# New Scientist

**WEEKLY** November 7–13, 2020


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Europe locks down again as second-wave cases surge

*What went wrong in Germany?*

How antibodies from survivors could help save lives

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An intriguing new theory about what goes on inside our heads at night, and why

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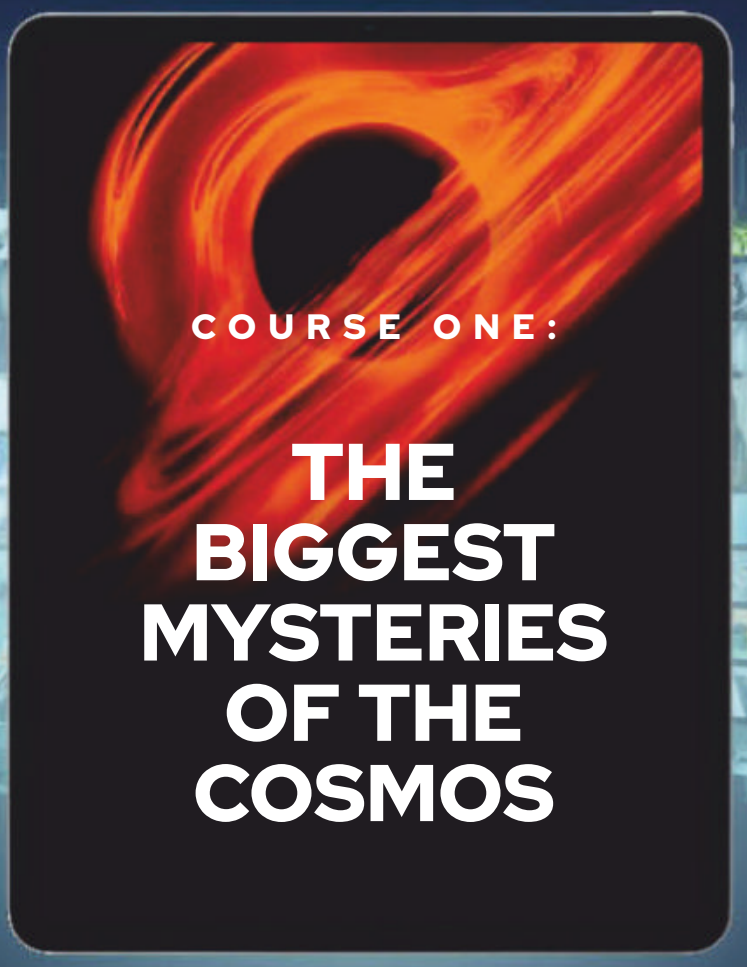


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### Covid-19 daily briefing

The day's coronavirus coverage updated at 6pm GMT with news, features and interviews.

**newscientist.com/coronavirus-latest**


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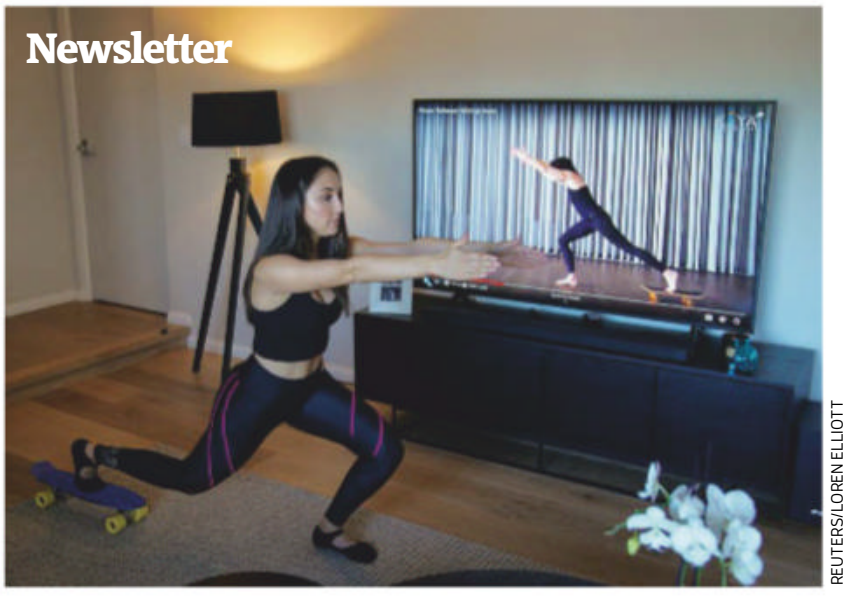
**Scary tales** Podcast special looks at "real" monsters and zombies

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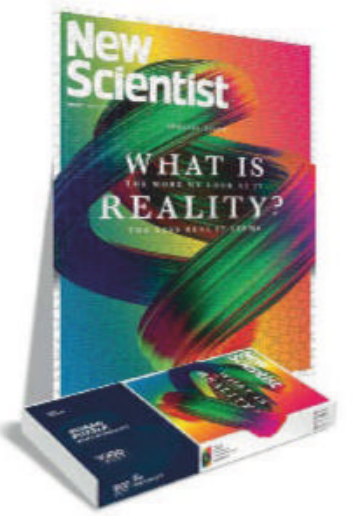
**Tone from home** Stay fit and healthy during the pandemic

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# Dreaming about exploring the world again?

While travel is still little more than a dream, we all need something to look forward to and we know that many of you are still eager to pencil in your next adventure. So we've been focusing on next year's tours and wanted to share with you a few of the new science focused tours we have created for 2021 and beyond.

All these new tours will be going on sale later this month, so if a specific tour catches your eye why not register your interest now and we will contact you when we start taking bookings again.

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# Realism needed

## Beware those who promise you that this will all be over soon

AS THE coronavirus began spreading through Europe in the spring, many scientists warned that worse could come in winter. Now, it seems they were right. The continent's wave of second lockdowns (see page 7) has brought gloom, anger, fear and, in some countries, protests. In the UK, the prime minister, Boris Johnson, has tried to offer his citizens some hope, telling them that everything will look much cheerier come 2021.

Such offerings of hope should be treated with caution. Perhaps things will be better when spring returns to the northern hemisphere. But it isn't immediately clear why that should be the case.

It is possible that by then we will have a stopgap therapy to create immunity without a vaccine, but as Graham Lawton writes on page 12, the results are still too early to equate to a panacea. An actual vaccine may become available, but if so it will only be available to some at first. It may also fail to deliver on any number of other counts, for example, requiring repeated booster injections.

A vaccine, as we have said before in these pages, was never going to be a quick or easy way out. Meanwhile, in the UK at least, testing for coronavirus and tracing the contacts of those who test positive is patchy at best.

So what next for those countries hardest hit? First, we need to stop thinking short term. The pandemic could well continue to significantly affect our lives for years. It would be wise to plan accordingly.

Second, we must admit that lockdowns are an indication of government failure and ultimately do nothing to stop the virus spreading if the pause isn't used to build testing and contact tracing capacity. Brief, planned lockdowns, rather than the emergency ones being introduced now, could be a useful tool to keep infections under control, but really we need what we have always needed: working test, trace and isolate systems.

Finally, for test and trace systems to work, we need easy-to-access tests, quick results and to give those infected the financial and practical help they need to isolate. Such systems involve a huge economic hit – but then so do lockdowns. They also require something that is in short supply in places like the UK: trust in the government. Perhaps some realism from leaders, rather than offers of false hope, is a good place to start. ▮


