Chris Packham wants to be eaten by a *T. rex*

25 Letters
Helping the Great Barrier Reef

GEOFF SMITH/ALAMY

14 Happy bees The insects seem to show when they are pleased

Features

26 Benefits of heat
Sauna and hot baths can aid our heart and brain health

32 The greenest city
How we can walk the tightrope between our well-being and that of Earth

36 Young and gifted
We are finally understanding the lifelong impact of being marked as exceptional during childhood

40 The true nature of time
If the universe were a computer, it could explain why time passes

The back pages

43 Puzzles
Try our crossword, puzzle and quick quiz

44 *Almost* the last word
How do fish recognise others of the same species?

45 Tom Gauld for *New Scientist*
A cartoonist's take on the world

48 Feedback
A delve into the world of imaginary research abstracts

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The heat is on

It is vital we understand the differing effects of heat and humidity on our bodies

WHEN the final of the 2026 men's football World Cup kicks off in New Jersey this weekend, players can expect temperatures of over 30°C (86°F). Indeed, much of the tournament has been played in challenging conditions – like the high elevation and thin air of Mexico City's Estadio Azteca – giving pundits plenty to chew over.

But one factor has been less discussed: humidity. High temperatures may be uncomfortable, but it is really the combination of heat and high humidity that can make a football match – indeed, any activity – physiologically unbearable. Humid conditions make it harder for our bodies to benefit from sweating, as the air is already laden with moisture, hampering our ability to cool down.

This impact of humidity is still underappreciated. One way of taking both humidity and heat into account is the wet bulb globe temperature (WBGT), a measure of heat stress used by sports organisations. As *New Scientist* went to press, the most extreme match of this World Cup (Uruguay vs Cape Verde) had

"It is really the combination of heat and humidity that can make activities unbearable"

an estimated WBGT of over 33°C (91°F) – a level at which people are advised to suspend all outdoor activity. Most of us simply aren't prepared for such conditions, as we explore on page 16.

Yet, if we understand the dangers of humidity, we can start to grasp the advantages of dry heat. On page 26, we detail the many ways in which saunas and heat therapy can keep you healthy, from cardiovascular benefits to protection against Alzheimer's disease. The key is that saunas operate at extremely low humidity, allowing us to sweat comfortably while reaping the benefits of getting decidedly hot.

Saunas aside, we should still be wary of extreme heat. With European heatwaves on the rise (see page 4), the 2030 men's football World Cup – to be played across France, Spain and Morocco – is likely to see low humidity but temperatures of up to 40°C (104°F). With no sign of us cutting carbon emissions, the World Cups of the early 21st century may one day be fondly remembered as nice and cool. ▮

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Climate change

Heat rising dangerously

As Europe and North America swelter, **Jacklin Kwan** and **Alec Luhn** take a look at the data to see how heatwaves have changed over the past 50 years

A HEATWAVE in May set monthly temperature records across Europe. A heatwave in June became the hottest ever observed in western Europe. Now, the continent is experiencing its third heatwave in as many months.

And it's not just Europe. The US is also sweltering under a heat dome that started in the western part of the country and was spreading to the north-east as *New Scientist* went to press. Temperatures are forecast to be 20 to 30 degrees above average for the time of year, according to CBS News, and the heatwave is predicted to last a week.

Just 50 years ago, Europe's June heatwave would have been virtually impossible. But global warming is making heatwaves hotter, more frequent and longer-lasting because it is raising background temperatures. Hot seasons are also starting earlier and heat stress at night is getting more severe.

"This is just the start. Things are unfolding in a major way and the long-term effects will be savage"

Worldwide, heat is the deadliest type of weather, killing more than half a million people each year. One study, published at the start of July, estimated that June's heatwave killed around 20,000 people in Europe. In England and Wales, 2700 people may have died, according to an estimate calculated by Clair Barnes at Imperial College London and her colleagues. The team estimates that more than 40 per cent of these deaths were as a result of climate change.

Even if we reach net-zero emissions tomorrow, the number of people who will die from extreme heat will continue to rise, as the carbon dioxide we have already emitted will keep raising temperatures.

"This is just the start," says Hugh Montgomery at University College London. "Things are unfolding in a very, very major way now, because this isn't just about it [being] too hot in London, and the long-term effects are going to be savage."

1. HOT SEASONS ARE STARTING EARLIER

Outside the tropics, the time of the year in which temperatures above 32°C occur has lengthened by 12 days in the past half-century. In Europe, the fastest-warming continent, the season of strong heat stress now starts in June, on average, and continues until almost September. Sometimes, like this year, it starts in May.

That raises people's exposure to hot days and heatwaves. Parts of North America, Europe, South America and Africa now have up to 50 more days of strong heat stress compared with the 1970s.

"If you've got heatwaves that last longer, and then you've got more heatwaves, people are going to be in that raised physiological state for longer," says Neil Maxwell at the University of Brighton, UK. "That can lead to greater inflammatory marker responses, and that ultimately puts a greater stress upon individuals."

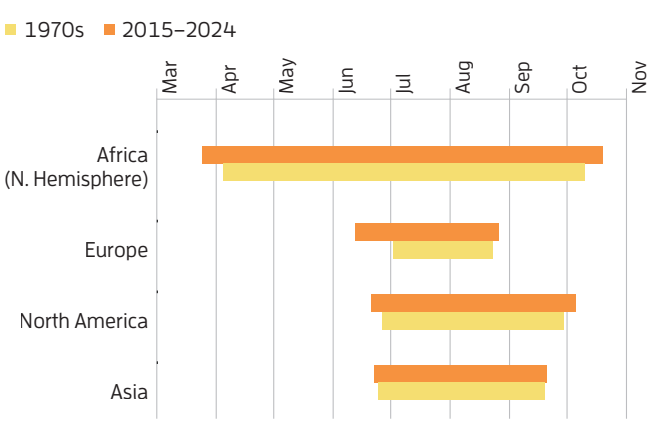
2. HEAT STRESS AT NIGHT IS GETTING MORE SEVERE

Strong heat stress almost never occurred at night before 1998. But now, nighttime temperatures in western Europe and other places are increasing at double the rate of global warming as a whole.

A drop in body temperature triggers sleep. If the environment is too hot, it is harder to fall asleep, as well as to enter a state of deep sleep. And loss of sleep over several nights in a row can hinder reaction time and boost anxiety and stress.

The frequency of a heat stress day followed by a tropical night of at least 20°C has increased by 73 per cent in Europe since the 1970s.

"If you don't get cooling periods at night, which we define in [the UK] as less than 20°C at night, sustained temperatures without cooling have worse impacts," says Montgomery.



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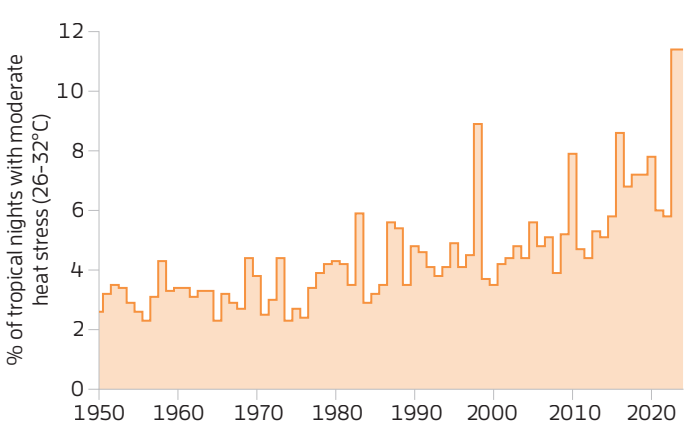


SOURCE: NATURE CLIMATE CHANGE

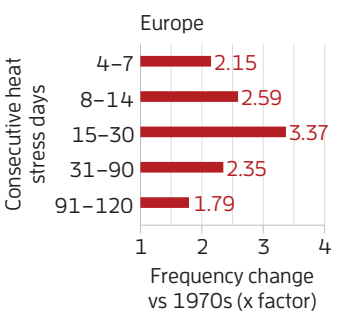
REUTERS/STEPHANE MAHE

People shelter from the sun at the French Open tennis tournament

3. EXTREME HEAT PERIODS ARE LASTING LONGER

Compared with the 1970s, recent years have seen more frequent runs of consecutive heat-stress days and tropical nights.

Heat stress spells lasting two weeks to a month are now 3.37 times more common in Europe than they were in the 1970s. And Africa is now almost three times more likely to experience hot periods lasting three-quarters of the year or more.



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4. JET STREAM KINKS LEAD TO LONGER HEATWAVES

A persistent kink or shift in the jet stream can trap warm air over Europe and lead to heatwaves lasting two weeks or more.

Heatwaves of at least a week are deadlier than ones spanning just a few days because people's bodies are under stress for longer. An early warning that a long heatwave is coming can give people, businesses and governments a chance to get ready.

Scientists only have daily atmospheric data for about 20 long heatwaves, so to understand these events better, Duncan Pappert and Olivia Martius at the University of Bern in Switzerland analysed 1900 plausible hot spells simulated by a state-of-the-art climate model.

They found that these periods tended to be driven by two types of atmospheric patterns. In both, Rossby waves – chains of weather systems that transport energy around the globe – alter the polar jet stream, the high-altitude belt of strong winds at roughly 60° north.

In the type I pattern, the jet stream gets wavier, kinking to the north around the UK and Scandinavia before veering south again to form a shape like the Greek letter omega. A persistent ridge of high pressure forms within this so-called omega blocking, setting the stage for a long-lasting heat dome over western Europe. Rather than breaking up the ridge, storms that come across the Atlantic Ocean reinforce the low-pressure cyclonic circulation at the beginning of the omega sign, which pulls hot subtropical air northwards as it spins.

In type II, the jet stream shifts polewards, again moving north of the UK but this time in a straighter pattern, and a ridge forms over Europe. The storm track then follows the jet stream, diverting low-pressure weather systems north of the continent, as warm subtropical air floods in from the south. In both cases, the outcome is a relentless heat dome in western Europe (*Environmental Research Letters*, doi.org/rfpn).

The heat dome behind the record heatwave in June was a type II before morphing into a type I, says Pappert. Europe's current heatwave largely resembles a type I, with a trough of low pressure to the west of a high-pressure ridge over Europe, he says.

It is hard to say whether heat-inducing atmospheric patterns like these jet stream shifts are becoming more frequent with global warming. Some research has suggested that high-pressure blocking related to the jet stream will become more frequent and persistent over Europe, while other modelling has shown no change.

The jet stream is starting to shift northwards in general, which could bring drier conditions to southern Europe, says Tim Woollings at the University of Oxford. If these type I and type II patterns did become more frequent or longer-lasting, it would be extremely damaging to economies and human health, he says. "It is a concern that we don't know," says Woollings. "We don't have a good enough understanding of these events really to know how their duration is changing." ▮

Climate crop losses

Global warming-fuelled heat and drought is hitting yields of maize, wheat and soybeans to the tune of $20 billion a year. This could rise to more than $160 billion by 2100, unless we slash emissions.

Yi Ling Hwong at the International Institute for Applied Systems Analysis in Austria and her colleagues calculated this by estimating the impact of heat and drought on yields of the three crops based on data from 1974 to 2004. They then used these statistical correlations to estimate crop losses from 2007 to 2019. Their results suggest that increases in heat extremes and drought have caused a 3.5 per cent decline in yields relative to the 1974–2004 baseline.

Next, they calculated the economic losses based on data showing how much farmers would have been paid at the time, before projecting future losses under several emissions scenarios. In a high-emissions scenario known as SSP3-7.0, global yields will fall by 35 per cent by 2100, with annual losses rising to more than $161 billion (EGU General Assembly 2026, doi.org/rfps).

Michael Le Page

Human reproduction

‘Major breakthrough’ for IVF

Lambs born from immature eggs could pave the way for improved success rates for IVF in people, finds **Carissa Wong**

HEALTHY lambs have been born via an experimental form of in vitro fertilisation (IVF) that coaxes highly immature eggs to become mature ones in the lab. This is the first time the approach has been demonstrated in a large animal, raising hopes that it could boost the number of eggs available for the fertility treatment and improve IVF success rates. While further research is required, it may be of particular benefit when the ovaries have been damaged by cancer treatment.

“It’s really a major breakthrough,” says Stine Kristensen at Copenhagen University Hospital in Denmark, who wasn’t involved in the work.

More than 30 years ago, the same approach led to live births in mice. “Much more than mice, reproduction in sheep is quite similar to in the human body,” says Manjushree Boob at the Shubham Hi-Tech Hospital and Test Tube Baby Centre in Maharashtra, India, who also wasn’t involved in the research.

Standard IVF involves daily injections for one to two weeks to stimulate immature eggs within follicles in the ovaries to develop into around 10 mature eggs. Of these, about six to eight are typically successfully fertilised in a dish in the lab. The resulting embryos are then implanted into the uterus. However, this leads to live birth in only around 20 per cent of cases.

That low success rate is why scientists are now looking at the potential of those immature eggs. Women are born with hundreds of thousands to more than 1 million of them, but the number declines throughout their life. During each menstrual cycle, one of these follicles forms a mature egg that is released during ovulation.

LAURENCE WINRAM

Five sheep have been born via experimental IVF, one of which has had two offspring

In the latest study, Helen Picton at the University of Leeds, UK, and her colleagues collected dozens of these follicles from sheep. They were bathed in a cocktail of reproductive hormones – such as follicle-stimulating hormone, which stimulates their growth and maturation – and growth factors, which coaxed about 60 per cent of them to become mature eggs.

They successfully fertilised around 30 per cent of these eggs to produce embryos, which were implanted into the uteruses of 18 sheep. This led to the birth of a female lamb in early 2024 and another four births this year. That female also had two lambs this year, Picton said while presenting the findings at the European Society of Human Reproduction and Embryology conference in London on 7 July.

“The technique could boost the number of eggs available for fertilisation”

Softer ovaries could lengthen fertility window

While the use of immature eggs could improve IVF success rates (see main story), women’s fertility window could also be extended by making the ovaries less stiff.

Women’s fertility tends to start declining in their mid-30s. As well as the number and quality of a woman’s immature eggs declining with age, there is also evidence that ovaries become stiffer over time, which may further affect egg development and quality.

To understand what is driving this, Shixuan Wang at Huazhong University of Science and Technology in Wuhan, China, and his colleagues measured the protein levels of the ovaries of women aged 18 to 28, 35 to 42 and 47 to 52. All of the women had a history of gynaecological cancer, but their ovaries were unaffected when removed.

The researchers found that a protein called interleukin-11 increased in the ovaries with age. This activates cells in connective tissue called fibroblasts, which make collagen – a driver of ovarian stiffness.

Next, the team genetically modified a group of mice to be unable to respond to interleukin-11. Not only did this reduce ovarian stiffness – measured via microscopy – as the mice aged, but the animals also ovulated more than an unmodified control group.

Finally, the researchers tested the potential of an experimental drug that blocks interleukin-11’s production by silencing the gene behind it. They injected the drug into the tails of 36-week-old mice – roughly equivalent to a person in their late 30s or early 40s – twice a week for four weeks.

This caused their ovaries to become 36 per cent less stiff compared with an untreated control group. What’s more, it doubled their conception rate from 25 per cent to 50 per cent and increased their litter size from three to five pups, on average. Among similarly aged rats, the conception rate rose from 20 per cent to 50 per cent and the litter size increased fivefold, from one pup to five (*Nature Aging*, doi.org/hb9xkj).

Francesca Duncan at Northwestern University in Illinois says the intervention could lead to similar outcomes in premenopausal women, given that interleukin-11 also increases with age in human ovaries.

Tosin Thompson

mRNA jab for older eggs reduces risk of chromosome error

The results suggest the technique could boost the number of eggs available for fertilisation, which may improve conception rates, says Kristensen. However, to maximise the chance of conception, this would probably be done in addition to standard IVF, so wouldn't make it more convenient and could even add to the expense, she says.

Lower risk

Picton adds that the approach is unlikely to be used routinely, because retrieving the follicles involves taking a sample of the ovary lining, which is more invasive than collecting mature eggs during standard IVF.

But women whose ovaries have been damaged by cancer treatment could benefit, says Picton. Doctors often work to preserve their fertility by removing and freezing fragments of ovarian tissue beforehand, then transplanting them back into the body when they are hoping to conceive, but there is always a risk the transplant contains cancer cells. Collecting immature eggs wouldn't carry the same risk because cancer generally affects only the surrounding tissue, says Picton.

However, studies first need to explore whether human eggs grown via this approach can be fertilised. These studies are expected to take place in the next few years, says Kristensen. If they go smoothly, small trials can attempt to achieve healthy live births, but it could be five to 10 years before researchers gain ethical approval for this, she says. This is because such research must ensure the benefits outweigh any risks to the prospective parents or their children, says Kristensen. ▮

HUMAN eggs that contain too many or too few chromosomes can lead to miscarriage, IVF failure and conditions such as Down's syndrome. Now, researchers have found that giving the eggs a single injection can reduce the likelihood of chromosome error. The approach could one day boost the chances of success for older women undergoing IVF.

"It really seems like a big deal," says Marcos Iuri Roos Kulmann at Nilo Frantz Reproductive Medicine in Porto Alegre, Brazil, who wasn't involved in the research. "To my knowledge, this is the first [therapy] to show such clinical potential for correcting this major cause of IVF failure."

During a process called meiosis, egg and sperm cells eject exactly half their genetic material. This means that when the two combine during fertilisation, the embryo has a complete genome. Sometimes, however, a sperm or egg cell has slightly more or less than it should contain. This is called aneuploidy and it affects about 10 to 25 per cent of eggs in the early 30s and becomes more common with age.

Clinicians sometimes screen IVF embryos for aneuploidy. But until now, there have been no ways to reduce the risk of it occurring in the first place,

"This is the first therapy to show such clinical potential for correcting this cause of IVF failure"

Agata Zielinska at Ovo Labs, a biotech firm in Germany, told the European Society of Human Reproduction and Embryology conference in London on 6 July.

Now, Zielinska and her team have found that the level of a protein called shugoshin-1 is much lower in older mouse and human eggs than in younger ones. Shugoshin-1 helps with a stage of meiosis in which two copies of each chromosome line up along the middle of an immature egg cell. The protein maintains the molecular glue that holds each pair together.

In vitro fertilisation may soon be getting an upgrade

JONAS GRATZER/LIGHTROCKET VIA GETTY IMAGES

When sperm penetrate an egg, the two copies of the egg's chromosomes separate and move to opposite sides of the cell. One end ultimately forms the final egg cell, and the other is discarded. But in older eggs, the glue holding the chromosome pairs together degrades, which can cause the two copies of each chromosome to separate before fertilisation. This leaves chromosomes spread unevenly in the cell – so the resulting egg may be aneuploid.

To see whether replenishing shugoshin-1 could prevent aneuploidy, the team collected 111 immature eggs from more than 30 women aged between 22 and 43 who were banking eggs or undergoing IVF and injected the genetic code for shugoshin-1, in the form of mRNA, into one or more of each donor's eggs. Other eggs from the same donor were left untreated. A few hours later, chromosomes had prematurely separated in 53 per cent of the untreated eggs, but in only 29 per cent of the treated ones. In eggs from nine donors aged over 35, aneuploidy rates in untreated eggs were 65 per cent on average. In treated eggs, this figure was just 44 per cent.

Further experiments showed the approach could prevent aneuploidy in mouse eggs, which were then fertilised to create healthy offspring. "We're confident that this approach doesn't interfere with pup health and pregnancy health," Zielinska told the conference.

The researchers are now working towards testing the effects of shugoshin-1 in people. This would involve tweaking standard IVF to use immature eggs rather than mature ones, says Zielinska. ▮ **CW**

Physics

Rewriting thermodynamics

Two hundred years after the laws of physics concerning heat and work were first devised, they could get a stronger mathematical underpinning, discovers **Karmela Padavic-Callaghan**

THE theory of thermodynamics has helped us understand devices like engines for over 200 years, but its mathematical foundations have always been a bit too imprecise. Now, researchers are putting the theory on a firmer footing, with mathematics more commonly used to describe quantum fields.