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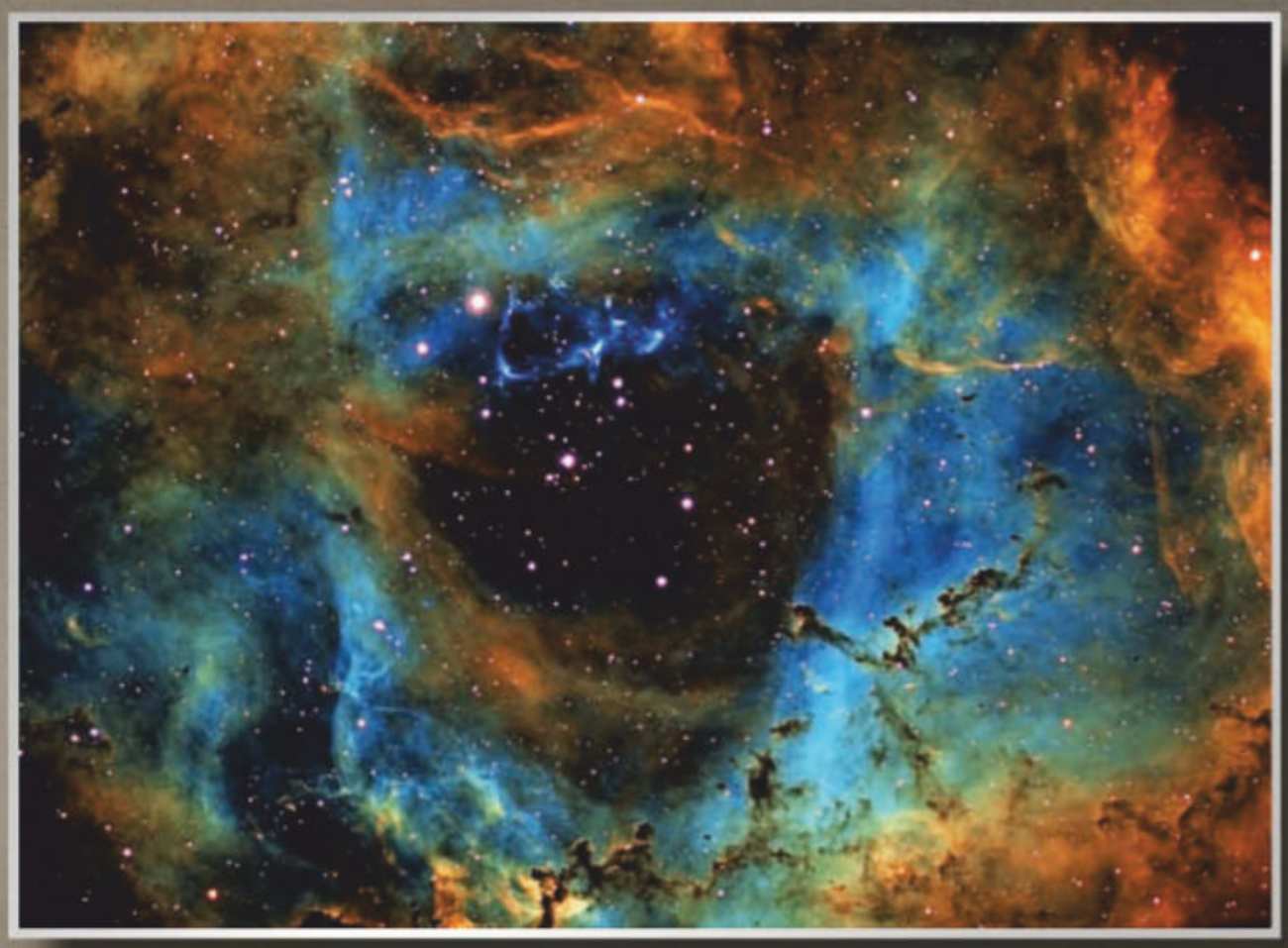

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**UK prime minister Boris Johnson announcing the latest English lockdown**

Europe's second wave

# Lockdowns across Europe

Many countries are starting new lockdowns, but it may already be too late to stop the second wave of coronavirus from eclipsing the first, reports **Michael Le Page**

ENGLAND has begun a second national lockdown, after weeks of regional restrictions failed to curb the spread of the coronavirus. The UK government didn't follow suggestions made by scientific advisers in September to institute a shorter lockdown weeks earlier, intended to halt the exponential growth of coronavirus cases.

This new lockdown is needed to stop the spread of the virus, but it and similar efforts across Europe may be too late to prevent the second wave of covid-19 being worse than the first.

"It's pretty bleak," says Paul Hunter at the University of East Anglia in the UK. He thinks the second wave will be more drawn out but will eventually lead to more deaths in the UK than the 44,000 seen in the first wave.

"I think probably we will ultimately see more deaths over the next six months," he says.

A sharp rise in cases has also been seen across Europe in recent months, and many countries are being forced to ramp up covid-19 control measures and introduce lockdowns. Northern Ireland increased restrictions on 16 October, stopping short of a full lockdown, while the Czech Republic was the first to impose a second lockdown, on 22 October, despite the government having stated that it wouldn't do so.

"We have no time to wait," said Prime Minister Andrej Babiš. "The surge is enormous."

Since then, Wales, Spain, France, Germany (see page 10), Belgium, the Netherlands, Italy and other countries have also announced new lockdowns or restrictions with varying degrees of severity.

In England, where a three-tier system of regional restrictions has been in place since 12 October, a four-week lockdown will begin on 5 November, while a five-tier system began in Scotland on 2 November.

In the Czech Republic, which did better at limiting the first wave than many other countries in Europe, the second wave is already far worse on every measure. There are six times as many people in hospital with covid-19 than during the first wave, and there are 16 deaths per million people per day compared with just one per million people per day in the first wave.

The second-hardest-hit country is Belgium, which had a big first wave. Belgium is reporting more than 1200 cases per million people per day – the highest rate in Europe. So far there are only a third as many people in hospital with covid-19 as during the first wave, and seven deaths per million people per day compared with 25 earlier in the year. However, government health spokesperson Yves Van Laethem has warned that all available intensive care beds ›

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in the country could be full by mid-November.

The skyrocketing numbers of coronavirus cases happening in Europe now were predicted by epidemiologists months ago.

"No government can claim they have been 'taken by surprise by virulence of second wave'," wrote Jeremy Farrar, director of the Wellcome Trust in the UK, in a tweet. The trajectory has been clear since at least the start of September in Europe, though it could be seen as far back as mid-July, he said.

After lockdowns during the first wave greatly reduced the spread of the coronavirus, most European countries opened their borders and relaxed restrictions. At first, case numbers continued to fall, but they started to creep up again in July and August.

Exponential growth means cases are now rising fast in most countries – including in Sweden, where the majority of measures to control the coronavirus are voluntary and where infection rates have been much higher than those of neighbouring countries.

## Underestimated cases

"Increased contact levels are at the heart of this," says Anne Johnson at University College London.

As people went on holiday in August, or returned to fully reopening schools and universities, they came into contact with more people, she says. And with more of life moving indoors as the weather gets colder, the risk of being infected has increased too.

Across Europe, daily case numbers reached nearly 250,000 last week, compared with under 50,000 during the first wave. However, in many countries, the actual number of people being infected probably hasn't yet exceeded the levels in the first wave. The reason is that little testing was done early on in the pandemic, so most cases were missed – only 1 in 50 cases were detected in the first wave, compared with around 1 in 4 now.

**"No matter what we do now, infections and deaths will go up over the next few weeks"**

In England, researchers get an idea of infection rates from surveys in which a random selection of people are tested regardless of symptoms, and the results are extrapolated to the entire population. The latest survey by the Office for National Statistics (ONS) suggests that 52,000 people were infected every day between 17 and 23 October.

Another survey, by the REACT 1 team at Imperial College London, put the figure even higher. It suggests that around 96,000 people in England were being infected every day between 16 and 25 October. That is more than four times the number of confirmed daily cases that have been reported by the UK government.

How does this compare with the first wave? We don't know for sure, because these surveys didn't start until the end of April. However, a modelling study by Nick Davies at the London School of Hygiene & Tropical Medicine suggests that in England there were 200,000 infections per day on average over a two-week period during the peak in March. At the very peak of the first wave, there were 250,000 infections on just one day.

"It is quite high compared to other estimates," says Davies. But it is based on the number of deaths and hospital admissions, so he is confident in the finding. This work hasn't yet been published.

REUTERS/YVES HERMAN

**People with covid-19 being treated in a hospital in Belgium**

If these estimates are right, the number of new infections in England could surpass the number during the first wave within days. The REACT 1 results suggest cases are doubling at least every nine days. "The rate of growth is really quite rapid," says Steven Riley at Imperial College London.

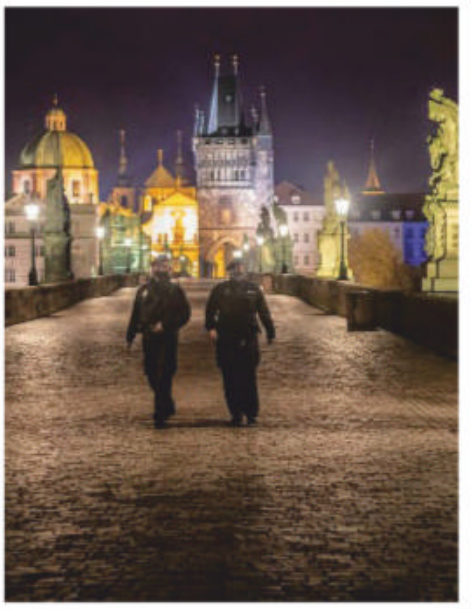
## Hospital admissions rise

It is clear that the three-tier system of regional restrictions introduced in England on 12 October didn't go far enough. Davies has been using data from Google indicating how much people are moving around to assess the system's impact, and his team's modelling suggests that the measures only slowed the spread of the virus, instead of halting it completely.

It will take several weeks for it to become clear what effect the various new measures introduced across Europe are having, due to the delay between people becoming infected, developing symptoms, getting tested and, in some cases, being hospitalised or dying.

"No matter what we do now, infections and deaths will go up over the next few weeks," says Duncan Robertson at Loughborough University in the UK. "These deaths are already baked into the system."

There are already some ominous warning signs. By 18 October, there were more people hospitalised than in the first wave in at least seven countries: Bulgaria, Poland, Hungary, Slovenia, Croatia, Latvia and the Czech Republic. This list may be incomplete as some countries, including Germany, the Netherlands and Sweden, don't report hospital admissions data to the European Centre for Disease Prevention and Control (ECDC).



MARTIN DIVISEK/EPA-EFE/SHUTTERSTOCK

**Police patrol a bridge after curfew in Prague, Czech Republic**

**250k**
**Highest reported daily rate of coronavirus cases across Europe**

**1 in 4**
**Cases detected now, compared with 1 in 50 during the first wave**

**20-29**
**Age group with the highest current rate of covid-19 in England**

**120k**
**Potential number of coronavirus deaths in the UK between September 2020 and June 2021**

In the UK, there are only half as many people in hospital with covid-19 as there were in the first wave. This might seem at odds with the idea that the infection rate is about to surpass the earlier peak. However, it is because of the lag between people being infected and becoming severely ill. "Admissions to hospital are going up later but in parallel with the number of cases," says Johnson.

What's more, the first ONS survey of England back in May found the highest rate of infections among people aged between 50 and 69. Now, the highest rate is among people in their twenties, who are much less likely to become severely ill.

Unfortunately, infection rates are starting to rise in older age groups too, says Johnson. She was one of the authors of a July report that warned there could be a protracted second wave, with 120,000 deaths in the UK between September and June 2021 – more than double the number in the first wave. "It was a reasonable worst-case scenario, not a prediction," says Johnson. "But we are not far off it really."

## Harder to contain

The figure of 120,000 deaths didn't account for the availability of better treatments than we had in the first wave, such as the steroid dexamethasone, which has been shown to reduce deaths from covid-19. However, another, more recent, reasonable worst-case planning scenario in a leaked report from the UK's Scientific Advisory Group for Emergencies (SAGE) is similar: 85,000 deaths in the UK directly due to covid-19, plus another 27,000 indirect deaths.

The UK government was advised a month ago by a SAGE subcommittee that the number of infections and hospital admissions in England was already higher than those in this worst-case scenario, and that the number of deaths would also soon exceed this scenario. "Were the number of new infections to fall in the very near future, this exceedance of the reasonable worst case scenario could be modest and short-lived," states a 7 October document made public last week.

England is far from alone. By January, the daily mortality rate in Europe as a whole could be five times higher than in April unless countries reverse course, said Hans Kluge at the World Health Organization in a statement on 15 October.

**"In January, the death rate in Europe could be five times higher than in April unless countries reverse course"**

While many countries have tightened restrictions since then, most haven't imposed measures as strict as the lockdowns put in place during the first wave. For instance, in England, schools and universities will remain open, unlike in March.

A tendency to stay indoors in winter might make it harder to contain an outbreak than in spring, especially if actual case numbers are already surpassing those from earlier in the year. The higher the number of cases, the harder it is to contain an outbreak, says Johnson, because the odds of people coming into contact with an infected person are higher.

"This is a serious situation," she says. "We have already baked ourselves into a lot more trouble, just because of the number of people infected." ▮

Europe

# Germany hit hard by second wave

## Though relatively unscathed by its first wave, the country is now faring worse

Layal Liverpool

HAILED as an example to follow for its initial coronavirus response, Germany is now struggling to curb surging infections amid Europe's second wave.

"We are now at a point where, on average nationally, we no longer know where 75 per cent of infections come from," German chancellor Angela Merkel said during a press conference on 28 October.

Unlike many nations, Germany didn't have to build up its testing and contact-tracing infrastructure from scratch when the pandemic hit. During its first wave in the spring, the country's 400 or so local health authorities facilitated rapid identification of source cases and tracing of their contacts.

Ahead of a gradual easing of restrictions in early May, Merkel and German state leaders focused on expanding the country's tracing capacity further, agreeing in April that local health authorities should each have at least five contact tracers for every 20,000 citizens. Combined with Germany's large testing capacity and its use of localised restrictions to quash emerging hotspots, this worked to keep cases and deaths low through the summer months.

"I think also the fact that Germany had a high number of beds in ICU [intensive care units] really helped to control the situation," says César Muñoz-Fontela at the Bernhard Nocht Institute for Tropical Medicine in Hamburg. "The system was never really overwhelmed."

Germany has the most hospital beds per 1000 people in the European Union and has had a much lower death rate from covid-19 than other European countries with a similar population size. During the first wave, deaths in Germany peaked at 2.78 per million people, compared with 13.88 in the UK, 13.59 in Italy, 16.87 in France and 18.57 in Spain, according to data from the European Centre for Disease Prevention and Control.

Yet Germany's success in containing its first wave and its low death rate from covid-19 may be the reasons why it is now finding it difficult to prevent infections.

"We have been living with the pandemic for many months now, and most people have not yet seen friends or family fall very ill or even die from covid-19," says Sandra Ciesek at Goethe University Frankfurt. This makes the threat of the virus seem abstract and may be responsible for a drop in adherence to restrictions, she says.

Cases have been climbing rapidly in Germany, and the country has been reporting record daily increases in new infections recently. Its contact tracers are also having a much harder time keeping up this time around.

"One of the very few things we have to manage the epidemic in the country is contact tracing," says Ralf Reintjes at Hamburg University of Applied Sciences. But contact tracing stops working above a certain threshold of cases and contacts, he says. The relaxation of rules over the summer has meant that each coronavirus case now probably has more contacts on average, compared with the cases in the spring, says Reintjes.

"The second wave in Germany is distinct from the first in many regards. The first wave was driven by relatively few introductions of the virus into the community – returning travellers from ski trips in the Alps were responsible for many of the cases. This made tracing of the cases relatively straightforward," says Ciesek.

In an effort to regain control of this second surge of infections, Merkel announced a partial nationwide lockdown for a month, which started on 2 November. Under the new restrictions, nicknamed "lockdown light" by the German media, bars and restaurants are only allowed to serve takeaway items, and public recreation centres – such as gyms, swimming pools and saunas – are closed.

> "Germany's contact tracers are having a much harder time keeping up this time around"

People are also being advised to work from home where possible and restrictions on meetings have been tightened. However, schools and nurseries remain open.

"I think Germany is acting quite fast, because the number of cases is still not as bad as other countries that are also implementing measures at the moment, like Italy or Spain," says Muñoz-Fontela. The goal of the new restrictions is to bring infections back down to levels that are controllable with contact tracing, he says.

If the new restrictions in Germany aren't successful, the only alternative will be to bring back tougher measures, says Stefan Kaufmann at the Max Planck Institute for Infection Biology in Berlin. "This is the light version. If it doesn't work, then we have to immediately respond to introduce a stricter response."

MICHAEL PROBST/AP/SHUTTERSTOCK

**People wear face coverings as they leave a subway in Frankfurt**

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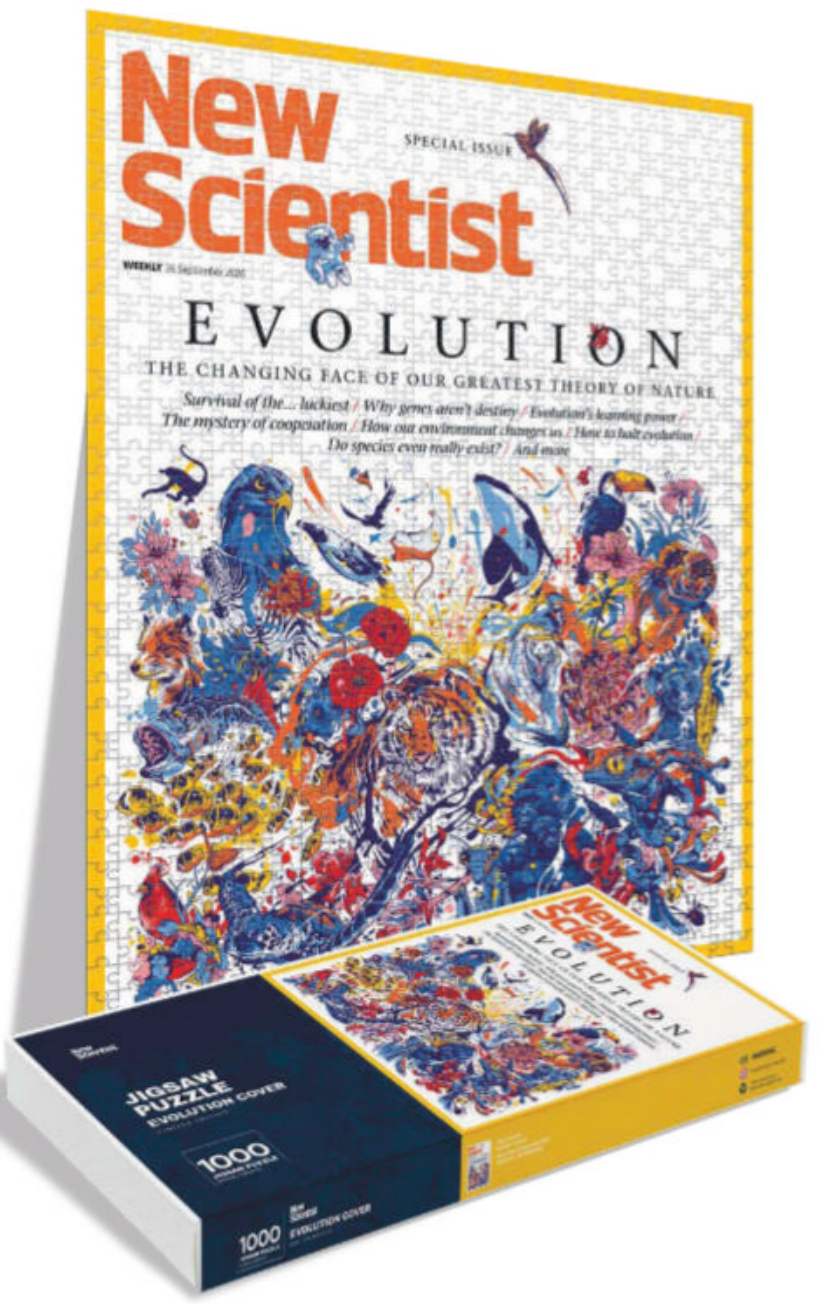


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Convalescent plasma

# The stopgap before a vaccine

Antibodies in the blood of people who have had covid-19 could be just what we need to tide us over until we have a vaccine, reports **Graham Lawton**

FOR people who have survived covid-19, there is an opportunity to add another chapter to their recovery story: they could help save other people's lives by donating blood.