Among all branches of physics, thermodynamics is among the easiest to connect to everyday life. This is because its development was driven in part by engineers looking to understand and maximise the efficiency of heat engines, which are idealised devices that model a wide range of technologies, such as car engines.

But although thermodynamics is a very successful theory, it has historically lacked mathematical rigour, says Bryan Roberts at the London School of Economics and Political Science. He has set out to rebuild it based on mathematical ideas that draw on geometry and quantum field theory, a notable departure from how thermodynamics has long been understood and taught.

Central to Roberts's approach is the concept of "gauge theory", which typically deals with properties of objects that aren't directly observable or manipulable.

A simplified example, involving marbles rolling along a surface, helps to explain the approach. The marbles appear identical, but each has a different colour hidden at its centre. In a gauge theory, there would be a mathematical space – the "observable" space – defined by numbers that capture the marbles' motion, and another space – the "bundle" space – that can be formulated to contain information about each marble's internal colour.

These two mathematical spaces are deeply connected, such that the observable space is the projection of the unobservable bundle space. Roberts says this is a little like shining a light on an object. Even if you were, for some reason, unable to look at the object directly, you could discern some of its properties by studying its shadow.

He thinks that it makes sense to use this approach to study thermodynamics because it, too, involves both accessible and inaccessible quantities.

> **"While thermodynamics is a very successful theory, it has historically lacked mathematical rigour"**

"There's kind of two levels to thermodynamics," he says. "There's the accessible level, things that you can extract work out of, because you can kind of grab onto them and move them around – like the piston that goes in and out of an engine." And there is a less accessible level: the heat that is generated or lost in a system, which can't really be manipulated as directly. Roberts defines this as a hidden contribution to energy.

This isn't a distinction that carries mathematical weight in traditional thermodynamics. There, "work" and "heat" are placed on an equal footing and their sum accounts for changes in an object's total energy. For Roberts, however, the hiddenness of the heat component of energy leads him to map thermodynamics onto the structure of a gauge theory, placing it in the bundle space.

He says that taking this approach provides an opportunity to take what has already been proved about gauge theory in other areas of physics, and use it to gain a deeper understanding of thermodynamics.

For instance, temperature and entropy – two fundamental quantities in thermodynamics – can be defined in terms of a specific projection from the bundle space onto the observable space. Roberts says that this is a more geometrical definition of entropy than many previous ones, which makes it easier to apply to general systems, from engines to black holes.

NEIL G PATERSON/ALAMY

The laws governing heat apply to many situations in everyday life

Feeling the heat

Additionally, gauge structure has been connected to experiments when it comes to the quantum theory of electromagnetic fields, and Roberts anticipates something similar might happen with thermodynamics. Specifically, he says that preliminary experiments with certain molecular junctions hint at a thermodynamic version of the Aharonov-Bohm effect, an experiment in which a charged particle seems to experience a hidden magnetic field.

Roberts presented the work at the Foundations of Physics conference in Irvine, California, on 16 June.

Lucas Céleri at the Federal University of Goiás in Brazil says that Roberts's idea is beautiful and complementary to ongoing efforts to understand thermodynamics in the quantum realm as a gauge theory as well.

When applied to quantum objects, thermodynamics becomes even less well-defined and clear, says Céleri. "I'm worried about quantum thermodynamics because there are so many definitions of heat and work, for example. So, if you can put this in a rigorous mathematical theory, then maybe we can formulate a [more] consistent and a unique understanding," he says.

He and his colleagues have been working to do so by turning to gauge theory, which Céleri says has so far been successful in reproducing some standard quantum thermodynamic results. ▮

AI put to work on Fermat's last theorem

Mathematicians are making quick progress in formalising the famous problem after turning to AI for help, reports **Matthew Sparkes**

IN A windowless meeting room of a central London hotel, academics are contemplating whether humans have a role to play in the future of mathematics, now that AI can prove theorems by itself.

The general mood is one of bewilderment at the recent jump in computer intelligence and excitement about the potential it unlocks – and perhaps a slight unease about what the future holds for them personally.

Twenty-five researchers from diverse fields and countries are here to spend a week working on formalising Fermat's last theorem with cutting-edge AI models. Fermat's last theorem puzzled mathematicians for centuries until it was proven in 1993 by Andrew Wiles. It states that there are no whole numbers a, b, and c that satisfy the equation $a^n + b^n = c^n$, where n is a whole number greater than 2. It is extremely easy to state, but very difficult to prove.

Now, Kevin Buzzard at Imperial College London is working on a five-year project to turn Wiles's 100 pages of mathematics into computer code called Lean, so that it can be formally checked for correctness and used as a foundation for further research.

Formalising mathematical theorems puts them into a configuration that allows computers to grapple with them, methodically working through the logic and exposing any flaws. Already, there are 2 million lines of formalised mathematics stored in a central repository called Mathlib.

This workshop has brought together mathematicians, computer scientists and AI experts in the hope that they can advance Buzzard's project to add Fermat's last theorem to this corpus by getting the latest AI models to do some of the heavy lifting. Groups are huddled around laptops, each displaying slightly different interfaces for one of the AI industry's leading models. The atmosphere is buzzing.

THE HISTORY COLLECTION/ALAMY

Pierre de Fermat's last theorem wasn't proven until 1993

Problems and sub-problems are split up, distributed and chipped away at by human brains steering AI. There were a total of 20,000 lines of code in the project before the workshop, says Buzzard. After just the first day, that had doubled.

The Formalising Fermat project was funded in 2024 and began slowly as Buzzard coded by hand. The pace picked up dramatically around December, he says, when the power of AI models to work with advanced mathematics seemed to grow rapidly. Then, in May, an 80-year old problem posed by Paul Erdős was solved by machine, taking the field totally by surprise. The whole affair has forced Buzzard to rethink things.

"I was always quietly confident that we were going to succeed. But now we're two years in and AI has got so good that now my instinct is, this is ridiculous – what I said I'd do is ridiculous. Let's just do something 10 times better," he says.

Wiles's proof may have stretched to around 100 pages, but it relied on another 2000 or so pages of mathematics from the 1960s, 70s and 80s. Buzzard's original project was to formalise only the final paper – or more recent improvements of it, at least – but assume that everything it rested on was correct.

If the whole set of theorems were a pyramid, Buzzard had intended to start climbing from 90 per cent of the way up, where the really interesting problems lived. But now he thinks it is possible to tackle the whole thing for the sake of completeness.

He is confident that, by the end of his five-year project, he will have done what he originally set out to do. How AI progresses in the coming years, how expensive it is to access and how this workshop goes will determine how far he gets on the rest of the pyramid.

A variety of tools are in use here, from the free and open source to the latest and most expensive models. Nobody at the event can say precisely how much money is being spent on tokens, the units of AI intelligence by which access is charged, but most agree that it will run into thousands of pounds a day. "I'm burning tokens like I'm not paying the bill, definitely," says Hang Lu Su at Imperial College London, who used ChatGPT to teach herself Lean.

A layer of slop

But to solve these knotty problems, the group will need quality as well as quantity. Su says that she and a colleague were both trying to formalise the same bit of maths on the first day of the workshop. She arrived at an 800-word solution, while her colleague found a 400-word one. Both could equally be said to have proved the theorem in question. But the shorter version, compiled faster, would be easier for AI to work on going forward and was also more easily comprehended by a human.

Many of the curators of the Mathlib library are cautious about adding lots of this AI-generated Lean code, even if it proves theorems, says Buzzard. Currently, the code in that library is expertly and carefully written by human mathematicians, who ensure it is efficient, concise and readable to humans. It is a solid foundation for future work. The code being created at this workshop is rather different.

"We're building a layer of slop on top – let's just call it slop – and now the question is, what happens when we try to move the next layer? Can we build the next layer on top or does it just grind to a halt?" asks Buzzard.

"There were 20,000 lines of code in the project prior to the workshop. After the first day, it had doubled"

These advances are also throwing up philosophical and existential questions for mathematicians. At the very least, the tools available to researchers are changing, and therefore so will their job – but at the most techno-optimist end of the spectrum, AI may end up taking over and expanding the borders of known mathematics on its own, outpacing and replacing human thought.

"We're all doing [maths] because we love it, and we think it's important. But now AI is coming along, and suddenly the question is, actually, why are we doing this? What's the point of it?" says Buzzard. "If a machine proves a theorem but no human can understand it, then what have we achieved?" ▮

Physics

Special relativity seen warping chemical bonds for the first time

Karmela Padavic-Callaghan

THE chemical bonds within molecules can be reshaped by special relativity – and now researchers have seen it happen.

Albert Einstein's theory of special relativity describes how moving at speeds close to the speed of light would affect travellers' experience of space and time. It is usually associated with particle accelerators and spacefaring objects, but within some heavy atoms, electrons experience relativistic speeds too.

Lai-Sheng Wang at Brown University in Rhode Island and his colleagues have now managed to take an unprecedented look at how this breaks the standard notion of chemical bonds within a charged molecule made from bismuth and carbon.

In the molecule, a bismuth atom and a carbon atom were connected by three bonds, one of which the researchers expected to be of "sigma" type and two of "pi" type. The difference between these two types stems from electrons' quantum character – each electron is "smeared" across some region of space, instead of being a tight ball, and whether these regions overlap head-on or side by side determines the type of chemical bond they create between the atoms.

"Within some heavy atoms like bismuth, electrons experience relativistic speeds"

In their experiment, Wang and his colleagues mapped the distribution of electrons throughout the molecule, effectively getting a look at its bonds. But instead of seeing electrons distributed in shapes associated with sigma and pi bonds, the team noticed that two of the bonds resembled two different mixes of sigma and pi shapes. "Their characters are different from our normal understanding," says Wang. "You can't really call it the sigma and pi."

His team turned to Kirk Peterson at Washington State University, whose calculations showed that this mixing was a consequence of electrons near the bismuth nucleus feeling such a strong electromagnetic interaction that they moved at relativistic speeds (*Science*, doi.org/hb9zk2). Peterson says this effect hadn't previously been captured in an experiment.

"The hardest thing about [studying] heavy elements is a lack of really good experimental data," he says. "To have such a beautiful experiment to be able to essentially compare very high-level theory to data is really a luxury."

Wang says one important part of the new experiment is that he and his colleagues could make the molecule very cold before looking at its electrons. This dampened any excitations that would have made the final images imprecise.

"As you go down to the bottom of the periodic table, the usual quantum mechanics is no longer sufficient. You need to take into account the effects of relativity," says Trond Saue at the University of Toulouse in France. He says that all elements in the same row of the periodic table as bismuth are subject to relativistic effects – for instance, gold would be the same colour as silver and mercury wouldn't be liquid without them.

Wang says that the researchers want to repeat the experiment but swap bismuth for elements close to it in the periodic table to see when exactly special relativity makes the traditional chemical bond structure collapse. ▮

Evolution

Ancient worm preferred to turn right

A 555-million-year-old worm had a predilection for turning right, possibly indicating the oldest known example of handedness.

The development of a tendency to favour one side over another is evidence of an advanced nervous system. It remains a feature of free-living mobile life today, but until this discovery, it wasn't thought to have emerged until the Cambrian Period, which began around 541 million years ago.

Scott Evans at the American Museum of Natural History in New York and his colleagues analysed 100 fossil specimens of a small flatworm-like creature, *Spriggina floundersi*, collected in South Australia over recent decades. This lived in what was a shallow ocean and is thought to have foraged on or close to the seafloor, moving by wriggling to the left or right.

SCOTT EVANS/AMNH

The fossils are mirror-image impressions of worms bending to the right

"We have around 50 specimens of *Spriggina* that are clearly bent," says Evans. Twice as many of the fossilised worms are bent to the left than to the right, he says. This means the creature itself bent to the right, as the specimens are mirror-image impressions of the animals, made when storms buried them in sand (*Scientific Reports*, doi.org/rfcd).

"Some specimens have multiple bends to both the right and left, suggesting that they all could bend both ways, which makes sense if you don't want to be stuck moving in a circle," says Evans.

"The presence of handedness in any kind of functional asymmetry, really deep into the fossil record, gives us important and interesting information about how these behaviours have evolved and how deeply in time they emerged," says Russell Bicknell at Flinders University in Adelaide, Australia. ▮

James Woodford

Neuroscience

Allergy culprit also boosts our memory

Michael Le Page

IN MOST of the body, histamine triggers an immune response, as people with hay fever know only too well. But in the brain, it seems to have a completely different role, with a small experiment demonstrating that boosting histamine levels improves the accuracy of our memory by around 10 per cent.

"We think it's changing something called novelty-linked arousal," says Michael Colwell at the University of Oxford. "So, how alert we feel when we see new things in the environment."

It has long been known that there are receptors in the brain for detecting histamine. "They are densely packed around areas of the brain which are involved in learning and memory," says Colwell. Animal studies support the idea that histamine is involved in learning.

This might explain some of the memory-related side effects of early antihistamine drugs, says Colwell. "A lot of those older ones got into the brain," he says. "They would have made people less able to remember things, which you often see when people were taking those antihistamines for a long time."

But what happens if the levels of histamine in the brain increase? There hadn't been a way of testing this in people, but Colwell and his colleagues realised an existing drug called pitolisant, which is used to treat narcolepsy, has this effect. It binds to so-called histamine 3 receptors and raises the molecule's levels throughout the brain, he says.

To put it to the test, the researchers recruited 60 volunteers and gave half of them pitolisant and half a placebo. They then imaged their brains in an MRI scanner while they did various memory tests. The scans showed that, in those given pitolisant, there was greater connectivity between the parts of the brain where histamine is made and the hippocampus, an area involved in memory. These people were also 11 per cent more accurate in retrieving information learned while they were in the scanner (*Nature Communications*, doi.org/rfcj).

But it would be a mistake to try to use pitolisant as a "smart drug", says Colwell. "I would imagine it's going to really affect sleep, and that's going to make your memory much worse in the long term."

Roland Seifert at Hannover Medical School in Germany says the findings confirm the results in non-human animals apply to people, too, and that this may boost interest in treating various brain conditions by targeting histamine receptors.

People who take pitolisant to help treat narcolepsy or a genetic condition called Prader-Willi syndrome have previously reported improved attention and alertness, says Holger Stark at Heinrich Heine University Düsseldorf in Germany, who helped create the drug.

> "It's changing how alert we feel when we see new things in the environment"

"A recurring finding has been that pitolisant can help restore impaired cognitive function and improve attention when these are compromised by disease," he says. "In most cases, however, the effect has been to normalise impaired function rather than to enhance cognition beyond normal levels." ▮

Health

Resuscitated retinas respond to light

Helen Thomson

HUMAN eyes have been kept active outside the body for up to 10 hours after death. Supplying donor eyes with blood and oxygen meant they continued to respond to light, while also preserving their structure and health for 24 hours.

"This work undoubtedly represents an important step towards the possibility of whole-eye transplantation," says Thomas Johnson at Johns Hopkins University in Baltimore, Maryland, who wasn't involved in the research. "Maintaining light responses outside of the body is a tremendous feat."

More than 1 million people in the UK are blind or partially sighted because of an irreversible eye condition, such as age-related macular degeneration, which affects the retina, the light-sensing tissue at the back of the eye.

Treating the retina is challenging, as it is connected to the central nervous system. It is also extremely sensitive to degeneration induced by oxygen loss, known as ischemia. "Even a brief period of ischemic time is likely to cause irreversible degeneration of light-sensitive neurons and circuits," says Johnson.

To try to reduce this damage, Eimear Byrne at the Barcelona Institute of Science and Technology in Spain and her colleagues created a system that involved inserting a flexible tube into the ophthalmic artery, which supplies blood to the eye and surrounding structures. They then perfused the donated eye with an oxygenated solution using a custom-built device they call the Eye-in-Care-Box, which uses sensors to automatically regulate pressure and flow.

To test the technique, the researchers took both eyes from six donors, perfusing one but not the other each time. The perfusion system preserved the structure of the retina and maintained the health of surrounding cells for up to 24 hours, while the non-perfused eyes degraded quickly after removal.

MINFOTOVERDENALAMY

Eye transplants could one day help improve someone's vision

They then perfused another 36 donor eyeballs and found that 15 of their retinas produced electrical responses to light, similar to those measured in living people. The responses lasted for up to 10 hours after death, double the 5 hours other scientists achieved in 2022 (bioRxiv, doi.org/rfcg).

Another major challenge remains before doctors can restore vision via a transplanted eye: regenerating fibres in the severed optic nerve so it can connect to visual centres in the brain. "Without this, a donor eye will have no way of communicating visual sensation to the recipient's brain," says Johnson.

The new work doesn't solve this, but, by keeping the eye metabolically healthy after death, it may make future vision-restoration strategies more feasible, ensuring donated eyes are less damaged by ischemia. ▮

Environment

How to prevent a super El Niño

Seeding clouds with seawater could shade the eastern Pacific and reduce the temperature spike from El Niño, but there could be unexpected consequences, finds **Alec Luhn**

SHORT-TERM geoengineering to brighten clouds over the eastern Pacific Ocean could limit the damage caused by El Niño and save the global economy trillions of dollars, although there could be winners and losers from the disruption of natural cycles.

The El Niño climate phase occurs when easterly winds weaken, allowing warm water built up in the western Pacific to slosh back across the central and eastern parts of the ocean. That heats the atmosphere and raises global temperatures, with losses to economic growth estimated in the trillions of dollars.

What could become a very strong or "super" El Niño is now developing in the eastern Pacific. But climate modelling has suggested that, in the future, a geoengineering method called marine cloud brightening might be able to cut this warming short.

The technique involves spraying tiny droplets of seawater into the air below low-lying stratocumulus clouds, where moisture condenses onto them. The clouds become whiter thanks to the increase in the number of droplets, reflecting more sunlight back to space.

"You can basically stop the dominoes from falling early when you do marine cloud brightening"

Shading part of the eastern Pacific called the Niño 3.4 region via cloud brightening could interrupt the feedback loops that cause an El Niño to develop. Cooler sea-surface temperatures would strengthen the trade winds to again blow warm water back into the western Pacific. More cool water would then well up from the depths of the eastern Pacific, further cooling surface temperatures, and so on.

NIK WHEELER/CORBIS VIA GETTY IMAGES; BELOW: NASA EARTH OBSERVATORY

Increasing cloud coverage could reduce warming from El Niño

"You can basically stop the dominoes from falling early when you do marine cloud brightening," says Jessica Wan at the University of California, San Diego. "We're kicking the cycle in the other direction."

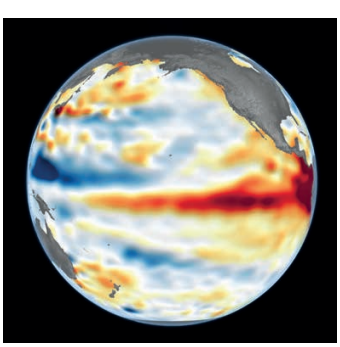
Wan and her colleagues got the idea from the "black summer" of catastrophic bush fires in Australia in 2019-2020, which were followed by La Niña, the opposite phase of El Niño that lowers global temperatures. Research has suggested that drifting smoke particles brightened clouds and cooled the eastern Pacific, intensifying and prolonging the "triple dip" La Niña that began in 2020 and persisted through three winters, rather than just one or two.

The study modelled what cloud brightening could have done to the super El Niño events of 1997-1998 and 2015-2016. It found that nine months of spraying seawater would have nearly halved warming of the Niño 3.4 region, from 2°C or more to a little over 1°C. It would have ended the El Niño by January, shaving several months off the events (*Science Advances*, doi.org/hb9vfh).

The hypothetical cloud-brightening mission would have been massive, involving an estimated 2400 ships and delivering an amount of seawater spray that isn't possible with current nozzle technology. But it would have turned a super El Niño into a moderate one.

Wan says she was surprised how well it seemed to work, given that it could only be started in June, once El Niño had clearly begun developing.