The plasma of people who have recovered from the disease contains precious antibodies that helped them fight off the virus, and could help others do the same, or even make them temporarily immune. Such antibodies are an increasing focus of research efforts to treat and prevent covid-19. According to senior US health official Anthony Fauci, antibody therapies could be a "bridge to a vaccine" – a stopgap to carry us safely to the promised land.

The use of antibody-laden blood plasma was developed more than 100 years ago to treat diphtheria. It fell out of favour with the introduction of antibiotics, but was revived in 2002 during the SARS epidemic, and has since been used against Ebola and H1N1 flu. Another reason for plasma injection is to provide "passive" immunity, effectively a short-term vaccine for diseases such as hepatitis B.

GUILLERMO LEGARIA/GETTY IMAGES

**A nurse checks plasma donated by a covid-19 survivor in Bogota, Colombia**

## Ready-made therapy

The research for using several types of plasma to treat covid-19 is still in its early stages. The most basic antibody therapy is convalescent plasma. The idea is simple: transfuse plasma from a recovered patient into a sick person's bloodstream to give them an instant immune response. "It's appealing because it's a ready-made potential therapeutic," says Jeffrey Sturek at the University of Virginia, who is running a convalescent plasma trial. "You can also borrow immunity from other people."

Plasma is the liquid part of blood, and donating it is similar to blood donation. Blood is siphoned from a vein in the arm, but then separated using a process called plasmapheresis. The plasma is retained but the red and white blood cells are infused back into the donor. Plasma infusions are similar to blood transfusions. The plasma is screened for pathogens, tissue-matched, then infused into the bloodstream.

**"We do lack randomised controlled trials, but what's the harm? It may be helpful and it's probably safe"**

There are no approved convalescent plasma therapies for covid-19 yet, but some small-scale pilot studies have reported benefits for very ill people. In August, the US Food and Drug Administration (FDA) granted the therapy an emergency use authorisation (EUA), which means it can be given to patients despite not having jumped through all the regulatory hoops. More than 50 clinical trials are under way, some looking at it as a vaccine.

As yet "there is only limited data", says Diana Gabriela Iacob at the National Institute of Infectious Diseases in Bucharest, Romania, who has published a review of potential covid-19 treatments. Some side effects have been reported, including risk of lung injury. However, Sturek says it is no more risky than a routine plasma transfusion.

"We're hopeful," he says. "We do lack the level of evidence from a randomised controlled trial, but what's the harm? It may be helpful and it's probably safe."

But it may also fail. On 22 October, researchers from the largest clinical trial to date, which involved 464 moderately ill

people in India, announced that there was no clinical benefit. However, that was just one small treatment trial and the plasma levels of antibody used were low.

"There may be ways to refine it as a treatment and deliver solid, demonstrable benefits," said Simon Clarke at the University of Reading, UK, in a statement.

There is also the issue of antibody-dependent enhancement, where an antibody backfires and makes the disease worse. However, this is a "somewhat theoretical risk", says Sturek. It is very rare in other infectious diseases and hasn't yet been seen in covid-19. The therapy also depends on a steady supply of convalescent donors, but they aren't hard to persuade, he says. "There is a sense of gratitude and wanting to give back."

## Turbo-charged plasma

Another approach called hyperimmune globulin (H-Ig) is also showing promise. This is essentially turbo-charged convalescent plasma that has been pooled, purified and concentrated. H-Ig is already used against numerous conditions including flu and other respiratory viruses.

There are four covid-19 H-Igs in development, two from a consortium of companies called the Plasma Alliance.

This approach is attractive because "it's cleaner and more consistent; you have a better idea what you're giving the patient", says Sturek. This is because standard convalescent plasma contains a variable amount of the desired antibodies, and might also contain toxins or other nasties.

But whereas convalescent plasma can be dispensed immediately, H-Ig takes time to prepare and scale up. You also need several donors to make one dose, but in return "you get a more consistent antibody potency and more antibody in a smaller volume", says Lutz Bonacker at CSL Behring in Hattersheim am Main, Germany, one of the companies in the alliance. All four H-Igs are being tested in a single trial as therapy for hospitalised patients in 18 countries. The trial is in phase III, assessing effectiveness, and could finish before the end of the year.

The next level up is monoclonal antibodies. The principle is the same, but the production method is different. The antibodies aren't extracted directly from plasma, they are pumped out by genetically modified cells.

The first step is to screen convalescent plasma to find the most potent antibodies, and then engineer cells to produce them in large quantities. Monoclonal antibodies are already used for hundreds of diseases, including cancers, autoimmune diseases and some infectious diseases.

The leading player for covid-19 is biotech company Regeneron in New York, which hit the headlines after its experimental therapy REGN-COV2 was administered to US president Donald Trump. It is a cocktail of two monoclonal antibodies selected for their ability to block the virus from entering cells, and is in clinical trials both as a therapy and a prophylactic.

Regeneron has said that people with confirmed cases who are given the antibody cocktail have a lower viral load, get better faster and need less medical attention. It hasn't revealed results from the prevention side of the trial.

**"Not everyone will respond well to a vaccine. For some, antibodies may be the only route to immunity"**

Two days after Trump left hospital in October having extolled Regeneron's virtues, the firm and its main rival, Eli Lilly, asked the FDA for an EUA for monoclonal antibody treatments. The FDA hasn't yet responded.

Results of monoclonal antibody trials released so far, which are mostly in animals, look good, and it is "plausible" that it will work in humans, says Robin Ferner at the University of Birmingham, UK, who assessed Regeneron's drug for the UK's Centre for Evidence-Based Medicine. He says a similar approach was tested on Ebola in 2018 and worked "somewhat".

However, monoclonal antibodies aren't a sure-fire success. Despite the production method not relying on donors, making large quantities is a challenge. Regeneron says it has enough of one of its monoclonal antibodies to treat just 50,000 people. "Costs are likely to be eye-watering," says Ferner.

There are also likely to be other roadblocks. Days after asking for an EUA, Eli Lilly halted recruitment for one of its clinical trials on the advice of a safety monitoring board. But the company has three other ongoing trials.

On 28 October, it published positive interim results from one of these, in people with mild or moderate covid-19 who hadn't been admitted to hospital. Those who had the treatment were less likely to end up in hospital (*NEJM*, doi.org/fgtm). The results have been peer-reviewed.

Aside from the Regeneron and Eli Lilly ones, at least two other monoclonal antibody trials are under way.

If antibody therapies succeed, the analogy of them being a bridge to a vaccine is a good one, says Sturek. But even when a vaccine is available, that bridge will still be needed. "Not everyone will respond well to a vaccine," says Sturek. For those people who don't get protection from vaccines, antibodies could be their only route to immunity.

*If you have had covid-19 and would like to donate plasma, please visit nhsbt.nhs.uk (to find UK sites); thefightisinus.org (US); or lifeblood.com.au/convalescent-plasma (Aus)*

**A covid-19 patient in Turkey is discharged after plasma therapy**


ILYAS GUN/ANADOLU AGENCY VIA GETTY IMAGES

Energy

# Fusion energy but cooler

A spherical nuclear fusion reactor in the UK is testing a new heat-reducing design

Adam Vaughan

RESEARCHERS have successfully tested a new £55 million nuclear fusion machine in the UK, which could provide vital insights for a future prototype power station.

The Mega Amp Spherical Tokamak (MAST) Upgrade at the Culham Centre for Fusion Energy in Oxfordshire took seven years to build. Last week, the machine produced its first plasma, the state hydrogen reaches when heated to extremely high temperatures.

Our understanding of how stars are powered by hydrogen fusing into helium dates back around a century, but efforts to harness clean energy from the reaction in a commercial power station still face many barriers – not least how to extract more energy than we put in.

One key problem is the heat from the plasma, which reaches millions of degrees Celsius. This means it gradually burns away the exhaust system that extracts heat from the tokamak, the machine in which the fusion reaction occurs with the plasma held in place by an electromagnetic field. In a power station, that could mean replacing the exhaust every three years or so, an unacceptable interruption and cost for a commercial plant.

The MAST Upgrade team hopes to crack this by using a new type of exhaust called a "super-X diverter". It works by sending the plasma a long distance around the machine and across a wider area than usual, reducing the heat density so it cools before being extracted.

Ian Chapman at the UK Atomic Energy Agency, the project's parent body, says the design could reduce the heat by 10 times, akin to taking temperatures facing a spacecraft entering Earth's atmosphere down to that of a car's engine.

Juan Matthews at the University of Manchester, UK, says designing an exhaust that doesn't need regular replacement is a big issue, but only one of many. "It's just one of the huge number of problems that are going to have to be solved before a [fusion] power system is built."

Most tokamaks are doughnut-shaped, but this one is spherical with a thin column in the middle, producing a plasma shaped like a cored apple.

Around 90 per cent of the Culham machine is new. The rest – primarily the building and steel "vaccum vessels" that contain the plasma – was salvaged from the original MAST, which ran from 1997 to 2013. The first plasma produced is about two years later than planned and the machine is over budget, but Chapman says that is unsurprising given how hard the technical challenge is.

**"The new facility will operate at 50 to 100 million °C, which is hotter than the sun"**

The new facility will operate at "near fusion" conditions of 50 to 100 million °C, which is hotter than the sun. By contrast, the world's biggest fusion project, ITER in southern France, aims to produce plasma in 2025 at 150 million °C. In July, ITER entered the assembly phase of its construction. ▮

**A computer simulation of the MAST nuclear fusion reactor in Oxfordshire, UK**

UKAEA

Biodiversity

## Saving forests could help prevent future pandemics

**WE COULD avoid future pandemics if unsustainable practices such as deforestation and the industrial-scale wildlife trade are halted, according to a global biodiversity report. The cost of doing so would be paid back many times over, simply because it reduces the chances of another pandemic.**

**Millions of people are living or working in close contact with wild animals that carry diseases, and these industries aren't properly regulated. The more people cut down forests for farmland, for example, the more they are pushing into animals' habitats and thus coming into regular contact with disease-carrying wildlife.**

**Controlling the global wildlife trade and reducing land-use change would cost $40-58 billion per year, the report says. That is a lot, but the covid-19 pandemic is estimated to have cost the global economy $8-16 trillion by July. Before the covid-19 crisis, pandemics such as the HIV and influenza ones cost a total of $1 trillion per year, including treatment costs and economic and productivity losses.**

**"It's a really incredible, efficient economic return on investment we're going to see if we can do this right," says report author Peter Daszak at EcoHealth Alliance in New York. The report was published by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).**

**Almost every known pandemic disease came from an animal, says Daszak. Covid-19 may have come from bats in China. "HIV emerged from the hunting of chimpanzees," he says, and recent Ebola outbreaks came from the hunting of wild primates.**

**The report will feed into the next major meeting of the Convention on Biological Diversity, which is taking place in China in 2021 after having been postponed due to the pandemic, says Anne Larigauderie, executive secretary of IPBES. The meeting will set global biodiversity goals for the next decade.** ▮

**Michael Marshall**

**$1 trillion**

The annual cost of pandemics in treatment and economic losses

Technology

## Software can guess what you are typing during video calls

Chris Stokel-Walker

**SOMEONE who types while on a video call may be giving away more than they realise. A computer model can work out the words that the person is typing just by tracking the movement of their shoulders and arms in the video stream.**

**"There are significant movements that occur when typing," says Murtuza Jadliwala at the University of Texas at San Antonio. "We thought if we are able to model them scientifically, we should be able to infer different keystrokes by looking at the video data."**

**Jadliwala and his colleagues developed a model to do just that. They mapped the movements onto a keyboard and cross-referenced the results against a dictionary of commonly typed words, finding they could correctly identify the word being typed 75 per cent of the time. Their experiments were conducted both in lab conditions and using real-life video call data.**

**The computer model removes the background information from a frame of a video call. It then detects the outer edges of the shoulder by analysing each frame using an image-processing technique called optical flow, which traces how pixels change in a video and maps arm movements onto a keyboard.**

**Touch typers are more difficult to discern than those who "peck" at their keyboard, for whom the model could recover 83 per cent of words correctly. Those who wore clothing with some sort of sleeve were also less susceptible to being analysed accurately (arxiv.org/abs/2010.12078).**

**Jadliwala says pixellating the shoulders would mitigate the issue, but Alan Woodward at the University of Surrey, UK, argues such a solution defeats the purpose of video calling. "The whole point of a video call is to see people," he says, adding that it is alarming that video calls can reveal so much.** ▮

Geology

# Earth may have had three geological 'big bangs'

Colin Barras

DAVID PARKER/SCIENCE PHOTO LIBRARY

**The San Andreas fault is where the Pacific and North American tectonic plates meet**

AT THREE moments in the past, Earth's geological activity picked up the pace. Its tectonic plates moved faster than normal and there were bursts of volcanic activity and mountain building that helped to create supercontinents. These three geological big bangs may have played a role in the evolution of life on Earth.

In 2014, Kent Condie at the New Mexico Institute of Mining and Technology and his colleagues found that Earth's gigantic tectonic plates are moving faster now than they were a billion or so years ago. That conclusion came from analysing several types of data, including magnetic signals locked in ancient rock that suggest where on Earth's surface the plates were at a particular time in the past. This can help establish how fast the plates were moving at the time.

Now, Condie and his team have analysed more data. They say there is no longer a signal suggesting the plates have accelerated through time. In its place is another, even more intriguing, pattern. At three points in Earth's distant past – 600, 1100 and 1850 million years ago – the tectonic plates sped up for a few tens of millions of years, so that the global average speed was 30 to 50 per cent faster than normal.

At the same time, there were peaks in volcanic activity and mountain building, heralding the formation of supercontinents – Nuna at about 1850 million years, Rodinia some 1100 million years ago and the coalescence of land

**"A hot plume hitting the bottom of tectonic plates increases plate speed and mountain building"**

masses some 600 million years ago that would lead to the formation of Pangaea.

"Something dramatic was happening at those periods of time that was affecting all of these systems," says Condie.

The researchers think this is evidence of a vast geological cycle that begins with the death of a supercontinent. As it breaks up, some slabs of Earth's crust sink down into the mantle – the thick layer of hot rock between the crust and the core. Condie says the slabs take 100 to 200 million years to drift down to the bottom of the mantle. When they arrive, the temperatures and pressures turn the former crust into a plume of hot rock, which rises back to the surface.

"When that hot plume hits the bottom of the tectonic plates, it increases plate speed, which in turn increases orogenic [mountain building] activity," says Condie, who presented the work at an online meeting of the Geological Society of America last week.

"The notion that the deep mantle is controlling the speed of Earth's tectonic plates just before supercontinent assembly is fascinating," says Hugo Olierook at Curtin University, Australia. Earlier this year, Olierook and his colleagues presented evidence that, 110 million years ago during the Cretaceous period, all of Earth's tectonic plates suddenly slowed down by 25 to 50 per cent, which they also linked to the return of crust to the mantle.

Condie says it might be no coincidence that two of the three geological big bangs roughly coincide with eventful episodes in life's history: the appearance of complex cells about 1.7 billion years ago and the emergence of animals about 600 million years ago. "Plume events pump carbon dioxide into the atmosphere," says Condie. "I think there would be an effect on life." ▮

Can the UK government's plans to dramatically increase spending on research and development keep British science at the top of its game? *New Scientist* asks the experts

# Unleashing innovation

Britain has long considered itself a powerhouse for science and technology. It takes pride in being the place where the structure of DNA was discovered, where the jet engine and the steam engine were invented, home to the originator of the web browser and the world's first test tube baby.

But Britain hasn't always been able to turn its scientific prowess into profitable enterprise. For example, the country was a computing pioneer but today plays a relatively minor role in the global computer industry.

Now the UK government is aiming to change that with a huge increase in the amount it invests in research and development. In March, the Chancellor Rushi Sunak unveiled plans to increase R&D spending from 1.7 per cent of GDP in 2017 to 2.4 per cent by 2027. The plans include significant increases in spending from both the government and the private sector.

That raises some important questions about how the money should be spent, how it can unlock investment from industry and whether the approach will ultimately create jobs and wealth while solving the most pressing problems facing society.

## Spending roadmap

Last month, these questions took centre stage at an online New Scientist Debate sponsored by BAE Systems. A panel of experts from industry, academia and government discussed how the new money might best be used and what else might be needed to achieve the government's goals.

Under the new scheme, public funding for UK research and development will rise from £11 billion per year to £22 billion per year by 2024 to 2025. If all goes to plan, total R&D spending – including inputs from industry – will rise to £65 billion, or 2.4 per cent of the UK's GDP, by 2027. In July, the government set out its ambition for this new spending in its "Research and Development Roadmap".

An important question is whether 2.4 per cent is an achievable target, particularly when it assumes such a large input from industry. "It's a stretch," says Peter Williams, Group Technology Director of INEOS and a member of the UK's Engineering and Physical Sciences Research Council. "But it is worthwhile setting a target."

On the other hand, the 2.4 percent assumes a healthy growing economy. "Ironically, a post-Covid economy may mean we reach the 2.4 per cent by having a relatively flat public increase in spending," says Chris Skidmore, MP and former Minister of State for Universities, Research, Innovation and Skills.

One idea from the Roadmap is to run a number of ambitious "moonshot" programmes with inspirational goals that can attract talent and create payoffs far more beneficial than a business-as-usual approach.

Precisely what those moonshots should be is yet to be decided but one potential focus for inspiration is the UK's commitment to achieving net zero carbon emissions by 2050.