El Niño causes higher sea surface temperature (red) in the Pacific Ocean



Mat Collins at the University of Exeter, UK, warns that these results might not translate to the real world, where warming seas typically start dissipating low-level clouds, leading to further warming and dissipation through a feedback loop.

"In a model with a stronger cloud feedback, you would have to do more aerosol injection," he says. "The experiments seem to be at the limit of what can be done."

Wan admits this approach could have unexpected consequences, since the model only projected the impact over two-year periods. In both simulations, La Niña started earlier after El Niño subsided, and in the 2015-2016 case, this subsequent cooler phase became stronger. That could be bad news for regions like the Horn of Africa, where strong La Niñas have, in the past, disrupted rainfall and contributed to widespread famine.

But she says the idea is worth further research. Unlike geoengineering aimed at reducing global temperatures for the long term, short-term geoengineering like this could avoid the risk of "termination shock", where any disruption to the spraying of low-level seawater or stratospheric aerosols could allow years of pent-up warming to come roaring back.

"This study is opening up doors for a completely new target for geoengineering research, which is climate variability and things like El Niño," says Wan. "It's potentially very powerful, because you're not locked into these long-term risks." ▮

Quantum computing

Peter Shor's algorithm could break the internet – but he's not worried

Karmela Padavic-Callaghan

"SO, HE'S the Beyoncé of this event?" a young woman standing behind me says to a colleague. The three of us are looking at the back of a crowd, whose members are all watching a bearded man in an orange sweater. Getting a look at him is like trying to see the *Mona Lisa* – only fleeting glimpses are possible. "His algorithm is the algorithm that will break everything," the colleague says, as I briefly catch sight of people posing for selfies and getting their conference badges signed.

I'm at the Quantum.Tech World conference in Boston, and Peter Shor is the star attraction. Shor is one of the most influential researchers in the history of quantum computing, and it all comes down to his creation, known as Shor's algorithm.

In the 1990s, Shor was at Bell Labs in New Jersey. Quantum computers were barely on his radar, until he attended a seminar by the quantum computing pioneer Umesh Vazirani. There, he heard about a problem that quantum computers could solve better than any conventional computer. The problem was extremely contrived, so Shor wondered whether there was something more practical that quantum computers could be good at, too.

Over the course of about six months, culminating in the spring of 1994, he not only identified such a problem – the factoring of very large numbers – but he also developed a recipe that a quantum computer could follow to solve it. Shor's algorithm, the one that could "break everything", was born. It quickly became recognised as an outstanding contribution to the field and gave researchers an urgent reason to actually build quantum computers.

Most modern encryption relies on the mathematical task of factoring very large numbers. As long as computers struggle with this task, our digital data, from emails and medical files to bank transactions, remains safe. But a quantum computer running Shor's algorithm would be exceptionally good at this. So good, in fact, that a sufficiently powerful quantum computer could use it to decrypt our most secure data.

Yet, during a rare quiet moment at the conference in Boston, Shor tells me that he isn't worried.

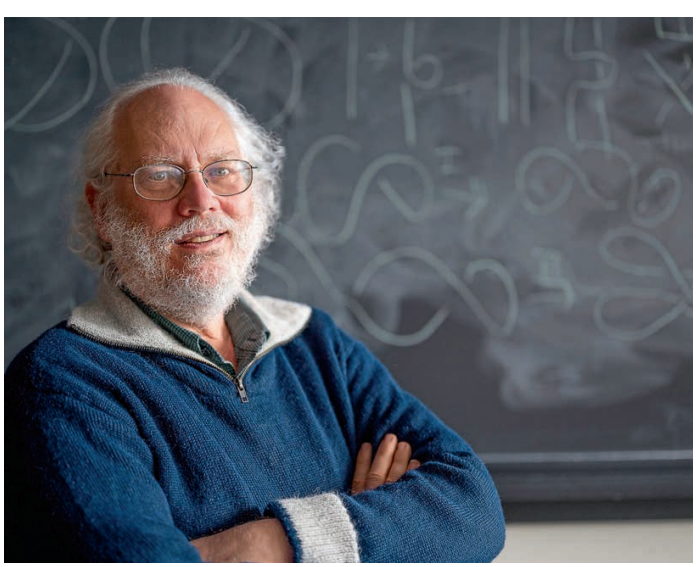
"We have good methods for post-quantum cryptography, we just have to implement them"

"We have good methods for post-quantum cryptography, we just have to implement [them]," he says. He pauses, then adds the caveat: "This will be incredibly hard."

Indeed, there are ways of encrypting information that are resistant to his algorithm, and institutions like the National Institute of Standards and Technology (NIST) in the US have established quantum-proof encryption standards, but adapting them will be both difficult and costly. Large institutions like banks may need years just to audit their communications networks for possible weaknesses, then an equally long amount of time to update their systems.

The clock is ticking. The best existing quantum computers aren't yet reliable and computationally powerful enough to run Shor's algorithm, but recent years have seen fast progress in terms of both quantum computing hardware and software. Tech firms like Google are now targeting 2029 to complete their migration to post-quantum cryptography, and US President Donald Trump recently signed an executive order requiring that all high-value and high-impact systems within the US government do so by 2031.

"[Quantum computers] are still toys, but they'll stop being toys very soon," says Shor. He tells me that he is impressed with the work researchers have done to make quantum computers bigger, which also increases their computational power. Efforts across academia and industry to improve how quantum computers catch and correct their own errors have been incredible too, says Shor.



CHRISTOPHER HARTING

Peter Shor: "Quantum computers will stop being toys very soon"

A lot to learn

He says that people are wrong when they think that anything you can do with a conventional computer, you could do faster with a quantum computer. "I don't think that quantum computers will help predict the stock market," he says.

In his view, the set of problems that quantum computing researchers ought to target is fairly narrow. Beyond cryptography, key applications will simulate complex systems from quantum mechanics and molecules of interest to chemistry and biomedicine, says Shor. He is particularly interested in optimisation algorithms, which he says may have been dismissed too quickly by some.

Yet he acknowledges that, so far, developing more truly useful quantum algorithms has proved difficult. Why has no one created an algorithm as meaningful and powerful as his? He suspects that that we are either not smart enough to develop more great quantum algorithms or that quantum computers simply aren't useful for all that many tasks.

I can't help but ask him what he thinks we ought to do to get smarter. We should play with actual quantum computers to see what they can do, and try some weird ideas, he says. "But you have to understand all of quantum mechanics and all of computer sciences, and that's really a lot to learn." ▮

Animal behaviour

The inner lives of bumblebees

James Woodford

BEES seem to show when they are pleased and like something, rather than just need it, in one of the strongest signs yet that insects have subjective experiences.

In recent decades, it has become clear that bees are capable of more complex behaviours than we had thought, such as counting. But discerning whether they have inner states akin to our emotions is more difficult.

To find out, Andrew Barron at Macquarie University in Sydney and his colleagues ran a series of experiments involving buff-tailed bumblebees (*Bombus terrestris*). First, the team offered the bees a water droplet containing sugar, along with others that contained salt and quinine, while filming them using high-resolution video.

After tasting the sweet liquid, the bees repeatedly stuck out their glossa, which is a hairy tongue that they use to lap up nectar in flowers. After tasting the salty and bitter samples, the bees wiped their mouths and shook their heads.

To discern whether the responses were just a reaction to the different chemicals, rather than a sign of enjoyment or displeasure, the researchers reduced the concentration of the sugar and mixed it with a small amount of salt, resulting in a dramatic reduction of the glossa protrusions. Then they exposed the bees to 40°C (104°F) temperatures to dehydrate them, after which, when the bees were offered salty droplets, the bees repeatedly protruded their glossa.

"If I just handed you an electrolyte drink right now, you'd probably think, 'well, that actually tastes pretty foul'," says Barron. "But if you had just come back from a long run and I handed you an electrolyte drink, you'd think, 'that's fantastic'. It's

DAWN MONROSE/ALAMY

Buff-tailed bumblebees stick their tongue out when they enjoy food

because your internal state has changed, and that internal state is changing your evaluation of things – that's what we think we're seeing in the bees."

For the final part of their experiment, the researchers wanted to determine what would happen if they meddled with the chemistry that, in mammals, underpins appetite and the enjoyment of food.

When the bumblebees were treated with dopamine, which in mammals affects the motivation to seek food, their glossa protrusions didn't increase, suggesting that although they had greater desire, their enjoyment "tell" – tongue protrusions – didn't change. But when the bees were treated with endocannabinoids, which increases the "liking" of food in mammals, it led to an increase in their glossa protrusions (*PNAS*, doi.org/rd74).

"What this is showing us is that even from an animal like a bee, there is some sort of inner life for that insect," says Barron. "It's experiencing its world and it's not a robotic entity running on a program." ▮

Ancient humans

Hints humans and Neanderthals shared culture

ABOUT 59,000 years ago, *Homo sapiens* moved into a coastal cave in Turkey that was once home to Neanderthals. Yet the tools and trinkets found in the cave remained remarkably consistent, hinting the species had a shared material culture.

Situated on Turkey's Mediterranean coast, Üçağızlı II cave is a 56-square-metre space. Naoki Morimoto at Kyoto University, Japan, and his colleagues carried out the first full archaeological dig at the site in 2020. Teeth and jaw remains revealed that Neanderthals inhabited the cave from 77,000 to 59,000 years ago and our species, *H. sapiens*, from 59,000 to 47,000 years ago.

Altogether, nearly 20,000 stone artefacts were recovered. But, surprisingly, the stone-tool technology used by both species remained consistent. This raises the possibility that Neanderthals and *H. sapiens* co-existed.

"We cannot definitively prove a temporal or physical overlap between the two hominin species in the region of the site or the site itself," says Morimoto. "However, this is indeed a hypothesis we are exploring."

Across every layer of human occupation in the cave, the foundational toolkit was exactly the same, says Morimoto. More remarkably, the Neanderthals and *H. sapiens* collected a shell that seemed to have no useful purpose as a tool or as a food.

Nearly 30 examples of the shells of the sea snail *Columbella rustica* were found throughout all layers of deposits left by both species. In a few cases, these shells had their point broken off or had holes that may indicate a decorative purpose (*PNAS*, doi.org/rd8c).

"Neanderthals and *H. sapiens* collected a shell that seemed to have no useful purpose"

The "striking consistency" in both the stone-tool technology and the collection of shells is "difficult to explain by independent, parallel processes alone", says Morimoto.

Although there is no definitive evidence for friendly relations between the two species, this is the scenario the team is leaning towards. "What we propose is that a model involving regional contact, cultural exchange or overlapping occupational territories offers a plausible explanation for the archaeological evidence," says Morimoto.

John Gowlett at the University of Liverpool, UK, says the puzzle of the relationship between the species has gone from 100 to 1000 pieces. "They must have been aware of one another regularly and the implication may have been a very strong 'us and them' distinction, but this paper helps show that this did not need to mean separate material cultures or even hunting patterns," says Gowlett. ▮

JW

Sea snail shells were found with Neanderthal remains

NAOKI MORIMOTO

Salt batteries are about to shake up EVs and grid storage

Stand aside, lithium: batteries made with sodium ions hold the promise of being cheaper and less flammable, reports **Alec Luhn**

ON 5 February, a black sedan was speeding down an icy track in northern China at 95 kilometres per hour when its tyre burst, releasing a puff of white into the -32°C air. The car coasted to a stop without spinning into the snow. This was meant to demonstrate that even the harshest conditions were no barrier to the auto-maker Changan's new line of electric vehicles, which includes the first mass-produced EV with a sodium-ion battery.

Changan's Nevo A06 model is expected to hit the market later this year with a new, more powerful generation of sodium-ion batteries made by energy-storage giant CATL.

While most rechargeable batteries are made from lithium, a critical mineral, this kind of battery is made from salt, a much more abundant – and therefore cheaper – material. If sodium-ion batteries can perform almost as well at a lower price, they could challenge lithium's dominance. That could pave the way for other kinds of batteries, so that someday each type of device might have its own preferred battery chemistry.

"This is just the start of the battery revolution, in which we are going to see a plethora of new batteries coming to the market and targeting special segments," says Maria Crespo-Ribadeneyra at Queen Mary University of London. "Sodium is the pioneer that can prove that a world beyond lithium is possible."

While a predecessor of the sodium-ion battery was created by the firm Ford in 1966, companies only began to seriously develop the technology in the past 15 years, as electrification of the power grid and automobiles hiked demand for lithium-ion batteries. It works the same way, but sodium, rather than lithium, is dissolved in the electrolyte, and the electrodes are different compounds.

Storage solutions

But because sodium is three times heavier than lithium, sodium-ion batteries with the same storage capacity weigh more. Their potential was long seen as limited to electricity grid storage, since the extra bulk doesn't matter at a large facility, or to mini EVs with a small battery range.

A handful of sodium-ion grid storage plants have been built in China, Germany and the US. General Motors, the largest US auto-maker, just partnered with the start-up Peak Energy to build more. Peak Energy is also selling sodium-ion batteries to data centres, which can use them to store electricity at times of day when it is cheap. And the firm Eleven Energy has started installing sodium-ion home batteries in the UK.

Now, sodium-ion specs have improved to the point that the technology could break into the general EV market. A recent study by Moritz Schütte at Aachen University in Germany and his colleagues found that a sodium-ion battery by the manufacturer Hina rivals Tesla's lithium-ion batteries on most parameters, although it would still be a third heavier.

But CATL claims its sodium-ion battery has an energy density of 175 watt-hours per kilogram, which can compete with the lithium-iron-phosphate batteries in low-cost models from Tesla and others. And while sodium-ion batteries still haven't quite beaten lithium batteries on price, that could change as they expand, according to Schütte.

"The ramp-up of the sodium-ion batteries is fast," he says. "That means the production cost is getting lower and lower. The materials are getting more advanced with every generation. We don't know where it ends, at which energy density."

Sodium has other advantages, too. Lithium processing is energy-intensive and often has a large carbon footprint. China controls most of this industry, and supplies could be disrupted in a geopolitical conflict, such as over Taiwan. What's more, at sub-zero temperatures, lithium ions move through the electrolyte more slowly, which is why phones lose charge in the cold. In the heat, lithium electrolyte can erupt in flames or even explode.

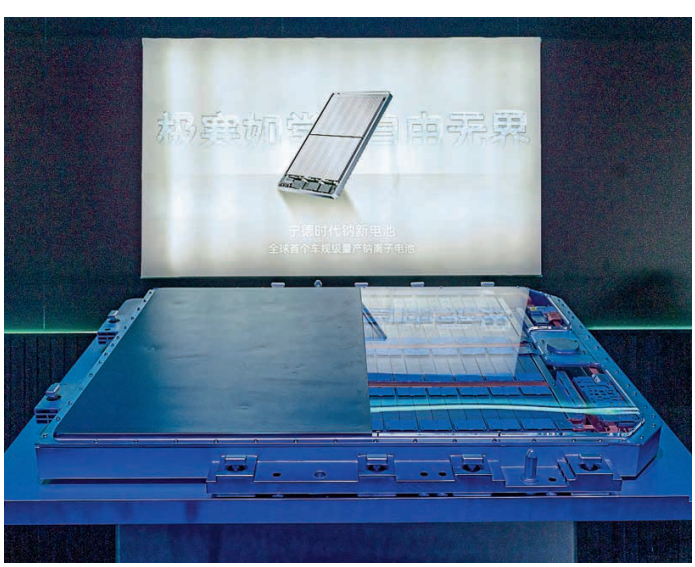
But sodium ions generate less heat in electrochemical reactions, reducing fire risk, so less money can be spent on cooling. They also form weaker bonds with the electrolyte, so they don't slow down as much in the cold.

"When the battery was sawed in half, it didn't catch fire and continued to power a light bulb"

At the launch in freezing northern China, CATL said its sodium-ion EV battery retains 90 per cent capacity at -40°C (-40°F). When the battery was sawed in half, it didn't catch fire and even continued to power a light bulb.

Elliot Richards, a Shanghai-based EV vlogger who attended the launch, calls the sodium-ion battery the "lithium killer". While high-end cars are likely to continue with lithium, sodium could dominate budget EVs, models for hot and cold climates, cargo lorries, and grid and home energy storage, he says.

"We're all underestimating probably how much this will impact everyone's daily lives," he says. "It's going to be a lot cheaper to own [an EV] than a combustion car; it's going to be a lot cheaper to get batteries into your home; it's going to be a lot cheaper for the energy provider to deliver energy to your house."



QILAI SHEN/BLOOMBERG VIA GETTY IMAGES

Sodium-ion batteries like this one by CATL could power electric vehicles

Heating up A short spell in a heat chamber showed **Alec Luhn** that his body isn't adapted to high temperatures – but regular exposure can train the body to respond more effectively

Alec Luhn is an environment reporter at *New Scientist*. He has filed stories from wildfires, droughts, earthquakes, melting glaciers and a polar bear "invasion". Follow him @alecluhn or Ice Mushroom on Substack

Alec's week

What I'm reading
The Beauty of Dusk, *about what journalist Frank Bruni came to perceive when he started going blind*

What I'm watching
Guy Ritchie's Young Sherlock, *a mystery engaging enough to take my mind off the heat*

What I'm working on
Growing a plant from jalapeño seeds

THE heatwave that hit Europe at the end of June was the hottest ever and came less than a month after another record-breaking heatwave in May. Now, another heatwave has started that is forecast to last even longer, bringing temperatures of up to 34°C (93°F) to the UK.

To better understand the impacts of this heat, I visited the University of Brighton's Environmental Extremes Laboratory, just across a field from the stadium of Brighton and Hove Albion Football Club, which has worked with the lab to assess players' fitness.

Spending just 10 minutes in a heat chamber was enough to show that, as heatwaves get more frequent and intense, I'm not prepared – and you probably aren't, either.

The heat chamber is a windowed room where researchers can control temperature, moisture and oxygen content, recreating the ambient conditions found at Mexico City's high-elevation World Cup stadium or in a European city during a heatwave.

"[Heatwaves] are here to stay, and we've got to help people get used to preparing for heatwaves and dealing with it, not on an off-chance, but on a regular, every-year basis, on multiple occasions," said lab director Neil Maxwell during my visit.

"Heatwaves are here to stay, and we've got to help people get used to dealing with them on an every-year basis"

On a dial outside the door, Maxwell and his colleagues set the temperature to 35°C (95°F) and the humidity to 50 per cent, similar to London during the June heatwave. They measured my heart rate and blood oxygen level with a fingertip pulse monitor and my skin temperature with an infrared thermometer pistol. They also asked me to rate how hot I felt and my level of exertion.

BILL NORTON

Alec spent 10 minutes on a treadmill in a heat chamber set to 35°C and 50 per cent humidity

As we entered the chamber, the heat hit me like a wall, and I had a twinge of nervousness. What was I about to expose myself to in the name of science?

To simulate moving around outside, the researchers had me start walking on a treadmill set to a 1 per cent incline. I began to sweat, but because the high humidity was slowing evaporation, it didn't cool me down much. In the oppressive heat, even this moderate walk became taxing.

After 5 minutes, the thermometer showed my skin temperature had risen from 33°C to more than 36°C. My body was shunting warm blood from my core to my skin to try to shed heat, explained Maxwell.

My heart rate had also jumped, from 72 beats per minute to 81 beats per minute. As I sweated out water, my blood was thickening, forcing my heart to pump harder.

After 10 minutes of plodding, I was feeling tired, and my heart rate had reached 95 beats per minute. I felt light-headed as Maxwell helped me off the treadmill and into a chair outside the chamber.

I asked him how I'd done. "You're not heat-adapted," he said. Even relatively healthy people can be at risk, he added.

Maxwell handed me a strawberry ice pop, which not only tasted heavenly, but also started cooling my body from the inside. Then he had me plunge my hands into a tub of cold water. The hands, feet and ears have dense concentrations of arteries, veins and capillaries. Targeting those areas can cool large flows of blood.

"We get people's temperature to drop so much quicker by using that method," said Maxwell.