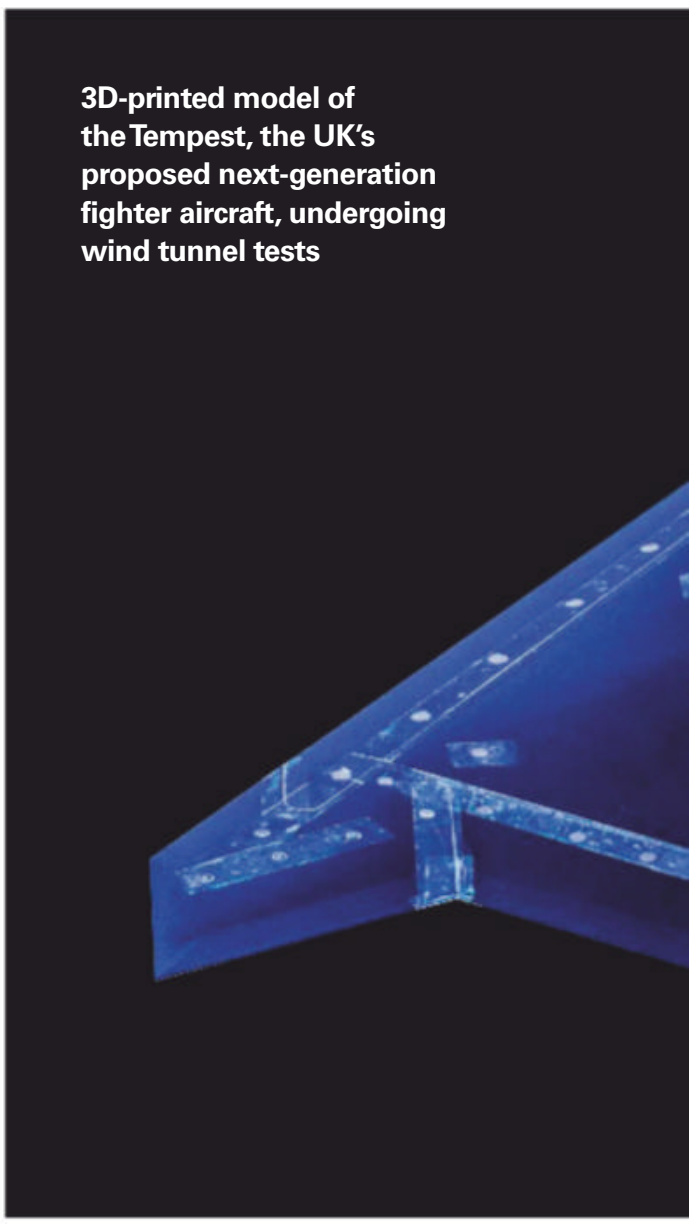
Andy Wright, Strategic Technology Director at BAE Systems, likes the goal of building an airliner that can fly across the Atlantic with zero net carbon emissions, a project called Jet Zero. "It's a fantastic project to bring enthusiastic individuals into engineering,"

## THE ADVANCED RESEARCH PROJECTS AGENCY

**In the 1950s, the US created the Advanced Research Projects Agency (ARPA) to build a technological lead for the country during the Cold War. Famously, it went on to develop the internet and other hi-tech breakthroughs.**

**Now the UK government wants to take a similar approach with its own ARPA that is oriented towards specific goals with pre-agreed milestones to check progress. But how would this work in the UK?**

**"I think it's quite an exciting proposition," says Andy Wright from BAE Systems. And Frances Saunders agrees. She has seen how it works in the US and points out that an ARPA-style approach would need to be more brutal than UK researchers are used to. "The key is to have a portfolio of projects – some of which can be very high risk – and a good programme manager with the authority to make the decisions to cut programmes that are not performing," she says. That money can then be reallocated to programmes that look more promising. "It's a very different culture from the research culture we've tended to use in the UK up until now," she says.**



3D-printed model of the Tempest, the UK's proposed next-generation fighter aircraft, undergoing wind tunnel tests

**The Unleashing Innovation panel** (clockwise from top left): **Andy Wright,** BAE Systems**; Frances Saunders,** Science and Technology Facilities Council**; Justin Mullins,** *New Scientist***; Chris Skidmore, MP,** former Minister for Universities, Research, Innovation and Skills **; Peter Williams,** INEOS

he says. "That would put the UK at the forefront of aerospace. We're already a strong aerospace nation and this would allow us to maintain that position."

Skidmore was also the energy minister who signed the net zero agreement into law. He agrees that it provides a useful focus for future R&D. "It's a huge task, and we don't yet have the technologies to achieve it, but we have a process in place," he says.

Making sure talented people are able to work in the UK will be of paramount importance to the success of the whole effort. "We're going to need around 50,000 extra individuals performing research-related activities either in industry or academia," Skidmore says. "It doesn't matter how much money we throw at this if we haven't got the people on the ground."

While Brexit makes this a more complex prospect in the short-term, the UK has long been part of the European Union's research and innovation programme. To maintain access to the same level of international financial investment, the government hopes to continue this after leaving, much like Switzerland and Israel do now.

Williams also stresses the importance of working together. "Collaborations are of fundamental importance. Being competitive means being able to participate in international collaborations, so it's very important to pay attention to this in the measures we take."

The private sector will be important too. "All international companies have a choice about where to place their research and development activities, so we need to carefully examine what makes the UK attractive," says Williams. This is where the government needs to make the UK R&D friendly using tools like a beneficial taxation regime and R&D credits.

Frances Saunders is a former Chief Executive of Dstl, the UK Ministry of Defence's Science and Technology Laboratory. This background in the defence sector gives her some optimism that UK-based researchers will avoid becoming isolated. Britain has traditionally been good at defence-related collaborations with the US, Canada, Australia and New Zealand, she points out. And Williams is optimistic too. "Ultimately, if a strong collaboration makes sense, a way will be found to make it happen," he says. "We all share the same objectives in terms of health and wellbeing, technology and growing the digital economy."

Wright is similarly optimistic about industry's proposed role in the new research plan. He says it asks a lot for industry to inject such a significant proportion of the cash, but BAE Systems' role in developing the Tempest combat aircraft shows that industry and government can work well together for mutual benefit.

"Most of what we rely on in society depends upon technology," he says. "For the UK to maintain jobs and prosperity, we have to invest in the science that will underpin the technology we need in the future." ▮

**Watch the full debate for free at https://bit.ly/35TDsJt**

Biology

# Corals evolve in an unusual way

## These are the first animals seen to pass on mutations found outside sex cells

Michael Marshall

ALEX MUSTARD/NATUREPL

**A diver approaching a large colony of Elkhorn coral in the Caribbean Sea**

CORALS have an evolutionary superpower. Adult corals can pass on mutations they have acquired during their lives to their offspring, overturning a long-standing belief that no animals can hand down such mutations – although most can't.

"Juvenile corals inherited mutations that were acquired during the parents' lifespan," says Iliana Baums at Pennsylvania State University. "It has not been observed before in animals, but it has been observed in plants."

Corals belong to one of the oldest animal groups. They are similar to plants in many ways, such as spending most of their lives fixed in one place, in their case on reefs, says Baums. One way that corals and their relatives differ from mammals or birds is in their germ line, the cells in their bodies that form eggs or sperm.

In most animals, including humans, the germ-line cells are strictly separated from the rest of the body. This limits which genetic mutations can be passed on. For example, a gene might mutate in one cell of a person's body and change that cell's behaviour – perhaps turning it cancerous – but the mutation won't be passed to their children. Only mutations in germ-line cells can be inherited.

Biologists already knew that coral germ lines aren't like this. Adult corals have groups of primordial stem cells that can give rise to both germ-line cells and body cells. Body cells sometimes change back into stem cells, and then into germ-line cells. This blurs the line between the germ line and the rest of the body.

Baums and her colleagues have now found evidence that mutations that arise during a coral's lifespan can enter the germ line and be passed on.

They studied elkhorn corals (*Acropora palmata*) from Florida and Curaçao. These live in colonies of genetically identical polyps that divide asexually, allowing the colony to grow. They also release sperm and eggs into the water that were thought to need to encounter sperm or eggs from another colony to develop.

The study began with a peculiar observation: some eggs developed into larvae without being fertilised. To confirm this, the team collected more larvae and compared their genes with the parent colony.

**"Corals have a way of creating genetic diversity even when reproducing asexually, like plants"**

The larvae only contained genes from the colony, albeit reshuffled. "There was no input of foreign sperm," says Baums. The team still isn't quite sure what happened.

However, there was an even bigger surprise lurking. The team knew that individual polyps in the colony weren't quite genetically identical. It has been there for many years, and some of the polyps had acquired mutations during their lives that weren't there in the founding individual.

The analysis revealed that some of these mutations were present in the larvae (bioRxiv, doi.org/fgf5). The finding indicates that corals can pass on new genetic variants, and evolve, in a way that no other animal is known to do so.

"They ran all thinkable controls, therefore I think technically it's absolutely sound," says Thorsten Reusch at the GEOMAR Helmholtz Centre for Ocean Research Kiel in Germany.

Baums and Reusch both say it is important not to misinterpret the finding. One possible misreading concerns the long-disproved idea that acquired traits can be inherited and that this explains how new species evolve. For example, the long necks of giraffes were imagined to have arisen because early giraffes stretched to reach tall trees, making their necks longer, and they passed this to their offspring. The idea is sometimes known as Lamarckism, after biologist Jean-Baptiste Lamarck.

However, in Lamarckism, mutations are driven by an animal's actions, so the creature has some control over which genes it passes on. In reality, mutations arise randomly and any that benefit an animal may help it survive and produce offspring – and that seems to be just as true of the corals. "It doesn't reintroduce Lamarck," says Reusch.

But it means corals have a way of creating genetic diversity even when reproducing asexually. In this, they again resemble plants.

Reusch and his colleagues showed in a recent study that colonies of seagrass can undergo a similar process, in which clones pass on acquired mutations. Beneficial ones can spread to dominate entire seagrass colonies.

Baums and her team have yet to find evidence that any of the coral mutations are beneficial, but they plan to investigate this next. ▮

Biology

# Viruses shown to produce energy on their own for the first time

Michael Le Page

A FEW giant viruses appear to generate their own energy, which viruses aren't supposed to be able to do. The finding will fuel an already fierce debate about whether giant viruses really are viruses, and if they are alive or not.

"It is really incredible to have energy in a virus," says Bernard La Scola at Aix-Marseille University in France. Why any virus needs to produce its own energy remains a mystery, he says.

Up until 2003, all known viruses consisted of nothing more than RNA or DNA wrapped in a protein coat or membrane. These have no working machinery inside them and are reliant on cells they infect to copy themselves. Under many definitions of life, they aren't alive.

But in 2003, La Scola reported the discovery of the first giant virus, called mimivirus. Since then, hundreds more giant viruses have been discovered and the division between viruses and living cells has become blurred.

Some giant viruses are bigger than some bacterial cells, and have large genomes with lots of genes. They have some machinery to copy DNA into RNA on their own, which is unusual for viruses. They can get attacked by smaller viruses and have a kind of immune system. "Twenty years after the discovery of the mimivirus, all the definitions of a virus are no longer true," says La Scola.

He and his colleagues have now found that some giant viruses called pandoraviruses generate a membrane potential – an electrical gradient – across their outer membrane (bioRxiv, doi.org/fggb). It takes energy to generate a membrane potential, and since these are present in isolated viruses as well as in those inside cells, that energy must come from the virus itself, says La Scola.

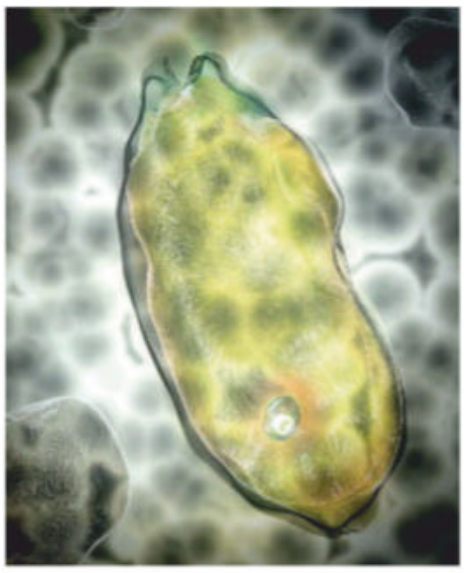
Why they have membrane potentials is still unclear. In most cells, these drive the production of a molecule called ATP, but the viruses don't make ATP.

The researchers also found that a virus called *Pandoravirus massiliensis* has many genes that code for enzymes resembling those needed to generate energy. They confirmed that at least one of these enzymes has this function by transferring it to a bacterium.

"This suggests an active energy metabolism in viral particles, similar to that of cells," says Gustavo Caetano-Anollés at the University of Illinois at Urbana-Champaign.

But David Wessner at Davidson College in North Carolina isn't convinced. The team looked only at viruses that had just been released from cells, he says, and not all had membrane potentials.

**Pandoraviruses seem to produce energy, raising the question: are they alive?**



GIOVANNI CANCEMI/SHUTTERSTOCK

La Scola thinks the discovery adds to the evidence that giant viruses should be regarded as a group separate from both normal viruses and from prokaryotes – organisms with simple cells.

Even if they generate energy, they are still viruses, says Grieg Steward at the University of Hawai'i at Manoa. "Pandoraviruses are viruses because they replicate by an assembly process inside of a host cell," he says. La Scola previously saw viruses as living inside cells. But if a pandoravirus makes energy outside cells, it is even "more living", he says. "So yes, it is alive, I think."

Frank Aylward at Virginia Tech recently reported finding genes involved in energy production in giant virus genomes, which may be used to manipulate a host's metabolism. Giant viruses are turning out to be widespread, which suggests they have a huge impact on the planet.

"It does not matter whether they are alive or not, they are out there and doing all these important things," says Aylward. ▮

Solar system

# Ring molecule found in Titan's sky may be building block of life

A CIRCULAR molecule spotted on Saturn's moon Titan may help form precursors to life. This compound hasn't been seen in the atmosphere of any planet or moon before.

The molecule is called cyclopropenylidene and is made up of three carbon atoms in a ring with two hydrogen atoms attached. Conor Nixon at NASA's Goddard Space Flight Center in Maryland and his colleagues spotted it floating in Titan's thick atmosphere using the Atacama Large Millimeter/submillimeter Array in Chile.

Finding this molecule on Titan was a surprise. It is extremely reactive – if it bumps into any other particles, it tends to be quick to chemically react with them to form new compounds. Because of this, it had previously only ever been seen in tenuous clouds of gas and dust in interstellar space. Somehow, it lasts in the upper layers of Titan's skies.

Ring-shaped molecules like this tend to act as the building blocks of molecules necessary for life, such as DNA and RNA. "This is a really small building block, but you can build bigger and bigger things with it," says Nixon. "I don't think anyone necessarily believes that there's microbes on Titan, but the fact that we can form complex molecules like this on Titan could help tell us things like how life got started on Earth."

Conditions on Titan now may be similar to those on Earth early in the planet's history, when the air was dominated by methane instead of oxygen. Studying its potential for life could help us learn about the beginnings of life here as well.

**"This is a really small building block, but you can build bigger and bigger things with it"**

Titan has the biggest variety of molecules on any moon or planet we have investigated, says Nixon. "It's sort of this happy hunting ground for new things," he says. "Molecules like this are almost an early warning sign that there's more exciting chemistry to be found."

Right now, we can only look for that from Earth, but the Dragonfly spacecraft, planned to launch in 2027, will examine Titan's surface up close. ▮

Leah Crane

Animals

## Endangered possums take refuge in back gardens

Jake Buehler

**IN WESTERN Australian residential neighbourhoods, endangered marsupials have made themselves at home in private gardens.**

**Western ringtail possums (*Pseudocheirus occidentalis*) are nocturnal, cat-sized creatures that live in trees and shrubs. They once ranged over much of south-western Australia, but habitat loss and predation by invasive red foxes have dramatically reduced their range to three small enclaves.**

**These last remaining pockets overlap with the urban areas of Busselton, Manjimup and Albany in Western Australia. The possums frequently turn up in back gardens in these places, dining on roses and the leaves and fruit from trees.**

**"We wanted to know if the habitat within gardens is sufficient for these animals to live exclusively in these areas, or whether they are still dependent on some natural habitat to survive," says Bronte Van Helden at the University of Western Australia in Albany.**

**She and her team caught possums from 16 private gardens in Albany by exploiting their sweet tooth – they baited traps with almond meal soaked in strawberry essence. The researchers fitted 20 possums with radio-transmitter collars before releasing them. For the next three months, the team tracked signals from the collars to work out where the animals were moving and how much they were using the gardens versus nearby bushland.**

**Surprisingly, none of the possums ever left the private gardens. They hopped between multiple gardens, feeding primarily on non-native plants like avocado trees, which made up the bulk of the garden flora (*Animal Conservation*, doi.org/fggf).**

**Van Helden says "gardens may contain sufficient resources to support wildlife" like possums, and that such areas shouldn't be overlooked as valuable habitat.** ▮

Climate change

# China's climate goal needs negative emissions tech

Donna Lu

CHINA'S pledge to reach carbon neutrality by 2060 may depend on extracting greenhouse gases from the air at massive scales.

President Xi Jinping announced the target in September at the UN general assembly, saying that China's aim was "to have $CO_2$ emissions peak before 2030".

To do so would require significant use of negative emissions technologies, such as capturing carbon dioxide directly from the air and the planting of new forests, according to an analysis led by Shreekar Pradhan at the University of Virginia.

The researchers used a model that includes projections of future changes to global temperature and atmospheric carbon concentrations.

They simulated four potential trajectories of emissions cuts: a scenario with no climate mitigation policy, used as a reference; one in which China is the only country to achieve net zero by 2060; a global net-zero scenario in which all nations achieve overall carbon neutrality by 2060; and a final scenario that limits global warming to 1.5°C by 2100.

The researchers predicted that the global net-zero scenario will result in about 1.8°C of warming by 2100.