Simple actions like taking a cool shower – not too cold, or the blood vessels will constrict – can be surprisingly effective. But surveys Maxwell and his colleagues are doing show that only a small fraction of the UK population takes measures for protection from the heat. He pointed out that I had come without a water bottle, even though it was a warm day.

In the long term, we need to teach people how to improve their bodies' heat tolerance, says Maxwell. To start with, aerobic exercise like jogging makes your heart better at moving blood to the skin.

Then there's heat exposure. A one-person sauna tent was standing off to the side of the lab. Regular sauna sessions can teach your blood vessels to dilate quickly and your skin to sweat more. Your sweat even gets less salty, preserving your electrolyte levels.

"The narrative at the moment is [that] we've got to get rid of heat; heat is bad, bad, bad," said Maxwell. "I think we need to change that narrative to: safe heat can actually be therapeutic."

After I got home, my head hurt, and I felt hot and thirsty. I decided I need to go to the sauna more. As for the jogging, well, I'll work on it.

Purple patch Some marathon runners and other athletes swear by beetroot juice shots, but is there evidence they really do anything for our bodies? **Alice Klein** investigates

MY FRIEND Lizzie, a very athletic doctor, recently showed me some concentrated beetroot shots she was planning to take before an upcoming marathon. I never run anywhere, but she let me try one anyway. I could only manage slow sips of the intensely beetroot-tasting purple liquid, but she assured me it has a raft of benefits for athletes and non-athletes alike. I decided to look into it.

Most beetroot research, I discovered, has been led by Andy Jones, an exercise physiologist at the University of Exeter, UK. His team's interest arose because it is a natural source of nitrate. In the body, nitrate is converted to nitric oxide, an important signalling molecule that causes blood vessels to widen. This reduces blood pressure and allows more oxygen-rich blood to flow into muscles.

In their first beetroot study, published in 2009, Jones and his colleagues asked eight recreational athletes to cycle hard for as long as possible. They lasted about a minute-and-a-half longer, on average, when they had consumed beetroot juice daily for six days beforehand, compared with when they had blackcurrant juice.

Since then, Jones's team and others have shown that beetroot juice gives an edge in a range of athletic pursuits, including swimming, running and rowing. Beetroot shots have been credited for assisting Eliud Kipchoge's marathon records and Jonas Vingegaard's Tour de France wins. The International Olympic Committee lists nitrate (from beetroot or other sources) as one of only five dietary supplements with "good to strong evidence of achieving benefits to performance" (the others being caffeine, creatine, sodium bicarbonate and beta-alanine).

But what about for those of us who are firmly in the non-athlete category? I don't think any amount of beetroot juice could turn me into a marathon runner, but it might make exercising a little bit easier and motivate me to do more. A study by researchers at the University of Alabama at Birmingham found that adults with obesity took longer to reach exhaustion in a cycling test after having a beetroot shot, hinting that the supplement may "assist easing the burden of exercise and perhaps improve participation in and adherence to exercise".

Drinking beetroot juice may make exercise a little bit easier

SHUTTERSTOCK/KUVONA

One thing that seems clear is that daily beetroot juice can slightly lower blood pressure in people with hypertension, by around 5 mmHg for systolic blood pressure. This isn't as effective as anti-hypertensive medication, which usually lowers systolic blood pressure by around 10 mmHg, but it may be a useful add-on. A study by researchers at King's College London published last month found that chewing sugary gum after drinking beetroot juice lowers blood pressure even further, because it enhances the activity of bacterial enzymes in the mouth that kickstart the chemical reactions that turn nitrate into nitric oxide.

On the other hand, people with low blood pressure are advised to be careful with beetroot juice because they could feel dizzy or lightheaded if their blood pressure drops further. Beetroot juice is also moderately high in natural sugars, so large quantities may not be suitable for those with diabetes.

If you don't like beetroot, you can also get nitrate from other foods like spinach, rocket (also called arugula), lettuce, celery, tomatoes, bananas and oranges. I personally don't think I could stomach daily beetroot juice, but I do like the vegetable whole, so I plan to eat more salads with roast beetroot and burgers with sliced beetroot in the hope that they might slightly lift my energy levels. My friend Lizzie always gives me good health recommendations, and in this case, it seems she hasn't missed a beet. ▮

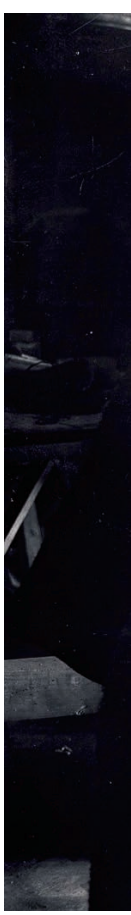
Alice Klein is a reporter at *New Scientist* based in New South Wales, Australia, who mainly writes about health, biology and the environment

Alice's week

What I'm reading
The 2018 book Superhuman *by my colleague Rowan Hooper*

What I'm watching
Every minute of the FIFA World Cup

What I'm working on
My next column on beef liver supplements



On thin ice

Royal Geographical Society Riverside Press

AFTER the British ship Endurance (far left) became stuck in ice in the Weddell Sea off Antarctica in January 1915, the expedition's photographer, Frank Hurley, made a brave decision. He waded into the icy water filling the lower deck to rescue hundreds of his precious glass-plate photo negatives.

To Hurley's dismay, Ernest Shackleton, the expedition leader, informed him he would have to abandon most of the negatives as they would weigh down the lifeboats. Hurley smashed 400 of them on the ice, salvaging 120.

The Endurance sank for good in November 1915. After months on the ice, the crew moved to Elephant Island in April 1916. From there, Shackleton took the James Caird lifeboat (top, near left) on a journey across the Southern Ocean to seek rescue.

The UK's Royal Geographical Society has now published *The Endurance Photographs*, a compilation of Hurley's images. New, high-definition scans uncover previously hidden details, like a sixth crew member, hidden behind the smoke from the stove (bottom, near left). Below is Hurley's shot of Leonard Hussey lifting the expedition's largest sledge dog, Samson.

Alice Klein

‘I’d throw myself in front of a *T. rex*’

As **Chris Packham**’s new show *Evolution* airs, he tells Penny Sarchet why it is vital we change our relationship with nature – and some unexpected details about his favourite animals

IN *EVOLUTION*, an ambitious new five-part TV programme, broadcaster and naturalist Chris Packham fleshes out the evolutionary backstories of five beloved animals. From elephants to ostriches, he takes us all the way back to the last universal common ancestor of all life on Earth, and with the help of CGI, he introduces us to pivotal ancestors along the way.

He reveals why understanding the latest evolutionary science is so important if we are to truly appreciate the natural world; why he likes adding more science to *Springwatch*, the BBC nature programme he co-hosts; and how he would happily die at the hands of a *Tyrannosaurus rex*.

Penny Sarchet: Congratulations on the show. What drew you to the subject of evolution?
Chris Packham: We like a challenge. We’d risen to that with our previous series, *Earth*, looking at enormous time spans and inconceivable events. To take something that big, that complex, and make it comprehensible was a challenge, and *Earth* was very popular. I think people took a lot from it. So, evolution – again, something perceived to take a long time and to be inordinately complex – was something we thought we would rise to.

We learned some lessons with *Earth*. We didn’t approach evolution in the school-room sense, starting with the first cell and working through to the present. We chose five iconic animals to carry a narrative about the evolution of locomotion, intelligence, feeding and reproduction, etc. That gave us the capacity to come up with some surprising stories which are accessible and engage our audience. I like the idea that we start our programmes with little things they will be so excited by that they’ll have to pick up their mobile [phone] and text it to their mates, or tell them down at the pub.

I thought it was very engaging, the way you go several levels deeper with each animal. For example, with bats, you look not just at how they evolved to fly at night, but the whole story of why animals began to feed.
I think the fundamental things can be the most surprising for people, [but] sometimes we don’t ask those questions. We get through childhood when we should have been asking those questions – why is the sky blue, why do stars twinkle – and then we find ourselves as adults and we kind of forget about them. But if you bring [science] back to basics and look at it in a not-childish but child-like way, it can be joyous.

Another key thing was to identify [for] these iconic animals the key turning points. We can use CGI to rebuild some of the creatures that otherwise we would be talking about in a purely conceptual way, or we might have a fossil model. It’s those turning points I get the most joy from – little things like gills becoming jaws, and then part of the jaw becoming ear bones that give us the capacity to hear. You don’t normally think about that.

And bats need to eat half their own body weight every night. How are they going to do it? Well, they need their ears, and in fact, that’s part of the mechanism they’re actually eating with. I love all those things coming together.

I was excited to see things brought to life. When I studied evolution, it was dusty fossils and textbook ideas. Now, CGI and scientific detail have come together very well.
Science is never standing still. What we’ve done is to tell that story in a different way, using CGI plus what we know now. We’re not saying we have all the answers. One of the trials of making this programme is that sometimes there are several groups, and they disagree. So, we either have to build in ambiguity, or to say there are two theories. I quite enjoy not knowing, because it gives the programme and people’s imagination somewhere to go.

BBC STUDIOS/TOM HAYWAR

How did the elephant get so big? Chris Packham probes a 4-billion-year-old story

What can a deeper appreciation of evolution bring to our love of wildlife?
There is a misconception that we [humans] are the be-all and end-all of evolution. We are a remarkable organism – inventive, creative, imaginative, resourceful, resilient and so on. But we’re not “it”, you know. Evolution continues, and will always, whatever we do. It’s not about us, it’s about life – we are not isolated, we are part of nature, we are dependent on nature.

That’s something we really do need to reinforce, because we’re doing so much harm to nature and ourselves. We’re never going to look after it unless we care about it. David [Attenborough] has done a sterling job engaging people with wildlife and nature, getting them to develop a deep-rooted affinity for it. No one could have done more, frankly.

But now we’re in a different space – they don’t have to just love it, they’ve really got to care about it. And I care about things more if I know more about them.

If you could travel back in deep time, what would you want to see?
I’m the kid that grew up with *T. rex* as the best animal in the world. Big, fierce and, most importantly, extinct. When I was a kid, I never imagined that I would know what *T. rex* looked like. If you were in a

classroom and you got the felt-tip [pens] out, everyone would do *T. rex* in a different colour, and my perception was that we would never know what colour that dinosaur was.

However, I'm 65 years old now. We've had 60 years of rapidly advancing palaeontological knowledge, and we've completely redefined that animal. We've learned more in the last 60 years than the past 65 million years.

For me, [it] is enormously exciting to see that animal evolve through scientific discovery.

But there are questions about it that we don't know. So, if I'm trickling towards the end of my life and you offer me 5 minutes in a time machine, I'm [going to] the Cretaceous. I want to know what colour it was, how it was hunting. And if it didn't interrupt the space-time continuum, I'd throw myself in front of it to be consumed.

What a way to go!
It'd be great on the tombstone, wouldn't it?

I liked that you don't just meet the five-star animals in *Evolution*; you also see modern relatives and analogues for important ancestors. Did you have any favourites?
The little velvet worm. I'd seen velvet worms in books, photographs and film, but I'd never met a velvet worm and they are just so unbelievably weird. When the little velvet worm came out on the log, that was amazing.

I really liked the lungfish. I've read about them but I'm not sure I'd ever seen video.
Oh, the lungfish! Really slimy, quite bitey, gulping. The legs [limbs] looked like tentacles, but they're not, they're articulated. That was another really special moment. Behind the scenes, scientists turn up and tell you everything they know, and you try to get as much of that in the script that is relevant. I was talking to the lungfish man for about 2 hours! Should have made a separate programme...

You're always bringing science into *Springwatch*. Could nature programmes in general benefit?
I started doing research at a very young age, I published stuff before I got to university. I was mentored by some really great scientists and

"We are a remarkable organism – inventive, creative, imaginative, resourceful, resilient. But we're not 'it'"

I love science. When they said, do you want to make *Springwatch*, I thought: yes, but I've got to bring something to it.

The benefit of *Springwatch* is we can bring science about species which people are very familiar with, back garden animals, things flying round their neighbourhood. Scientists did some experiments where they offered swallows the choice between white feathers and coloured feathers to line their nest, and they found that 75 per cent of the feathers they chose were white. We see that this is because they're broken down by particular bacteria which produce antimicrobials, which mean that they have a higher hatching rate and fledging rate with more white feathers.

I've known swallows all of my life. Our audience have known swallows. I can't think of anything more exciting on *Springwatch* this year than knowing that those little birds, when they're flying around, they're choosing the feathers to line their nest to improve the chances of getting their chicks on the wing – it's absolutely brilliant!

What do you hope the audience will take away from watching *Evolution*?
I hope they'll be excited, I hope they'll be surprised, I hope they'll rethink what evolution is and what it means, and most importantly, I think that they'll think about what the context is for this point in time.

When you think of the beauty of evolution and the way that it's worked, yes, there are processes, but there has also been an enormous amount of chance. We are so fortunate to be here at this point, on this one little blue dot floating in space with this enormous richness and diversity of life, thanks to evolution – do we really want to mess it up? ▮

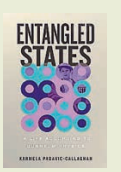
Listen to the full interview on our podcast, *The World, The Universe and Us*. *Evolution* is airing on BBC Two and is available on BBC iPlayer now

New Scientist *recommends*

Alison Flood
Head of books
London

I started my colleague Karmela Padavic-Callaghan's first book, **Entangled States**, with trepidation. How could they deliver on its subtitle, "a life according to quantum physics"? I finished it with both a better understanding of all things quantum and a deeper desire to understand myself after reading Karmela's own thoughtful journey as a queer, millennial immigrant.

This is a unique blend of memoir and science writing, in which Karmela interweaves growing up in Croatia, moving to New



York, doing a physics PhD, teaching in high school and working as a *New Scientist* reporter with big physics concepts.

So, how do you make links between, say, indefinite causality and a life-threatening tooth infection, or wave-particle duality and the realisation that you are queer? Somehow, Karmela does, and it all works to create a book that is clear and friendly on a scientific level, and candid and insightful on a personal one.

What horses are really saying

There is much to like in this exploration of horse "language" and the equine mind, but beware unexpected flaws, says **Christa Lesté-Lasserre**

Book

A Horse's World

Janet Jones

Little, Brown and Company

ALLISON RAGSDALE PHOTOGRAPHY

Neuroscientist and horse trainer Janet Jones with her horse, True North

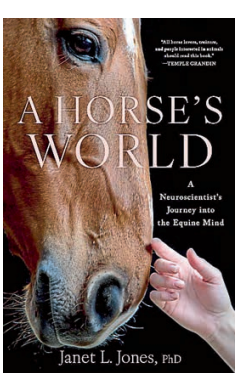
"People often tell me they wish their horses could talk," writes Janet Jones, equestrian, neuroscientist and international bestselling author. "But in fact, horses talk to us all the time, just not in speech. Every movement has a meaning; most people just don't know how to decipher it."

Readers might recognise Jones from her 2020 hit, *Horse Brain, Human Brain*. But this strikingly accurate, if not provocative statement comes from chapter six of her new book, *A Horse's World: A neuroscientist's journey into the equine mind*. It echoes what horse behaviour scientists have said for years: seemingly quiet, stoic beasts, horses are communicating endlessly, but we humans are so brutishly reliant on loud, spoken speech that we tend to miss it.

Jones, it seems, does not. As we find throughout the book, where she blends scientific explanations with colourful storytelling about her adventures with her horse True North, Jones "speaks True" – literally. She explains how she gets to see the world from his viewpoint, listening, bonding, training and providing good welfare as his "guide" in the human world. She speaks his language and aims to help readers do the same.

It is a romantic story, and an easy read, as Jones expertly slips scientific concepts into an engaging tale that illustrates her points, while presenting True and other horses at her barn as unique characters. That's sure to delight horse lovers and general readers, and especially her fanbase.

Particularly praiseworthy are the book's central chapters on horse ethology (exploring herd dynamics, their need for outdoor grazing and why they like to live in groups) and fear responses (what scares them, how they react and why). That kind of well-researched, evidence-based knowledge will significantly improve the lives of horses and their relationships with humans. We care for our animals much better when we know what to expect, without foisting human characteristics – wrong, bad, mean, stupid and so on – onto them. This is reassuring in a general interest book, and Jones is to be lauded.



As a science journalist who has been writing about horses for 20 years, though, I found several chapters tough going. First, there were tangents, such as the fitness benefits of riding and the athletic prowess of different breeds.

But some of Jones's declarations acted as stumbling blocks, too. For example, her key premise is that horses' "prey brains" are nothing like the "predator brains" of humans, dogs, cats and monkeys. That's not only frustratingly reductive, but is often contradicted across Jones's chapters. Like humans, she writes later, horses learn better with rewards and without fear, appreciate predictability, play more when young, experience collaborative brain hemisphere function on all tasks, and share many brain chemicals with us, such as serotonin, dopamine and oxytocin. Like most mammals, horses have a strong sense of time, feel separation anxiety (normal and pathological) and "get the zoomies on cool, frisky days".

Jones also tends to explain horse brain function by citing studies on primates, dogs and rats coupled with her own experience with horses because of what she repeatedly describes as a lack of relevant research. I was perplexed. From the early 2000s, researchers have made great progress in understanding horse brains, cognition, behaviour, emotions, personalities, communication and relationships. Equitation science emerged as a field, devoted to such themes and their use in ethical horse training, management and horse-human relationships.

More than ever, scientists know what is going on in horses' minds. *A Horse's World* largely ignores this. It also lends no weight to the much-studied concept of how horses learn, known among behavioural scientists as "learning theory". Instead, Jones describes "reward" training that poorly aligns with current science, while promoting her own "direct brain-to-brain communication" in which closely bonded horses and humans live "temporarily inside each other's brains, sharing neural information... in real time without linguistic or mechanical mediation". Not only is there no evidence for this, but her description still invokes touch ("bodily cues") as an intermediary.

All this doesn't make horses any less magnificent: science confirms they are sensitive, intelligent, keen learners and, as Jones reminds us, excellent communicators. Readers will finish *A Horse's World* with a greater appreciation of horse "language" and a deeper respect for the equine mind.

Christa Lesté-Lasserre is a science journalist specialising in animal health and behaviour

'You have cancer.'

Three words we all hope we'll never hear.

Yet nearly half of us will.

Every day, more than a thousand people in the UK are diagnosed with cancer.
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when you can't hear a single word that's being said, because you have hearing
difficulties.

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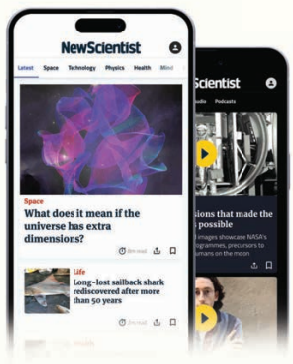

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Editor's pick

Helping the Great Barrier Reef and its communities

13 June, p 38

From Keith Noble, Townsville, Queensland, Australia

It was good to read Thomas Lewton's story on the health of our world's coral reefs. What caught my eye was one researcher's point that the success of initiatives to restore reefs "often comes down to social factors" and that giving "autonomy to the people of the reefs… seems to be a recipe for success".

Here in Australia, government spending on Great Barrier Reef protection and research has been well over AUS$5 billion in recent years, a reasonable investment in maintaining a complex natural asset that generates 77,000 jobs and contributes $9 billion annually to Australia's economy. But funding can be fickle, which has led my colleague Jelenko Dragisic and I to propose recognising and managing the Great Barrier Reef as an economic zone, rather than a closed environmental system.

Reef adaptation should be systemic, not siloed, with economic resilience, ecological health and social stability equally recognised as essential outcomes. A Great Barrier Reef economic zone would be a step towards a governance framework that redefines traditional conservation funding models, fostering a self-sustaining economy that builds resilience and prosperity for both the Great Barrier Reef and the reef region.

Q-Day won't be stopped by rolling back research

Letters, 4 July

From Richard Machin, Marston, Oxfordshire, UK

John Bell is right to be concerned about the threat that quantum computers pose to encryption. But I don't think legislation, however well-meaning, will achieve much. The security services of every nation will make use of quantum computing – I'm sure they already are – and they don't always answer to civilian laws. The only way to stop quantum computing from rendering our current encryption methods obsolete is to devise new encryption methods.

I know firsthand how the brain changes as we age

27 June, p 30

From John Newton, Seaton, Devon, UK

I read with interest your article on our ever-changing brain. I have rewired mine several times, first as a bank clerk, then as a student and member of the clergy. Next, I became a school chaplain and teacher, before finally becoming a theatre and event-lighting technician. Along the way, I have also been a coastguard, auxiliary firefighter and coach driver.

Apart from the usual forgetfulness of words that comes with age, I don't feel my mind is at all old and, at 87, I am still doing some lighting and driving safely (so I think). In all, I have been blessed with an active and varied life, which I feel sure has helped me keep an active and healthy mind. Or is it the other way round?

Say no to driverless cars in London and elsewhere

27 June, p 20

From Alfred Beale, London, UK

There are three reasons why I don't share Matthew Sparkes's positive attitude towards driverless cars, the first being my negative experience of them. As I crossed a road near a junction recently, a Waymo was coming towards me. I'd expect a human driver to ease up slightly to ensure I crossed before they reached me. (It would be clear to a human being that I was laden and slow-moving.) But the Waymo continued accelerating, and then, at the last moment, it or its human minder hooted its horn. I had to leap out of the way.

Second, what happens when driverless cars kill pedestrians or cyclists, as has already happened in the US? Who will be in the dock facing charges? Until there is a clear law holding a named individual liable for any harm, there should be no question of allowing them on our roads. And third, any development that encourages the use of single-user powered transport in London is environmentally disastrous.

Don't disregard the ethics of insect experiments

4 July, p 9

From Anthony Spiteri, Durhamville, New York, US

You write that cockroaches have been controlled via electrical implants and fitted with diving suits. As a biological scientist, I understand that animal experimentation can, in certain contexts, be ethically justified. I also understand the importance of proportionality, necessity, refinement and careful welfare assessment in experimental design. This is why I found the framing of this work so disturbing.

The issue isn't sentimentality about cockroaches. It is the principle that uncertainty about an organism's capacity for suffering shouldn't be treated as permission to instrumentalise it without serious ethical scrutiny. If the same procedure were described in relation to a mammal, we would speak of coercion, bodily violation, distress and confinement. With insects, the moral discomfort is simply bypassed. I am not arguing that all invertebrate research should be prohibited, but that this particular framing crosses a line. It treats a living animal as an engineering substrate while the ethical burden is almost entirely unexamined.

What's inside Uranus? Its axis may be a clue

27 June, p 9

From Bruce Denness, Niton, Isle of Wight, UK

The thick, gassy atmosphere of Uranus "makes it hard to know what is inside" it, writes Alex Wilkins. That it is only a quarter of the density of Earth suggests it is mainly gas, but with a rock or ice core. The fact that, unlike most planets, the axis of Uranus lies almost parallel to (rather than perpendicular to) its orbital plane seems to challenge received wisdom on planetary formation.

Perhaps a clue might lie in the core's origin. For instance, if it had been a lump of debris from a distant stellar explosion – perhaps like 'Oumuamua, which recently passed through the solar system – it may have entered the proto-solar dust and gas cloud already rotating on its side and attracted, and imparted its angular momentum to, its dusty gas mantle. When I once presented this idea to the astronomer Fred Hoyle, he told me I was "entering a subject in which there are as many theories as people working in it". ▮

For the record

▮ Gamma decay can occur when one element transforms into another (25 April, p 34).

▮ Producing a lithium-ion battery emits about as much carbon dioxide equivalent per kilowatt-hour of capacity as driving a petrol car 1000 km (4 July, p 10 and 11 July, p 47).

▮ Gottfried Hohmann and Barbara Fruth are at the Max Planck Institute for Animal Behaviour in Radolfzell, Germany (4 July, p 30).

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Heat therapy

Sauna and hot baths don't just make us feel good – they can also have a positive impact on our heart and brain health, finds **Bill Gifford**

IN 1976, a British Army physician named H. Foster wrote a letter to the *British Medical Journal* about a pressing issue in European public health: the epidemic of fatal heart attacks among middle-aged Finnish men. In it, he speculated that the reason Finland had one of the highest rates of coronary heart disease in the world was the nation's sauna.

On the face of it, the hypothesis made sense. A sauna is a stressful environment for the body, with an ambient temperature of 80°C (176°F) and above. The pulses of steam place repeated strain on users' cardiovascular system. Stay in for too long, and you will surely perish.

But more recent research suggests Foster may have got it entirely wrong, and that frequently partaking in Finnish sauna – as well as other kinds of heated bathing – may significantly reduce the risk of heart attacks, while improving health across the board.

Having grown up mostly in swampy, humid Washington DC, I have never really enjoyed feeling hot and sweaty. But after nearly two decades of writing about health and longevity, watching as data piled up suggesting that limited heat exposure might benefit our bodies and minds, I decided to give sauna a go. I found the research so compelling that I ended up spending three years digging into it and writing a book about the myriad benefits of heat. What's more, along the way, I discovered why we are so well-primed to reap all these benefits.

We humans have a complicated relationship with getting hot. For starters, it can be uncomfortable – and we are hardwired to know that extreme heat can injure and potentially kill us, via a temperature-sensing network of pathways in our skin, gut and brain. But on the other hand, humans intuitively know heat can be good for us – that much seems clear, given that so many cultures around the world participate in heat-bathing rituals, including Native American sweat lodges, the Mexican *temazcal*, the Russian *banya*, the Middle Eastern hammam, the Korean *jjimjilbang*, the Irish sweathouse and the Japanese onsen. Two thousand years ago, of course, most European cities had their own lavish Roman baths. Now, we have the modern hot tub, invented by Roy Jacuzzi in 1968.

Feeling hot, hot, hot

All of these represent variations on the same basic recipe: heat an enclosed space to a very high temperature and then add people. Steam may be optional, but sweating is mandatory.

"There are sweat baths all over the world; it's as common as the baking of bread or fermenting the grape into wine," says Mikkel Aaland, author of *Sweat*, a 1978 study of global heat-bathing traditions.

It took until the mid-1980s for scientists to start to catch on to the profound benefits of getting sweaty. Back then, researchers at what was then the University of Kuopio in central Finland enrolled about 2600 middle-aged men in a long-term study of cardiovascular disease, intended to identify potential risk factors driving the Finnish fatal heart attack epidemic that so intrigued Foster. Participants had extensive blood tests and physical examinations and filled out a lengthy questionnaire about their daily habits, family health history, and social and working lives. As the subjects aged, researchers looked for correlations between various lifestyle factors and outcomes such as heart attacks, strokes and cardiovascular disease.

Over the years, this Kuopio Ischaemic Heart Disease Risk Factor Study has yielded key insights into possible relationships between heart disease and alcohol consumption, cholesterol levels, dietary protein and other potential risk factors. About 1000 women were added to the study cohort in 2001, with research finding similarly beneficial results. Then, around 2015, a Finnish cardiologist named Jari Laukkanen noticed that the subjects' intake questionnaire had also asked about their sauna habits – how often they used the sauna, for how long and even at what approximate temperature.

Laukkanen compared the men's stated sauna habits with their health outcomes. The correlation was startling: frequent sauna bathing was inversely correlated to rates of heart attacks and other cardiovascular events, and powerfully so. Men who said they used sauna two to three times per week had a 22 per cent lower rate of fatal heart attacks compared with those who bathed only once per week. The most frequent sauna bathers, men who went four to seven times per week, had a 63 per cent reduction. According to the researchers, the frequent sauna bathers also experienced lower all-cause mortality over 20 years: 24 per cent lower for the twice-or-thrice-weekly bathers and 40 per cent lower for the most frequent bathers.

The more that the participants used sauna, it seemed, the longer and healthier their ›

ANTONIO SORTINO

lives were. There was also a plausible mechanism: heat stress causes the heart rate to accelerate, increasing blood flow and dilating blood vessels, similar to what happens during light-to-moderate exercise.

Saunas, it turned out, are good for you – and the deaths that so concerned Foster are now generally thought to have been related to poor diet, rural poverty and easy access to vodka and cigarettes from the neighbouring Soviet Union.

Laukkanen's study, along with more than three dozen follow-up papers, has helped drive the boom in sauna use in the UK, Ireland, North America, and Japan over the past decade or so. In the world of physiology, the Finnish sauna studies changed the conversation around heat and its effects on human health.

"Prior to those studies, everyone was focused on prevention of heatstroke, reduction of heat risk and how you regulate that," says Anthony Bain, a physiologist at the University of Windsor in Ontario, Canada. "Since those data came out, I think the focus has shifted to the idea of heat therapy."

Healing power of heat

Instead of looking at heat as something that is always dangerous, even potentially deadly, the Laukkanen sauna studies raised a revolutionary question: could heat be harnessed for healing?

Our evolutionary history suggests it can. While heat, especially extreme heat, can be highly dangerous to humans, as seen in the recent European heatwave, we are also uniquely equipped to handle hot conditions – more so than any other mammal, with the possible exception of the camel – thanks to our ability to sweat. This isn't an accident. Humans' ability to sweat to cool ourselves may, in fact, be one of our evolutionary superpowers, a trait that enabled our long-ago ancestors to climb from the middle to the top of the food chain. The secret lies in special structures called eccrine sweat glands, which secrete a mixture of water and salt onto our skin, where it evaporates, carrying away body heat. These are distinct from the sweat glands in our armpits and other hairy regions, which produce the more smelly type of sweat.

A little more than a decade ago, a University of Pennsylvania geneticist named Yana Kamberov began digging into the origin of our sweatiness as a species. She found that, at some point, more than a million years ago, a rapid-fire sequence of genetic mutations caused eccrine sweat glands to proliferate all over the bodies of our prehuman ancestors. At the same time, these primates lost much of their body hair. Humans have 10 times as many eccrine sweat glands as one of our closest relatives, the chimpanzee, and our relative hairlessness allows that sweat to evaporate more easily.

"We are uniquely equipped to handle hot conditions thanks to our ability to sweat"

"That's the key step," says Christopher Minson, a physiologist at the University of Oregon who has studied heat and athletic performance extensively. The change of state from liquid water to vapour transports an enormous amount of heat energy from our bodies. "That sweat has to evaporate. Dripping sweat doesn't do anything."

Their newfound ability to sweat allowed these ancient ancestors to forage for food during the middle of the day, when their predators were forced to stay in the shade. It also enabled them to pursue prey animals that tired more easily in the heat. "Humans were born to run," declared the evolutionary biologist Dennis Bramble and anthropologist Daniel Lieberman in their seminal 2004 Nature paper describing our evolution into the ultimate endurance athletes.

Although we humans are now more likely to run marathons in big cities than to chase down antelope, our ability to sweat still helps us in a number of ways. This is because it enables us to tolerate heat stress, which unlocks myriad therapeutic benefits, independent of exercise. When we put our innate cooling system to the test by sitting in a sauna or similar hot space – even a hot tub or an ordinary hot bath – we reap benefits. For starters, our skin temperature heats up quickly. This activates our cardiovascular system, as

GIOVANNI MEREGHETTI/UCG/UNIVERSAL IMAGES GROUP VIA GETTY IMAGES

Regularly bathing in hot water could bring health benefits

PETRI JAUHIAINEN/ALAMY

Being in a sauna causes a similar physiological response as exercise

our heart rate accelerates and our brain diverts up to 70 per cent of our blood flow to the skin, in an effort to cool us down.

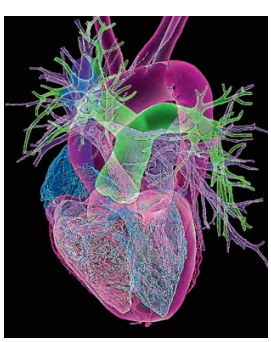
Shortly after, sweating ensues, as our eccrine sweat glands draw liquid from our cells, intracellular spaces and blood plasma and pull it to the skin. In a sauna, we might sweat more than a litre of fluid per hour. To replace that liquid, our body seeks to expand the volume of blood plasma, which is one reason why it is important to hydrate during and after sauna use.

This is similar to the physiological response to gentle or moderate exercise (minus the beneficial effects of muscle activation). So, it isn't surprising that Laukkanen and his colleagues went on to discover that the Kuopio study participants' regular sauna bathing delivered a suite of health benefits, including a reduction in the incidence of strokes, as well as a lowered rate of respiratory illnesses.

One of the most striking findings from the Kuopio study of middle-aged Finnish men was that the most frequent sauna bathers, who bathed four to seven times a week, had a 63 per cent lower incidence of Alzheimer's disease over 20 years compared with once-weekly bathers. Even better, this finding was echoed in a similar study on a different set of men and women. This retrospective study looked at nearly 14,000 people using Finnish mobile health clinics from the 1970s, aged between 30 and 69 at the time of treatment. It found that men and women who had said they used sauna nine to 12 times per month had less than half the rate of Alzheimer's disease diagnoses over 20 years versus those who used a sauna less than four times a month or not at all, and a 20 per cent reduction over 39 years. It suggests that frequent sauna use may at least delay dementia, if not prevent it outright.

"Frequent sauna use may delay dementia, if not prevent it outright"

Frequent sauna is linked with lower rates of cardiovascular events



K H FUNG/SCIENCE PHOTO LIBRARY

This picture is made even more vivid by the curious story of a man named Doug Whitney, who was born with a genetic mutation that virtually guaranteed he would develop Alzheimer's disease in his late 40s or early 50s. But he didn't, remaining cognitively normal through his 60s and into his late 70s. It turned out that Whitney had worked for decades as an engine-room mechanic aboard naval ships, at temperatures of 50°C (122°F) or more. In this sauna-like work environment, he often became so hot that he needed to be hosed off to cool down. While that may not seem healthy or even safe, it may have saved him from dementia.

Body and mind

When Jorge Llibre-Guerra at Washington University in St Louis, Missouri, and his colleagues analysed Whitney's cellular proteins, they discovered he had extremely high levels of different heat shock proteins, a stress-response mechanism that kicks in as our core temperature rises. These proteins help maintain cell membranes, other cell proteins and the structure of our DNA, while speeding up the removal of cellular junk such as misfolded proteins. The researchers speculated that the heat shock proteins may have helped protect him from accumulating the deposits of misfolded tau and amyloid proteins in the brain that are linked with Alzheimer's disease.

There are even hints that heat treatment may bolster mental health. One of the more striking findings of the Finnish sauna research was that frequent sauna users had a lower risk of experiencing psychosis over their lifetimes than the less-frequent users.

More recently, researchers have begun investigating the possible use of "whole-body hyperthermia", in which a person's core body temperature is intentionally elevated, as a potential treatment for depression. One study, for instance, found that when people with severe depression had their core body temperature warmed to 38.5°C (101°F), then allowed to cool, over 45 to 90 minutes, they reported 30 per cent fewer symptoms of ›

poor mental health, with the effect lasting up to six weeks.

The exact mechanism by which heat therapy might relieve depression is unclear. One idea is that it reduces brain inflammation. Another is that warming people up may have a similar effect to antidepressant medications: studies in rats have found that heating up their brains stimulates a brain region known as the dorsal raphe nucleus to produce more of the brain-signalling molecule serotonin. Larger studies are ongoing to determine whether heat therapy – perhaps paired with a cold plunge or talk therapy or both – might be a useful adjunct to antidepressants and psychotherapy.

Indeed, there is so much positive correlational data on heat therapy and a multitude of health benefits that it seems fair to ask: is there anything sauna and heat therapy can't do? The more pertinent question, though, is: can we go beyond correlations and prove that heat therapy really causes all these beneficial effects?

Critics of Laukkanen and his colleagues' studies point out that their sauna-use data lacked a true control group of people who never used sauna. They were comparing people who used sauna almost every day with people who said they used it once a week.

"A hot tub or even a hot bath may convey similar health benefits to sauna"

But this wasn't a deliberate omission. In Finland, almost everyone goes to sauna, it is part of daily life, and out of the entire 2327-person original Kuopio study cohort that Laukkanen examined, only 12 participants said they never used sauna at all. So, there effectively was no control group.

Another critique is that perhaps the frequent sauna users were healthier to begin with? After all, it takes a certain degree of grit to handle a 90°C (194°F) Finnish sauna and its recurring blasts of *löyly*, or steam. They could also have been wealthier or less stressed, since they had time to visit sauna every day or two. But Laukkanen insists that his team controlled for factors including age, smoking, alcohol consumption, physical activity, body mass index, cardiovascular risk factors and socioeconomic status. Indeed, in a subsequent analysis, Laukkanen and his colleagues found that frequent sauna bathing appears to effectively compensate for the deleterious health effects of low socioeconomic status.

Also, shorter-term studies have suggested that sauna use may indeed improve cardiovascular health in a mechanistic way. In one such study, Laukkanen and his colleagues found that a single Finnish sauna session of 30 minutes at 73°C (163°F) reduced blood pressure slightly. In another study, the group found that sauna use activated the parasympathetic (or "rest-and-digest") nervous system.

Given all the evidence supporting the case for heat's healing power, the next question is: what is the most effective dose of sauna or other heat therapy?

Sadly, the data is patchy and, right now, there is no single prescription. "The jury is still out on this," says Earric Lee, who did his PhD work in Laukkanen's lab and now works at the Montreal Heart Institute.

Personally, I sauna like the Finns, who simply stay in for as long as they feel like. I also try to make it to a session every week. If you don't happen to be in Finland or don't have a sauna nearby, other studies suggest that enjoying a hot tub or even a hot bath may convey similar health benefits. A large 2020 study of around 30,000 Japanese adults, for example, found that people who took regular hot baths at home had a significantly reduced risk of death from cardiovascular conditions – to the tune of over 25 per cent for those who took hot baths close to every day, compared with those who bathed two or fewer times a week.

Good things happen when we get really hot, it seems. And ongoing clinical trials may help us understand whether heat-based therapies might prove effective in treating depression or staving off Alzheimer's disease at scale. As for me, after decades of drilling into the science of ageing and understanding the vital role of diet, quality sleep, regular exercise and strong social connections in maintaining our long-term health, I am sure that targeted heat therapy deserves its own spot in our longevity toolkit. Apologies to H. Foster. ▮

REUTERS/DANIEL AGUILAR

Heat therapy is used around the world, such as in Mexican *temazcals*

Bill Gifford is a science journalist and author of two books about longevity – *Spring Chicken* and *Outlive*, with Peter Attia

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GREGORI SAAVEDRA

Living the good life

A Portuguese city is showing us how we can walk the tightrope between our well-being and that of Earth, discovers **April Reese**

IN THE rolling hills of northern Portugal, where castles are almost as common as churches, the city of Guimarães is undertaking an ambitious experiment that could influence the world. With a zeal reminiscent of the city's 12th-century battle for independence, when the city's Portuguese nobility fought off Spanish invaders to establish the new nation's first capital, elected officials have joined forces with sustainability scientists to transform the region once again.

At a time when many of us feel like helpless bystanders as environmental crises escalate around us, Guimarães's green transition is showing how it is possible to live within the planet's essential limits – while ensuring a comfortable quality of life for everyone. "Social justice and the principle

of leaving no one behind are truly central to our approach," says biologist Carlos Ribeiro, who heads the Landscape Laboratory, a research and education facility created to help drive these sweeping changes in the city.

These might sound like utopian aspirations, but behind Guimarães's plans are solid calculations that, against common wisdom, suggest it is possible for the entire global population to tread the tightrope between our well-being and that of Earth – and that, in fact, the two are intertwined. But achieving that vision will require seismic shifts in economies and the way many people view luxuries versus necessities. Can this be achieved without limiting personal freedoms – and who gets to decide how much is enough to live well?

The idea that there is a safe operating space that humanity must find a way to live within was first described in a landmark 2009 paper by Earth system scientist Johan Rockström at the University of Potsdam in Germany and his colleagues. They identified nine planetary boundaries – limits on phenomena such as climate change, ocean acidification and land-system change – that, if breached, will knock us out of the stable conditions that have allowed humanity to thrive for 12,000 years.

Humanity has now crossed seven of these boundaries, largely because of what we consume and how quickly we consume it (see "Earth's safe operating space", page 35). Total domestic water use, for instance, has increased sixfold over the past 50 years – a faster rate than in agriculture or industry. The overall extraction of natural resources and energy use have tripled over a similar period.

Part of this increasing consumption is vital for lifting lower-income nations – and poorer communities in wealthier countries – out of poverty. But this growth isn't happening where it is required to achieve this. In a 2025 study, sustainability scientist Joel Millward-Hopkins at the University of Lausanne in Switzerland and his colleagues analysed national trends in the use of energy and materials around the world. The team divided countries into those that have enough energy and resources to provide "decent living standards" – a basic floor for well-being based on access to needs like nutrition and housing, plus a buffer to address inequality – and those that have more than enough. High-income countries already consume far more resources than low-income nations, as you might expect. But worryingly, the team found that this trend is escalating: the growth rate of consumption was four times higher in countries with surplus consumption. If these trends continue, decent living standards won't be fully achieved in lower-income countries until the end of the century, and all the while, environmental pressures from overconsumption will intensify. "We risk breaking the planet," says Millward-Hopkins.

Facing these realities, in recent years, sustainability scientists have widened their lens to include principles of fairness and sufficiency. The idea is that, above a certain level – when essential needs are met and you have enough to live comfortably – additional wealth has little impact on well-being, leading to what Millward-Hopkins calls "useless overconsumption". So, by setting a reasonable ceiling on consumption, the hope is that we can collectively walk along a "consumption corridor" that ensures a basic quality of life for everyone while keeping within the planet's boundaries.

Within Europe, led by a green-minded mayor, Guimarães has become a leading light on this path. "We are trying to design a city with a better quality of life, where people can live well," says Ribeiro. A decade ago, sustainability scientist Sara Pires at the University of Aveiro, Portugal, and her colleagues conducted a pivotal analysis of Guimarães's ecological footprint. The assessment found that if everyone in the world lived like the city's residents, we would need the resources of almost 2.3 Earths. This is significantly more than the average global consumption of 1.7 Earths. The results left city leaders determined to become a "One Planet City" – an official designation created by sustainability consultancy Bioregional and the World Wildlife Fund – by 2050. Since then, the council has baked sufficiency and sustainability into all its decision-making. "They really have an impressive capacity to change," says Pires.

The green transition

The council is investing millions of euros in efforts to reduce the city's resource use. Some changes are simple: recycling-collection trucks adorned with the words "recycling saves money" trundle down the cobblestone streets, a nod to the council's "pay-as-you-throw" waste collection system, which charges residents per kilogram of refuse. And regular repair fairs encourage people to extend the life of items like electronics rather than throwing them away. Guimarães now has a waste circularity index – a measure of how effectively an economy reuses, recycles and recovers materials – that is 2.5 times the average for Portugal.

Beyond that, more fundamental changes are under way to squeeze the city's economy into a consumption corridor. Guimarães is also developing a circular economy – an economic model designed to continually reuse resources – off the back of its historical textile industry, which dates back to the Middle Ages but has declined in recent decades due to overseas competition. Companies like RDD Textiles and Zouri shoes are reforming the industry into a greener mould by using recycled materials and natural dyes to produce quality products that some consumers are willing to pay more for. Each year, more than 20 tonnes of textiles are recovered across the city through this approach.

Guimarães's Landscape Laboratory is housed in a remnant of this same industry: an old textile and cutlery factory beside a now partially restored stream. Iberian chub, northern straight-mouth nase and other native fish now ply its clear waters. Founded by the city in 2014, the laboratory – in ›

JACEK SOPOTNICKI/ALAMY

Guimarães Castle is now surrounded by a rain-fed meadow

collaboration with the University of Minho and the University of Trás-os-Montes e Alto Douro – conducts research that seeks to improve quality of life for residents while reducing the city's environmental footprint. For instance, the laboratory, alongside the city and local industries, has already restored some 95 hectares of green space since 2012. The vast lawn surrounding Guimarães Castle, built in the 10th century to defend a monastery from the Normans and Moors, is now a rain-fed meadow, and a network of greenways connects far-flung parts of the city.

Aside from the innate health benefits of having nature on your doorstep – and the value of creating habitat for wildlife – these changes are also designed to curb consumption. A 2020 study, led by environmental psychologist Yannick Joye at Vilnius University in Lithuania, found that when participants' attention was directed towards the natural elements of their environment, they attached less importance to materialistic values. Cooling urban heat islands through ecological restoration directly reduces the need for energy-sapping air conditioning, too, while greenways encourage walking and cycling, which, in turn, drive local, circular economies.

Crucially, these nature-based strategies also offer protection from extreme heatwaves and floods, which are becoming more intense and frequent in the city due to climate change. Floodwater retention basins, which combine wetlands and meadows with retaining walls, were constructed in the city a few years ago. In January, a series of heavy storms hit Portugal, with floods killing at least 16 people and forcing thousands to evacuate their homes, but in Guimarães, the basins held the water back.

Yet the scale and speed with which changes must be made to rein in our planetary overshoot can lead to pushback from local communities. To mitigate that, the laboratory solicits the community's help, offering them autonomy over what actions to take. A recent call for project and activity ideas garnered 200 suggestions, 150 of which are now being implemented, says Ribeiro, such as new trails and outdoor dance performances. Environmental awareness is also at the core of the laboratory's work, he says, inspiring "green brigades" of citizen volunteers who organise clean-ups, plant trees and conduct biodiversity surveys.

The bare necessities

During Green Week in June, held in a shady square in the city centre, Ribeiro remembers taking in the scene – seeing thousands of residents, from grandmothers to toddlers, creating nature-inspired art and learning about how ecological restoration makes the city safer – and thinking about the sense of community pride that has coalesced around Guimarães's green transition. "It's very important to improve that sense of belonging, the sense of identity," he says. "It's a different approach to changing some mindsets."

Earth system scientist Tim Lenton at the University of Exeter, UK, describes shifts like these as social tipping points: when changes in attitudes and behaviours trigger a much larger, often rapid and self-sustaining change across a society or system.

When it comes to creating a ceiling on consumption, one vital shift in a society's attitudes is what it considers to be luxuries and what it views as necessities. The efforts under way in Guimarães suggest that some of these shifts can be achieved organically rather than through coercive policies. "We don't need too much food in our freezer or too much money in our pockets, and we don't need to have 10 cars," says Sandra Freitas, a Guimarães native who runs a vegetarian café in the city. Freitas says she has noticed her community take greater pride in the city over the years. "Every year, we try to do better and better."

Yet evidence suggests that good intentions may only get us so far. Even holding green values seems to make little difference to your ecological footprint if you have a lot of money. One recent study found that, surprisingly, among the wealthiest 30 per cent of people, those who cared most about the environment had an even larger footprint than their peers.

Millward-Hopkins says that extreme wealth insulates people from economic pressures that might change their behaviour. He recalls witnessing this firsthand while on a cycling trip shortly after Russia invaded Ukraine and fuel prices skyrocketed. "I was passed by a convoy of supercars, each driven by a single middle-aged guy," he says. "The fuel consumption of people that rich has pretty much zero elasticity, by which I mean, unlike poor people, when fuel prices rise, their consumption is unaffected."

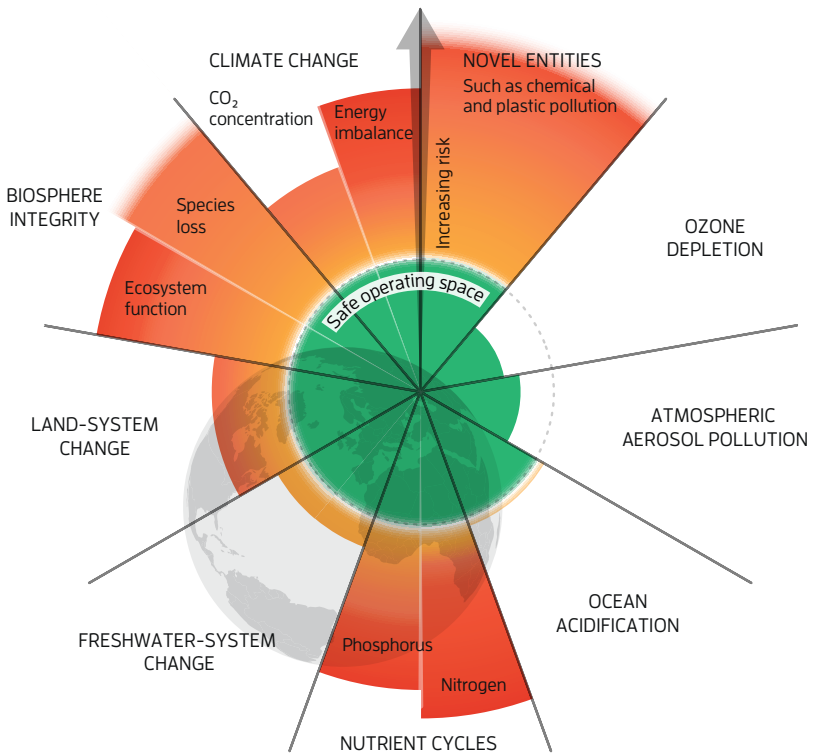
Still, for middling levels of wealth, Millward-Hopkins argues that any sense of loss brought about by limits to material consumption could easily be salved. "Any reductions in consumption that are required by regular people in Europe or North America could be more than compensated for by providing things that really improve people's lives: universal healthcare and education; healthy, affordable food; fulfilling work; and secure housing without the threat of eviction or mortgage spikes," he says. "All of these things can be provided to all without exceeding ecological limits, if we can direct our labour towards things that matter, not just what's profitable."

That might sound like idealistic speculation, but recent calculations demonstrate how, in principle, we can all live well within Earth's limits. In June, the World Inequality Lab published its Global Justice Report, which argues that by embracing sufficiency and reshaping our economies towards the real sources of human well-being, we can avoid climate breakdown (see "Less is more", right).

The centrepiece of the report is a global wealth tax on billionaires that would help fund the transition to greener forms of energy and a dramatic increase in spending on education and healthcare, shifting investment away from resource-intensive activities. "The climate crisis and inequality are very much intertwined," says Cornelia Mohren, environmental coordinator at the World Inequality Lab. "We think that it's necessary to make those pay who caused the climate crisis, which are the global rich."

Earth's safe operating space

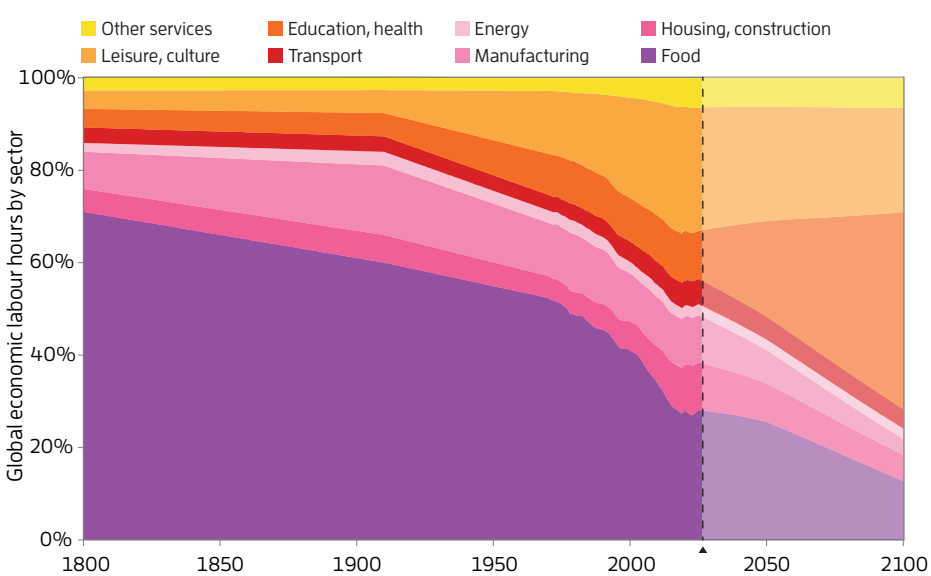
Nine planetary boundaries define the guardrails for human activities, beyond which we risk triggering catastrophic environmental collapse. Analysis suggests we are already transgressing seven of them



SOURCE: Azote for Stockholm Resilience Centre, based on analysis in Sakschewski and Caesar et al. 2025

Less is more

Over the past 200 years, humanity has shifted its labour away from the most extractive sectors, such as manufacturing and food production. To proposer within planetary boundaries, estimates suggest we need to accelerate this trend, with a renewed focus on education and health



SOURCE: Global Justice Report 2026

The Global Justice Report also calls for fewer working hours and dietary changes to reduce consumption. Despite these major adjustments, the report calculates that the average per capita income across all countries could be increased to around €5000 a month by the end of the century. Mohren acknowledges the report is somewhat utopian – more of a vision than a prescription. "The idea was really to provide a new story about a future that could be possible," she says.

Guimarães's own journey towards living within planetary boundaries has also been held back, to at least some degree, by affluence. The city is among the wealthiest in Portugal, and despite the new leafy trails and electric bus fleet, many residents still opt to drive, even amid high fuel prices. It is simply easier for many people to get behind the wheel. "The real challenge is changing behaviours," says Ribeiro.

Still, over the past decade, the city has made impressive changes to its levels of consumption. Against global trends, since 2018, Guimarães has reduced the average amount of waste generated per person by 18 per cent. Cash-incentivised recycling and waste reduction systems, as well as biowaste collection, have recently been rolled out to most households in the city. The council has also turned Bairro C, a city neighbourhood and UNESCO World Heritage Site, into a testing ground for zero-carbon policies and technologies that create economic opportunities.

In recognition of this progress, Guimarães was awarded the title of European Green Capital for 2026 by the European Union. Officials from cities in Belgium, France, Italy and Spain have visited to learn from the city's green transition over the past decade, and the Landscape Laboratory has been fielding its expertise to policy-makers in Brazil and beyond.

Regardless of which way the political winds blow, sustainability and sufficiency now seem as immutable as the city's medieval stone walls and Roman bridges. A new mayor was sworn in last year, but the change in leadership is unlikely to affect the city's green trajectory. He has thrown his support behind the work and the previous administration codified the city's sustainability commitments into law, cementing Guimarães's green future. "It's almost impossible for a new mayor to come and destroy that," says Pires. ▮

April Reese is a science writer based in Aveiro, Portugal

Young and gifted

We are finally understanding the lifelong impact of being marked as exceptional during childhood, finds **David Robson**

SIMBIE YAU

LADY GAGA may seem to have little in common with Mark Zuckerberg and Sergey Brin, other than being extremely successful. But there is a connection: all three were deemed gifted in childhood.

The idea of giftedness – possessing outstanding talent or intelligence at a young age – is, and always has been, controversial. Parents, teachers and psychologists have long argued over the nature of childhood precocity and whether labelling it does more harm than good. Many worry that designating children as gifted places undue pressure on them to succeed, setting them up for unbalanced and unhappy lives.

Until recently, little was known about what actually happens to these children when they grow up. Now, a spate of studies is providing answers and revealing the fascinating impacts of being marked as exceptional at a young age.

Far from growing into troubled adults, many gifted individuals appear to flourish later in life. Long-term studies suggest they are more likely than average to achieve professional success and, contrary to popular stereotypes, often enjoy better mental health. Scientists are also starting to understand what makes gifted brains so exceptional, finding that they are better integrated and can process information more efficiently, which raises the question of whether we should view giftedness as another form of neurodiversity. While that is still an open debate, what is becoming increasingly clear is that many of our assumptions about extraordinary minds – and the lives of those who possess them – may need revising.

The term "gifted" dates back to the 1920s, when psychologist Lewis Terman – who peddled several dubious ideologies, including eugenics – began studying childhood precocity. He believed it was these children who would go on to become our most prominent leaders and thinkers.

Using a variety of questions on general knowledge, memory, numeracy and verbal dexterity, he devised a way to calculate someone's "mental age". Divide this by their chronological age and multiply it by 100, and you get their "intelligence quotient", or IQ. A 10-year-old child with the mental age of an 11-year-old would have an IQ of 110, for example.

Through widespread screening across California, he selected around 1500 children with IQs of 135 or over – the top 1 per cent – then tracked their lives over the next few decades. Regular follow-ups largely confirmed his suspicions: the children excelled academically and many went on to have successful careers in the sciences, the arts and politics. The term "giftedness" was born.

Giftedness refers to exceptional talent or intelligence, which is usually apparent from an early age. There isn't a precise way to identify it. Although Terman relied on IQ, contemporary studies and programmes use various assessments centred on intelligence, academic achievement and, in some cases, creativity.

Like many historical studies, Terman's methods and analyses fail to meet modern standards, but later investigations have yielded similar conclusions. For instance, in the 1970s, scientists at Vanderbilt University in Tennessee began tracking more than 1600 adolescents aged 13 and under who were within the top 1 per cent for mathematical reasoning, according to their performance on college admission exams. More than 40 years later, they found these individuals "far exceeded base-rate expectations".

Depending on the year they joined the study, between 25 and 40 per cent of them had gained doctorates, compared with just 2 per cent of the general population. They were also more likely than the average person to have earned tenure at a university, published a book or risen to the top of a Fortune 500 company. A further study, yet to be published, has found they are also more likely to engage in altruistic acts, such as pro-bono legal work, and "as they approach retirement, they're planning to increase the amount of time they devote to volunteering", says David Lubinski at Vanderbilt University, who leads this research.

But what makes gifted people so exceptional? We don't have a clear answer just yet, though researchers have started uncovering some clues, finding that these individuals have unique brain changes, which may influence how they process information.

In a paper published earlier this year, neuropsychologist Karin Reuwsaat at the Federal University of Rio de Janeiro in Brazil and her colleagues analysed dozens of brain-imaging studies involving gifted individuals. They found that giftedness was associated with more grey matter – that is, tissue consisting mainly of the central bodies of brain cells – in the dorsolateral prefrontal cortex, the superior temporal gyrus and inferior parietal lobes. Because these areas play a crucial role in abstract reasoning and problem solving, this could make it easier for gifted children to excel at school and beyond, says Reuwsaat.

Academically gifted individuals also tend to have greater connectivity between brain regions. For instance, a 2021 study of 30 children found that white matter – which transmits signals across brain regions – was more highly connected in those who were gifted, particularly between the hippocampus, putamen and ›

prefrontal cortex, all areas crucial for thinking and memory. Other studies have shown that in gifted individuals, there is greater interaction between the default mode network – associated with imagination and creativity – and frontoparietal networks, which are involved in reasoning and attention. This may help them find "unusual associations between ideas", she says, and provide greater "cognitive flexibility".

Finally, the brains of gifted individuals may use energy more efficiently. Reuwsaat points to studies showing that such brains tend to have lower activity than average when completing easier problem-solving tasks. But activity then ramp ups as the difficulty increases. That suggests "an enhanced capacity to recruit additional neural resources when needed", she says. It also differs from people with lower cognitive capacity, who are more likely to disengage from challenging problems.

Reaching your potential

But the truth is, we are only beginning to grasp what sets the gifted mind apart. "I think we can explain up to perhaps 20 per cent of the variance in IQ," says Enrico Toffalini at the University of Padua in Italy, who has studied differences in intelligence across lifespan. The other 80 per cent, he says, remains a mystery.

Given these brain differences, some research groups and organisations have suggested giftedness is a form of neurodivergence, similar to conditions like ADHD and autism. "If neurodivergence is understood broadly as naturally occurring variations in brain functioning and cognition, then there is a reasonable argument that giftedness could fit within that framework," says Reuwsaat. After all, increased brain connectivity appears to underlie all three of these conditions, she says.

Yet neurodivergence tends to describe neurodevelopmental conditions, which can create functional problems in everyday life, such as inattention, emotional dysregulation or hyperactivity. That doesn't seem to be the case for gifted children. "It is simply on the higher end in a spectrum of human intelligence," says Mimi Wellisch, a psychologist based in Australia who has published on gifted children extensively. If gifted children have social and behavioural issues, Wellisch suggests their parents get them assessed for neurodevelopmental conditions such as autism and ADHD or for mental health conditions like obsessive-compulsive disorder. Problems with behaviour "are unlikely to be a byproduct of giftedness", she says.

Gifted children can, however, experience boredom or frustration in the classroom if they don't receive enough intellectual stimulation. As such, various programmes have cropped up to ensure these children make the most of their potential – often through programmes of "academic acceleration". Some supplement regular schooling with summer programmes. Others allow children to either skip grades or attend classes aimed at older age groups, a practice known as appropriate developmental placement.

But these initiatives have come under fire, falling out of favour in the UK and the US. For instance, last year, New York City Mayor Zohran Mamdani campaigned on overhauling the city's selective programme for early grades. The UK closed its national gifted programmes in 2010 over concerns about effectiveness and the lack of specialist support, though private programmes are available and individual schools may offer their own initiatives.

Part of the pushback comes from worries that such programmes – and even the label "gifted" – place pressure on children to succeed, ultimately causing them to burn out. This idea is known as the wrecked-by-success hypothesis. While writing her book *Gifted Children in Britain and the World*, Jennifer Crane at the University of Bristol, UK, found many accounts of children who responded badly to giftedness programmes. "Sometimes, that label can create a system of pressure," she says.

There are also worries that the excessive focus on academic potential may come at the price of developing social skills. If a child skips a grade, for instance, they will spend less time socialising with their peers.

But the emerging science paints a different picture. While few trials have directly tested the long-term outcomes of gifted programmes, those available suggest they can nurture achievement without sacrificing wellbeing.

For instance, in a 2020 study, Lubinski and his colleagues evaluated psychological wellbeing in more than 1600 mathematically precocious individuals at age 50. They found

"Academically gifted individuals tend to have greater connectivity between brain regions"

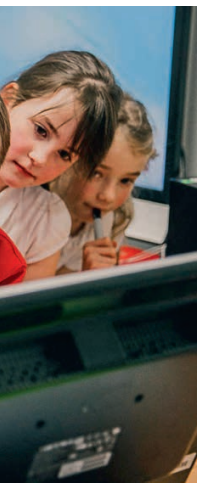
U.S. AIR FORCE/J.M. EDDINS/ALAMY

PG ARPHEXAD/ALAMY

that the amount of educational acceleration the participants received during adolescence had no bearing on their wellbeing in adulthood. In fact, gifted individuals tended to have greater wellbeing than non-gifted individuals, regardless of academic acceleration, contradicting the idea that they are somehow emotionally or socially disadvantaged.

Perhaps the best arguments come from the participants themselves. In 2025, Lubinski and his team published in-depth questionnaires with gifted participants aged around 50. When reflecting on their educational experiences, around half reported experiencing boredom and frustration in mixed-ability classes. "Most of my classes were not with others of the same intellectual ability and I not only felt unchallenged, but also somewhat embarrassed by my high intellectual abilities," one wrote. "I'm extremely fortunate that I was allowed to move rapidly in math to take college courses and to teach," wrote another. "Not only did it help advance my education, but it gave me self-confidence socially."

Gifted programmes also foster greater



Left: Engaging children in school can help them reach their full potential

Below: Gifted children are more likely to do volunteer work as adults

academic success. In 2015, for instance, Katie Larsen McClarty, now at the educational company McGraw Hill in Texas, identified around 100 US students who had been academically accelerated and matched them with students who had shown similar potential, yet didn't receive the same opportunities. Controlling for age, gender and socioeconomic background, she found that the academically accelerated kids significantly outperformed their peers in high school and university, with higher grades and better scores on university admission exams and scholarship tests.

Lubinski and his colleagues have found similar results in their studies of mathematically precocious young people. In a 2013 study, they compared more than 360 of these students who had skipped grades with roughly 650 who didn't. Whereas 27 per cent of grade-skippers later achieved a PhD, the same was true of just 15 per cent of those who stuck to the standard track. Similarly, nearly 13 per cent of those who skipped grades had published a scientific paper and almost 5 per cent had earned a patent, compared with roughly 6 per cent and 2 per cent, respectively, of those who hadn't been accelerated.

Given these efforts have benefits, a failure to meet those children's requirements by withdrawing the support could itself be seen as unfair. Lubinski even goes as far as to compare it to a form of prejudice. "We are stereotyping students' learning readiness by their chronological age," he says. "If you look at 9-year-olds' [literacy], the top 10 per cent are reading at or above the 25th percentile of 17-year-olds. It's the same with mathematics. And these kids will have different needs."

Despite their exceptional talent, identifying gifted children is challenging, especially when accounting for differences in socioeconomic backgrounds. Even though genetics play a large role in intellectual development, family circumstances heavily influence performance on traditional intelligence tests, particularly in early childhood. Children growing up in working-class families tend to develop a smaller vocabulary in their first years, for instance, which may increase the likelihood that teachers or psychologists ignore their learning potential.

The keys to success

Amy Lynne Shelton, executive director at Johns Hopkins Center for Talented Youth in Maryland, is leading efforts to identify advanced learners from underrepresented backgrounds. Her team is exploring three different options. The first tests fundamental cognitive skills involved in learning, such as the size of working memory – the amount of information our minds can consciously hold at any moment. The second analyses how children solve complex problems. "Can we see unique insights? Can we see deep thinking?" says Shelton. Finally, there is "embedded assessment of learning" – watching the ways children interact with new classroom material.

"We're in the preliminary stages," Shelton admits. But early results suggest these methods can help identify a broader range of advanced learners, without changing the number of upper-to-middle-class kids spotted for their potential.

While our understanding of giftedness and how to best spot it is improving, we know that intelligence isn't the sole guarantor of success. After all, many extraordinary achievers – including Nobel prize-winners like William Shockley and Luis Alvarez – didn't qualify as gifted. And many people who do fail to make an impact in their chosen careers.

This highlights an essential caveat: truly exceptional achievement depends on many factors besides intelligence. In fact, many psychologists consider two – conscientiousness and emotional stability – equally as important as IQ for shaping our performance in academia and beyond. While IQ speaks to the question of whether someone can do something, conscientiousness relates to whether someone will do it and emotional stability reflects how well someone performs under pressure. "When all three are high, the conditions for sustained success are especially strong," says psychologist Gilles Gignac at the University of Western Australia.

Yet, according to his research, only 0.0085 per cent of people are exceptional at all three. "Someone who is even somewhat above average in intelligence, conscientiousness and emotional stability at the same time is, in fact, pretty remarkable," says Gignac. Cultivating traits like conscientiousness and emotional regulation will, therefore, be valuable to any child's upbringing, including those identified for their intellectual precocity.

We can also hone these attributes in adulthood. A 2021 study found that simply practising aspects of conscientiousness and emotional stability for three months could lead to lasting improvements in both. If someone wants to become more conscientious, for example, they could commit to laying out their clothes for the next day the night before or writing down all the important birthdays for the year ahead. Likewise, keeping a gratitude journal or noting the positives in a negative situation seem to boost emotional stability. In other words, faking it till you make it really does work – at least to a degree.

"A normally functioning person may be able to shift their standing on a personality dimension by, perhaps, 10 per cent through sustained effort," says Gignac. "But such changes likely require ongoing maintenance." It may be easier, then, to change your environment instead of your personality, he says. If you are seeking greater emotional stability, for example, this may mean spending less time in high-conflict environments.

For those marked as gifted, the path to becoming the next global superstar or founder of one of the world's most successful tech companies isn't guaranteed. But by understanding more about what helps gifted people thrive in adulthood, perhaps we can unlock more of their lifelong potential. ▮

Additional reporting by Grace Wade

David Robson is a science writer specialising in the human brain, body and behaviour, and author of *The Laws of Connection*

Time's true nature

Is our universe really a computer? Physicist and computer scientist **Stephen Wolfram** tells Leah Crane how it may explain why time passes

MY COLLEAGUES and I have a running joke: time isn't real. Oh, you thought that deadline was tomorrow, but it's today? Time isn't real. The 1980s can't possibly be 40 years ago, can they? Nah, mate, time isn't real. If aliens were looking at Earth from a distant ship, would they see dinosaurs or just seas of magma? Time is definitely not real.

But, like so many jokes, there is a kernel of truth there. In this case, it isn't that time isn't real, but rather that we really don't understand it – and by "we", I mean humanity. Physicists and philosophers have been reckoning with the concept since, well, time immemorial, and while there are many ideas floating around, there still aren't any solid answers.

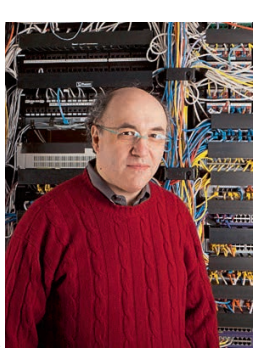
I took the question to Stephen Wolfram, a physicist and computer scientist who has created some of the most useful computing tools in physics. For decades, he has been working on what he calls "The Wolfram Physics Project", an effort to redefine physics in terms of computation, rather than the typical maths and thermodynamics used by most physicists and cosmologists to understand the universe. To say the project has been controversial in scientific circles would be an understatement. For starters, his ideas on time require the universe to be essentially one big computer. If true, this could explain what time is, why it flows smoothly forwards and why we can't tell the future. So, I called him up to have a chat about it.

Leah Crane: Let's start with an easy question. What is time?
Stephen Wolfram: Right. Time is the irreducible doing of computation.

Great! Although... what does that mean?
What we perceive as time is our experience of the process of the universe computing its successive states.

Can I think of that like images in a flip book, stacking up to make it look like motion?
In a sense, yes, although it is a little bit more complicated than that. As those successive states are computed, one from the previous, that corresponds to the passage of time. And the thing that isn't obvious is this: if you have a definite rule by which the successive states of the universe are computed, you might say, well, why can't I just jump ahead? Why is there anything that we perceive as the kind of inexorable passage of time? And the answer is this phenomenon I call "computational irreducibility" that I've been yakking about since the mid-1980s.

What does irreducibility mean here, and how does that stop me from time travelling or predicting the future?
If you know the underlying rules for a system, how do you know what the system is going to do? Well, one thing you can do is just run those rules and see what happens. The thing that we sort of got used to from the tradition of mathematical science, mathematical physics in particular, is that if you know the underlying rules, you can kind of just work out a formula for what the state of the system will be at any future time. You can plug any value of the variable t for time into that formula that you want. You don't have to work out the solution for $t = 1$, and then $t = 2$, and so on until you reach the value for t that you're looking for. But the thing one discovers is that, when you look at computational rules, it is often the case that you cannot jump ahead and just reduce the amount of computational effort needed to figure out what happens after some large number of steps. The only way you can figure out what's going to happen is to explicitly do each of those steps and see what happens as the system in question evolves forward in time. In an irreducible computation, you have to go through that entire evolution – there are no shortcuts.

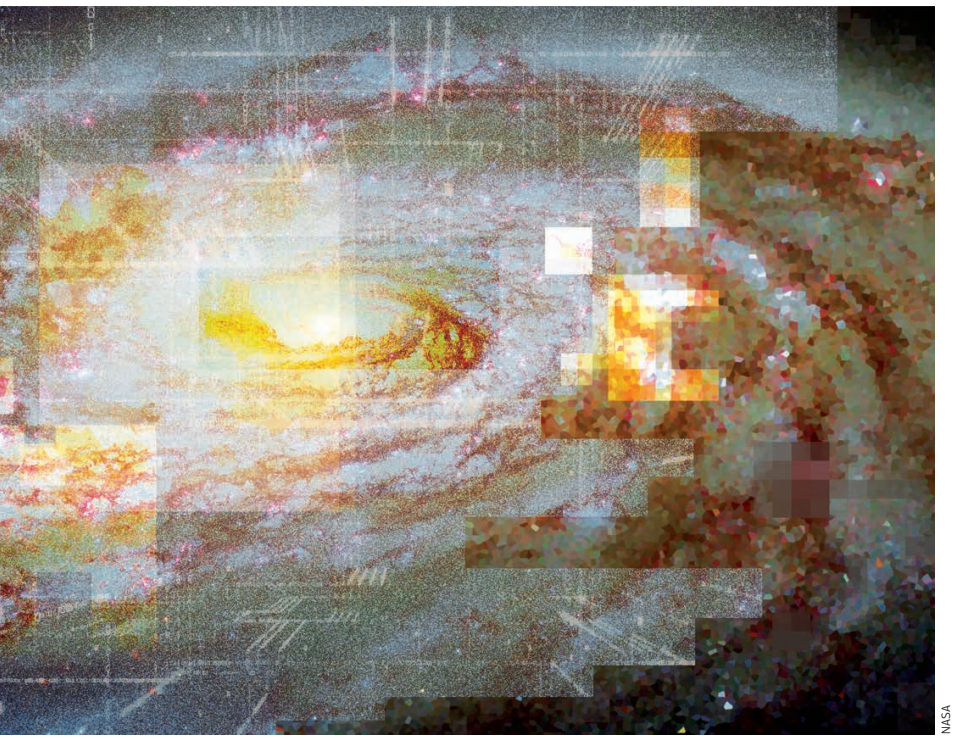


JIM NEWBERRY/ALAMY

Stephen Wolfram is trying to redefine physics

Can you give an example of something that might be computationally irreducible for a regular computer, rather than for the entire universe?
You can think about computing the digits of pi. Once you compute those digits, they look for all practical purposes like they're random, but there's a well-defined process for computing them.

You can't calculate the 1200th digit of pi on



NASA

If the universe is a computer, we may never predict the future

its own, though – you have to calculate the first 1199 digits first.

So, you can't just skip a step. Which means no time travel and no predicting the entire future state of the universe. Is part of that just because of the nature of humans?
As observers, humans are computationally limited. Let's say you're presented with some message, and it's encrypted. If our encryption systems work, we humans aren't able to just look at the encrypted message and know what the plain text of that message was. We're limited in the computations that we can do. So, in that case, to figure out what the original message was, we'd have to try all the possibilities and see what works. To say that humans are computationally limited or computationally bounded is to say that when there has been a computationally irreducible process, you can't do that whole irreducible computation. You can do only a limited computation; you can follow a limited number of steps. If you ask what's going to happen after a billion steps, you're kind of out of luck, because our brains don't get to do a computation like that.

If my brain were a better computer, could I predict the future?
If you had a computer that would do each step twice as fast as the universe does, then yes. But since the only computers we have are ones made out of things in the universe, if we're trying to predict the universe, there's no raw material out of which we can make a computer that will run twice as fast. You can't out-predict the universe from inside the universe.

But if everything is just computation, where do humanity and the prospect of free will fit in?
In a deterministic system, it's like you think: "Oh, I know the rules for the system, so I can predict everything that's going to happen. There's no free will going on here, because I can just predict what's going to happen." But with computational irreducibility, the only way you can know what the thing is going to do is to run the computation and see what it does. So, in other words, you as the external observer, and the computer with its internal experience, you're sort of running at the same rate. You can't outrun the system itself. To see what's going to happen, you have to experience it.

So, at some level, you might say that's really a bad thing, because it's a limitation on science and its predictive power. But on another level, it means that when we live our lives and we experience time, we've actually achieved something. There's some irreducible computation that's been done by that passage of time; the experience of time means something.

If I'm understanding you correctly, the answer is that it doesn't make that much of a difference in the underlying computation because, free will or not, we can't know the next step, so existence is important even without free will strictly existing.
The fact that there are rules, that things are predetermined by the previous state, doesn't necessarily make our choices within those rules meaningless. Yes, we are yoked to these rules, but it's not like that yoking immediately tells one everything about what we're going to do; simple rules can do very complicated things. What would it be like if there was free will, independent of any underlying laws? In other words, what if you are just randomly deciding to do this or that, in a way that has no external input from any previous state? You could have a picture where the universe is not deterministic, and just completely arbitrary things happen – that is a possible picture of how the universe works. I don't think that's the case, but that's a possible picture. But if that is the case, then the programme of finding laws of physics or laws of science is ultimately doomed. We'd just say, we don't know why this happened, and we can never know why anything happened. There is no law that determines what will happen. But as soon as any foundational theoretical science is possible, you don't get to have that picture.

So, if we want to have any laws of physics at all, we have to admit that we are, in some way, limited. The moment I can't say something absurd like, "I'm going to become an orb now," and become an orb, the concept of free will loses some of its meaning.
Right, as soon as there are definite laws that govern the universe, you can't have that notion of free will that you were implying. And so then the question is, why do we think we have free will? That's then the mystery: if, in fact, we believe there are underlying laws, how come we believe we have free will? And the answer, I think, is because of this phenomenon of computational irreducibility. That is, if we could always predict what we're going to do a year in the future, then we wouldn't imagine that it's up to us to figure out what we do a year in the future – we would just be sitting here as passengers, having the universe determine what we're going to do. ▮

This is an edited extract from our subscriber newsletter *Lost in Space-Time*. Sign up at newscientist.com/lost-in-space-time

Leah Crane is a senior reporter at *New Scientist*, covering topics ranging from private space flight and cosmology to quantum mechanics

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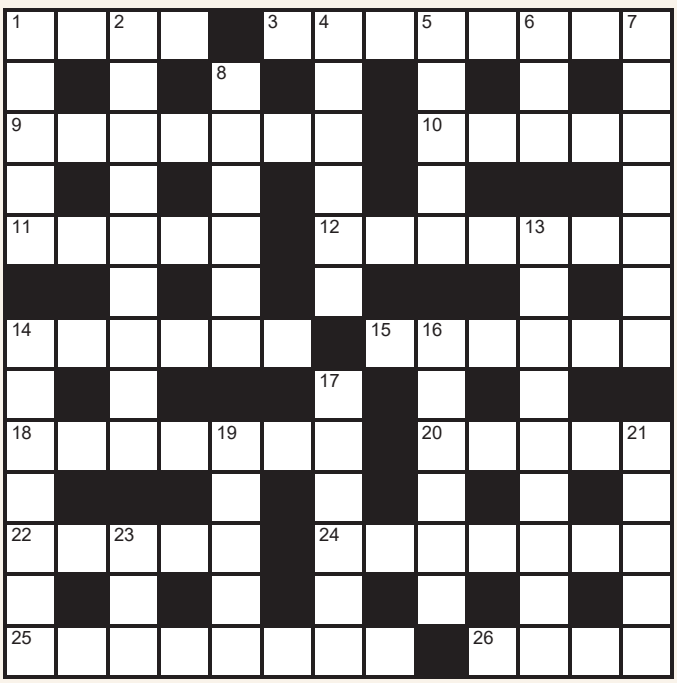
Cryptic crossword #192 *Set by Rasa*



Scribble zone

Quick crossword next week

ACROSS

1 Wires broadcast false appearance (4)
3 Pub urges tossing resistant one (8)
9 Obsolete phone message incorporated, beginning to end (7)
10 Short, round part of a plane (5)
11 Engine booster cut tail of flatfish (5)
12 Romantic turned red, clutching bundle of sheets (7)
14 Fanciful quality of online chats in question (6)
15 Toil at an advertising phrase (6)
18 Windstorm near Cambridge school brought back delay (4,3)
20 Antigua vacationer smuggles fruit (5)
22 Reportedly consumed small cube (5)
24 Feeding bit of salmon to monarch (7)
25 Ability to read and write "low in calories and spicy" (8)
26 Kelvin reflected on temperature unit for sailors (4)

DOWN

1 Thunberg, for one, with a rising notable (5)
2 Bitter mixture covered with "tasty" element (9)
4 Disorderly nudity needs correcting (6)
5 Gradually wear down staff kept by electrical engineer (5)
6 Weight ratio bumf I'd regularly ignored (3)
7 Madly in love, almost call astronaut (7)
8 Coming around, cuddles up to spies (6)
13 Millions on Instagram share mass movement (9)
14 Battery, source of water, blankets and so on (3,4)
16 Swarm district changing hands (6)
17 Spider's pouch covering up about two grams? (3,3)
19 I'll abandon retail counter in a while (5)
21 Half of army understood jargon (5)
23 Put up aquatic tower midsection (3)

Quick quiz #361
set by Chelsea Whyte

1 What is the name of the prototype cell created using 36 existing bacterial genes that is partly capable of replicating itself?

2 What caused NASA's Swift space telescope to begin falling back towards Earth, necessitating an audacious plan to boost it back into orbit?

3 A rising underwater volcano has been spewing chemical traces from ancient Earth's primordial magma ocean. Near which country's coast is it located?

4 What is the name for black holes that are bigger than whole galaxies?

5 African elephants are among the mammals that sleep the least. For about how many hours do they sleep each day?

Plus Side
created by Puzzlr

Circle numbers in the grid below to use them, or cross them out to get rid of them. Circled numbers must add up to both the target at the end of each row and the target below each column.

8	7	3	4	2	12
3	4	3	1	1	0
3	8	4	2	6	15
1	6	9	4	9	15
9	8	4	7	2	15
11	14	17	11	2	

Answers to this week's puzzles on page 45

Something fishy

The positions of most fishes' eyes mean they cannot see their own body. So, how do they recognise others of their own species?

Andrew MacColl
School of Life Sciences, University of Nottingham, UK
Leaving aside the issue of exactly how much of their body they can see (some fish, like eels, can probably see quite a bit of it), the question of how fish recognise their own species is an important one that is surprisingly poorly understood.

From what we know about other species, fish may "imprint" on a parent, enabling them to recognise adults of their own species later in life. However, most fish never see their parents. This leaves us with some form of inherited, instinctual recognition as the most likely possibility. The exact way in which that might work is unclear and may vary between habitats and species.

Some use of the senses must be involved, and given that most fish don't vocalise and have limited contact while mating, it seems most likely that sight and/or smell are involved. Sight

"The many closely related cichlids in East African lakes have a particular problem when it comes to species recognition"

is likely to be important for many species and could involve the recognition of shape, movement or colour patterns to define species.

For the many species of fish that live in dark or murky environments, sight must be of limited use and this leaves smell. The use of smell allows the possibility that species recognition could be "self-referential" – that is, dependent on an individual's perception of itself.

A final mystery is how species recognition keeps pace with divergence during speciation. The many closely related cichlids in East African lakes, for example, have a particular problem when it comes to species recognition and it is likely that any one mechanism is error-prone, but that the overall error rate is reduced by spatial and temporal context.

Mike Webster
School of Biology, University of St Andrews, UK
Recognising members of their own species is important to fishes, allowing them to shoal with others to gain protection from predators and ensuring that they direct courtship behaviour to members of the same species so that they can reproduce successfully.

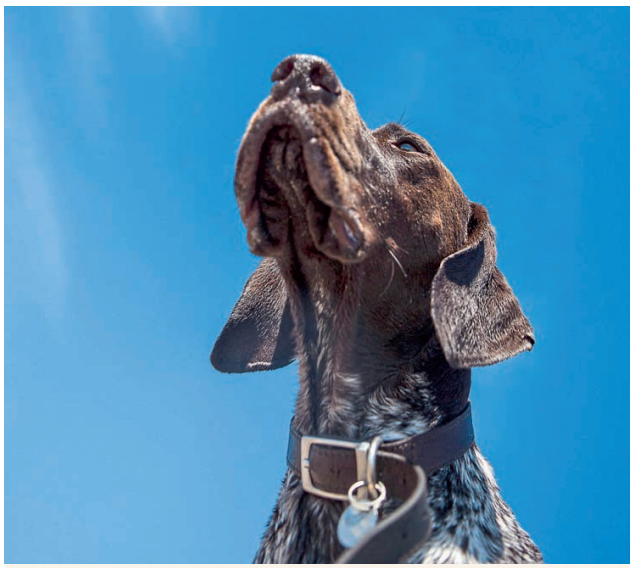
Some fish, including zebrafish, learn to recognise members of their own species through a process called imprinting. This is a type of long-lasting learning that occurs early in life in a sensitive period, during which they learn recognition cues of other nearby animals, which will tend to be members of their own species. This information provides them with a template for recognising others later in life, and it isn't necessary that they perceive their own appearance in order to do so.

For zebrafish, both visual and chemical cues are important for imprinting. For many species of fishes, multisensory integration combining information detected using different senses, including visual, but also chemical, tactile, acoustic and electrical cues, allows them to build an accurate representation of their surroundings, including the other animals they interact with.

The extent to which vision is important to fishes varies greatly between species and strongly depends on the habitat that they are adapted to. Fish inhabit a wide variety of environments. In shallow, coastal waters and clear rivers and lakes, sunlight can penetrate easily, and vision may be important to many of the fishes that live there.

In silty estuaries, algae-rich eutrophic lakes and in the deep ocean, however, light is quickly scattered by particles of suspended sediment or phytoplankton and doesn't penetrate deeper water. Fishes in these environments might still use vision to detect shadows or flashes of bioluminescence from predators or prey, but in the absence of sunlight, they tend to rely more heavily on other senses to detect and recognise others.

Finally, regardless of the sensory systems involved, species recognition in fishes isn't always accurate. Many fishes live in mixed-species shoals, and at least some of the time this might be down to misidentification of species. When it comes to reproduction, hybridisation – breeding that occurs between different species – is widespread in some fish families and more common in fishes than any other vertebrate.



LEE MARTIN/ALAMY

Why don't dogs look up when a plane or helicopter passes overhead?

This week's new questions

Hear that? **Why don't dogs look up when a low-flying plane or helicopter passes overhead? I've never seen one do this.** ***Tony Hersh****, Newbury, Berkshire, UK*

Moon move **What changes will occur on Earth as the moon moves further away from us?** ***John Grant****, Shelly Beach, Queensland, Australia*

Clear the table

How many of the 118 known elements in the periodic table could we permanently delete without any ill effect on our lives? (continued)

Guy Cox
Sydney, Australia
Previous correspondent Mike Follows is far too stingy in his list of elements essential for life. The

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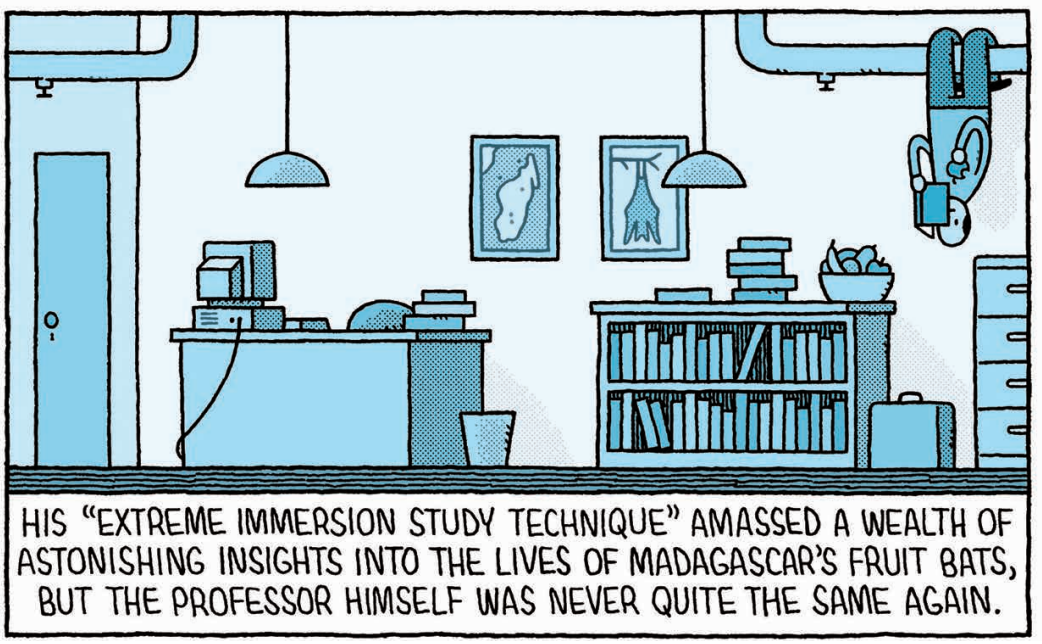

mnemonic CHOPKINS CaFe, mighty good – carbon (C), hydrogen (H), oxygen (O), phosphorus (P), potassium (K), iodine (I), nitrogen (N), sulphur (S), calcium (Ca), iron (Fe) and magnesium (Mg) – teaches us the essential elements for plant growth, to which we also have to add sodium and chloride (no salt on the table in this cafe?). Magnesium, by the way, is required for chlorophyll, which enables photosynthesis to take place.

But there are essential trace elements we humans also need in small quantities – copper, cobalt, selenium, manganese, molybdenum, zinc. Now we are up to 19 elements.

Silicon isn't just useful for computer chips, it is vital for many organisms, most obviously diatoms – aquatic algae with silica skeletons – and sponges. Getting somewhat left-field, some ascidians (sea squirts) need vanadium.

Correspondent Eric Kvaalen mentions that polonium is useful

"Silicon isn't just useful for computer chips, it is vital for many organisms, most obviously diatoms and sponges"

for killing people and there is one famous case of that (the 2006 murder of prominent Russia critic Alexander Litvinenko).

But that isn't the only use of polonium. Back when photography wasn't digital, one of my prized possessions was an anti-static brush that had a strip of polonium behind the hairs to neutralise the static created by brushing when cleaning film. They probably went off the market after that assassination!

Colin Nicholson
Stockport, Greater Manchester, UK
It is indeed interesting to consider which elements we can do without, but we have to be careful. I find it fascinating that evolution has come up with very different strategies in various phyla for the transportation of oxygen and carbon dioxide in the blood and the transfer of energy.

As mammals, we depend on iron atoms at the centre of haemoglobin molecules in our blood, as do fish, from which we may have evolved.

In crustaceans, octopus, spiders and scorpions, the oxygen-absorbing molecule hemocyanin is based on copper, while plants use magnesium in their chlorophyll to capture energy from sunlight.

Insects don't have the veinous system of us animals, but absorb oxygen directly through tubules in their skin. Their bodies are filled with a hemolymph based on large protein molecules containing copper, but this has evolved for other uses, not oxygen transport.

Howard Homler
Sacramento, California, US
Correspondent Simon Goodman forgot the iron in haemoglobin, which is essential in much more than trace amounts, only listing it as a structural metal.

Answers

Quick quiz #361

1 SpudCell

2 Solar flares

3 Madagascar

4 Stupendously large black holes (SLABs)

5 2 hours

Cryptic crossword #192

ACROSS 1 Guys, **3** Superbug, **9** Extinct, **10** Owing, **11** Turbo, **12** Dreamer, **14** Whimsy, **15** Slogan, **18** Time lag, **20** Guava, **22** Eight, **24** Stoking, **25** Literacy, **26** Knot

DOWN 1 Great, **2** Ytterbium **4** Untidy, **5** Erode **6** BMI, **7** Gagarin, **8** Snoops, **13** Migration, **14** Wet cell, **16** Legion, **17** Egg sac, **19** Later, **21** Argot, **23** Gut

Plus Side *Solution*

12	2	(4)	3	7	(8)
0	1	1	3	4	3
15	6	2	(4)	(8)	(3)
15	9	4	(9)	(6)	1
15	(2)	(7)	(4)	8	9
	2	11	17	14	11

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Imagining things

Late last year, between one news event and another (honestly, who can remember?), Feedback was delighted to discover the *Journal of Imaginary Research* (15 November 2025). This is an online magazine publishing "short works of fiction", but only if they take the form of "imaginary research abstracts". In other words, it's a collection of summaries of (entirely fictional) research studies, each of which is a little short story in disguise.

It's the creation of two academics in the UK: Kay Guccione at the University of Glasgow and Matthew Cheeseman at the University of Derby. It grew out of a workshop intended "to introduce creative writing concepts to researchers", especially those "who felt tense, anxious, about writing, or had fallen into a negative relationship with their writing" – in other words, an aid for professionals with writer's block. But, like the Marvel Cinematic Universe, it has grown beyond all expectations and is now a venue for rather lateral short stories.

The 2026 issue came out in late June. Reader Alex Gough alerted us to it, having published in it himself "after strenuous peer review". Alex's piece is titled "Seven new examples of adaptive radiation and insular dwarfism in etapods". He begins by explaining that "Insular dwarfism is a process in which species isolated on islands evolve to become smaller than their mainland counterparts, eg Lemerle's hippopotamus." From there he goes on to describe seven miniature species from a fictional archipelago, each of which has "developed behavioural traits suited to [its] unique environment".

For instance, "Etapodus malevolus is notably belligerent", in response to "the high prevalence of predators on its island". In contrast, "Etapodus somnolentus undergoes prolonged periods of hibernation to cope with its irregular food supply."

However, not all the species could be explained in this kind of adaptive evolutionary language. "Etapodus jucundus is habitually carefree and contented, for reasons we have not yet discovered."

We assume readers have got the joke by now. If not, go sweep the floor and whistle while you work, maybe it'll become clear.

Elsewhere in the issue, we find "Move fast and break everything: Deflecting anxiety in a tech-forward world". It explains: "For unclear reasons, the rapid-fire continuous release of life-altering and world-transforming technological developments in artificial intelligence, without oversight of any kind, has caused an increase in anxiety, with some people even proving inexplicably resistant to emerging technologies."

Fortunately, a solution is at hand. "The use of AI technologies reduces prefrontal cortex activity and critical thinking", which may lead to "brain atrophy, and therefore a reduction in distracting ethical questions". The problem solves itself!

Twisteddoodles *for New Scientist*

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Send it to feedback@newscientist.com
or New Scientist, 9 Derry Street, London, W8 5HY
Consideration of items sent in the post will be delayed

Etymological issues

Feedback is on a mission to get the word "nonomatopoeia" added to the dictionary. Attentive readers will recall that the neologism was proposed by Neil McKay and means the opposite of onomatopoeia, i.e. it is a word that doesn't sound at all like the thing it describes (6 June).

Several readers have submitted additional examples of nonomatopoeia, bolstering the evidence that the word would be a valuable addition to the language because it describes a widespread phenomenon. Elaine Coates says she has always struggled with "pedagogy". It refers to the method and practice of teaching, but, she says, "it sounds like some sort of foot fetish".

Likewise, Bob Munro nominates "valetudinarian". It sounds like a religious order, but actually refers to "a person who is chronically sick, or believes themselves to be". These two alternative meanings, incidentally, are so radically distinct they render the word effectively useless.

In a nicely meta twist, Sue Tudor says that "onomatopoeia" is itself an example of nonomatopoeia. She describes "onomatopoeia" as "surely one of the most non-onomaterwhatsit words in existence", because the sequence of syllables suggests "standing or sitting on a mat on a pier".

There is, we should say, a question about the etymology of nonomatopoeia, which computer scientist Julian Bradfield has flagged. "May I be the 94th reader to point out that onomatopoeia is Greek, so its negation is anonomatopoeia, not nonomatopoeia," he writes. "The opposite, rather than the negation, is antonomatopoeia."

We regret to inform Julian that he is so far the only reader to point this out, but if another 93 would care to write in making this same argument, we will place all this correspondence in one of our special folders.

Rats on parade

Our quest for the most niche scientific tourist attractions continues, with museums of grain and gas setting the pace (30 May).

Simon Goodman reports having found "a lovely example" in Siem Reap, Cambodia, which is the jumping-off point to visit the Angkor temple complex. There he found a visitor centre for the charity APOPO, which uses trained African giant pouched rats to detect landmines. "This is a must-see place," says Simon. "The highlight is seeing how the rats are trained and search out mines, which the carers show you live."

If that weren't enough, if you agree to remove potentially toxic substances like sun cream from your skin, "You are even allowed to cuddle the rats." They are cat-sized and "delightful", Simon reports.

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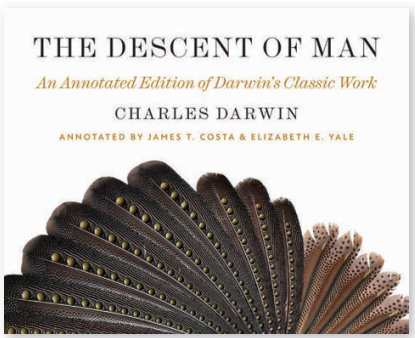

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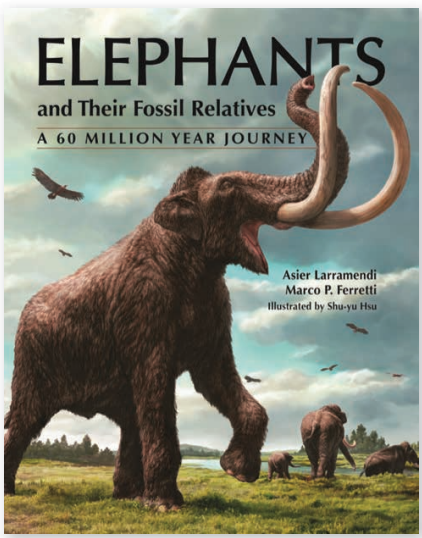

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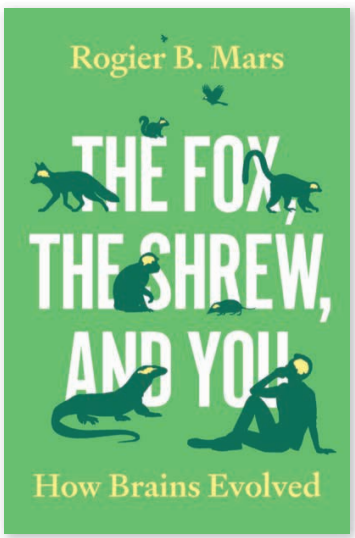

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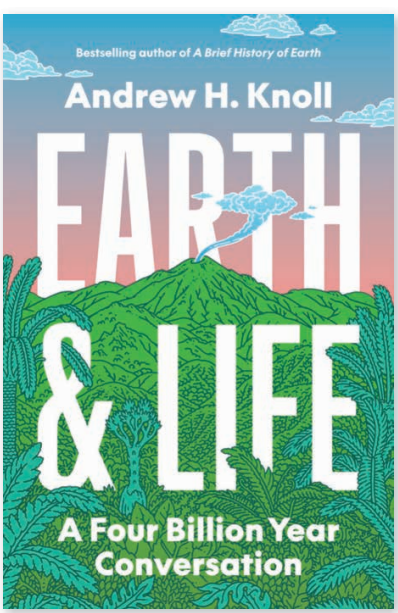

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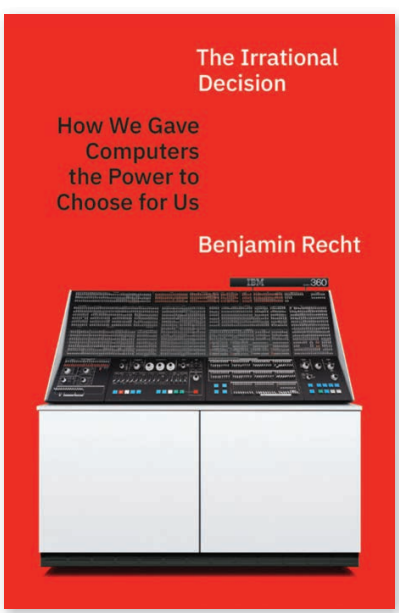

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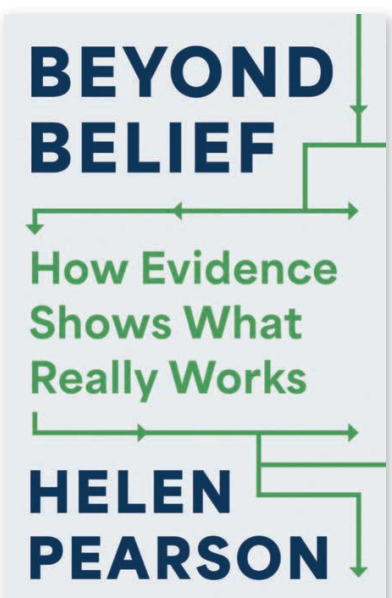

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