**2.5**

**gigatonnes of $CO_2$ that China may have to remove annually from the atmosphere**

Although China is now the world's biggest carbon emitter, the modelling suggests that if it is alone in achieving net-zero emissions by 2060, the planet will remain on course for more than 3°C of warming over pre-industrial levels by 2100.

The researchers also looked at China's path to net zero. They concluded that the nation will need to make significant use of negative emissions technologies in order to remove up to 2.5 gigatonnes of $CO_2$ per year from the atmosphere (arxiv.org/abs/2010.06723).

They say that there will be a heavy reliance on "direct air capture" that removes $CO_2$ from the atmosphere, an option that isn't currently available commercially. Direct air capture may prove to be expensive to operate. It may never become a commercial option.

"There is a risk of doing things with the expectation that negative emissions technologies will be realised in future," says Pradhan.

The priority should be to take immediate steps to overhaul China's energy system, instead of relying on the promise of future carbon-sucking technologies, says Li Shuo at Greenpeace East Asia in China. At present, two-thirds of China's power consumption is coal-based.

"There's no way to reconcile a zero-carbon future… with new coal-fired power plants," says Li. "When we talk about offsets [such as direct air capture], we are actually talking about the very last few miles in a very long journey."

Frank Jotzo at the Australian National University says that at least a modest level of negative emissions approaches will be necessary to reach net zero, both in China and globally.

"There will be some activities and processes that will have greenhouse gas emissions even in a world where we devote very great efforts to cut emissions," he says.

Jotzo estimates that employing negative emissions technologies to remove about 2.5 gigatonnes of carbon a year might cost China hundreds of billions of dollars annually. "That's within the realm of the affordable," he says. ▮

**A man tends to a crop near a coal power plant in China**

QILAI SHEN/BLOOMBERG VIA GETTY IMAGES

MJ PHOTOGRAPHY/ALAMY

Climate change

## Arctic ice loss could trigger huge extra global warming

IF ARCTIC sea ice vanishes in summers by the middle of the century as expected, the world could see a vicious circle that drives an extra 0.43°C of warming.

Ice losses in frozen regions trigger "climate feedback" loops. For instance, white ice reflects much of the sun's energy, and if it is replaced by dark open water that absorbs heat, more warming occurs.

Now Ricarda Winkelmann at the Potsdam Institute for Climate Impact Research in Germany and her colleagues have modelled what these feedbacks would lead to if ice disappeared from mountain glaciers, the Greenland and West Antarctica ice sheets, and the Arctic in summer. They found that the loss of ice in all four places would, over centuries to millennia, contribute an extra 0.43°C of warming globally in the event of the world holding temperature rises to 1.5°C.

However, Arctic feedbacks could bring some warming much sooner. Summers in the region are expected to be ice-free before 2050. That means the Arctic alone could account for an extra 0.19°C of global warming around mid-century, on top of the 1.5°C.

The models indicated that changes in reflectivity, or albedo, accounted for 55 per cent of the 0.43°C. Water vapour contributed 30 per cent, because warmer air can hold more water and trap more heat, and clouds 15 per cent (*Nature Communications*, doi.org/fgjt).

Winkelmann says emissions are pushing ice sheets to irreversible tipping points, so what we do in the next years can determine the fate of Earth's ice masses. **Adam Vaughan**

Human behaviour

## The wrong way to tweak human actions

A STUDY of the interventions used to change people's behaviour suggests that the methods that fail have common features.

Magda Osman at Queen Mary University of London and her colleagues analysed 65 scientific papers published between 2008 and 2019 that identified failed behavioural interventions, including nudges, which are subtle suggestions aimed at influencing people's behaviour.

The group found that behavioural interventions that relied on social comparisons and social norming – such as encouraging people to adopt a behaviour by indicating that it is common or normal in society – accounted for 40 per cent of the failed interventions studied.

Twenty four per cent of the failed interventions studied were strategies that delivered messages via letters or texts, while those using labelling on products made up 12 per cent. Methods that relied on defaults, such as opt-in or opt-out strategies, accounted for 15 per cent of the failed interventions (*Trends in Cognitive Sciences*, doi.org/fgjw).

The team also categorised the various ways in which methods failed, such as by producing no effect or by backfiring and producing an unwanted effect. Considering both the type of intervention and ways it may fail could assist with the design of more successful programmes, says Osman.

She and her team are developing models that could help predict how a given behavioural intervention might perform, based on their analysis of failed methods. "You can simulate different outcomes before you start running a behavioural intervention that might fail", which could save time and money, says Osman. **Layal Liverpool**

Zoology

## Spider listens with its legs to grab flying prey

SOME species of spider can grab prey out of the air at night without seeing it, and now we know how. The spiders use their legs to pick up the sound of flying insects, then throw a net-like web over the unsuspecting animal.

The ogre-faced net-casting spider (*Deinopis spinosa*), native to the southern US and parts of the Caribbean and South America, is a Jekyll and Hyde-like creature, says Ronald Hoy at Cornell University, New York. By day, it camouflages itself as a stick, but at night it becomes a stealthy hunter that casts a pre-spun net over prey passing below.

JAY STAFSTROM

Jay Stafstrom, also at Cornell, noticed that the spiders could also perform backflips to catch insects flying above them, even though these insects were probably outside their' field of vision.

Stafstrom, Hoy and their colleagues found that the spiders flipped backwards to cast their nets when they heard recordings that resemble flying insect sounds, and even isolated spider legs showed nerve reactions to a wide range of frequencies, from 100 to 10,000 hertz (*Current Biology*, doi.org/fgjv).

Despite these superpowers, with bodies up to 25 millimetres in length, net-casting spiders are relatively harmless to humans. "I've only been bitten once," says Stafstrom. "It only itched for a few minutes." **Christa Lesté-Lasserre**

## *Really* brief

MATHIEU MEUR/STOCKTREK IMAGES/ALAMY

### Suckerfish surf across whales' skin

**Remora fish use a suction disc on their heads to hitch a ride on blue whales. By attaching cameras to the larger animal, researchers found that the fish, also known as suckerfish, can detach themselves and skim along the surface of a whale's skin in the rapidly moving water produced by the whale swimming (*Journal of Experimental Biology*, doi.org/fgdv).**

### Hawk-like drone is an efficient flyer

**A robot with wings can glide like a hawk to fly more efficiently. Motors allow the robot's wings to fold in so that, when travelling at optimum speed, it uses 55 per cent less power than would be required with its wings fully open (*Science Robotics*, doi.org/fgdw).**

### Distracting gadgets affect memory

**People who report frequent media multitasking – such as texting while watching TV or reading while listening to music – perform worse on memory tests than those who don't. Media multitasking was also associated with lapses in attention (*Nature*, doi.org/ghg7j9).**

Conservation

## Biobank will house corals to restore reefs

AN AUSTRALIAN conservation team is compiling a living biobank of coral species, in case we need to rebuild the world's reefs in future.

The Living Coral Biobank plans to collect and house more than 800 species of the world's hard corals in a dedicated facility in Port Douglas, Australia.

"We're keeping this living stock of corals alive should we need to use them for restoration and rehabilitation activities," says Dean Miller, director of the project.

The Great Barrier Reef has experienced three mass bleaching events in the past five years, and has lost more than half of its coral colonies since 1995.

Starting on 6 November, the team will collect living fragments, tissue and DNA samples of corals from the Great Barrier Reef. On its first expedition, the team will identify and gather specimens of 20 coral species – 5 per cent of the Great Barrier Reef's 400 species.

The coral samples will be kept in holding tanks in nearby city Cairns until a purpose-built facility to house them is finished around 2025. Corals will also be stored in public and private aquariums around the world.

Under favourable conditions, corals can live for thousands of years, says Miller. They can produce both sexually and asexually, and under asexual reproduction, they bud and produce clones of themselves. "We anticipate that the corals will double in size every six months, so effectively the biobank collection will double every six months," says Miller. **Donna Lu**

Space

ESA/ATG MEDIALAB

## Subsurface ice on comet 67P is softer than candyfloss

**WHEN the Philae lander arrived on comet 67P/Churyumov-Gerasimenko in 2014, it bounced twice before reaching its final resting place. The second bounce exposed some very strange ice.**

**The European Space Agency's Philae lander was carried to comet 67P aboard the Rosetta orbiter. When Philae was dropped to the surface, the harpoons designed to hold it in place didn't fire, so the lander bounced.**

**The location of the first bounce and the lander's final resting place were both found. Now Laurence O'Rourke and his colleagues in the Rosetta team have located the second bounce site by analysing Rosetta's pictures from before and after Philae's landing.**

**They found a bright streak across a pair of boulders. "It was like a chainsaw sliced through the ice," says O'Rourke. Philae appears to have bounced between the boulders, revealing the primitive ice beneath the comet's surface dust (*Nature*, doi.org/fgjx).**

**Analysing the marks revealed that the strength of the ice was weaker than candyfloss.**

**"This ice that's 4.5 billion years old is as soft as the foam that's on top of your cappuccino," says O'Rourke. Leah Crane**

Marine biology

## Octopuses taste food with their arms

OCTOPUSES can taste their prey before eating it by using their arms to "lick" it, which adds to evidence that the appendages are analogous to tongues with "hands" and "brains".

Octopus arms are lined with suckers that include cells for neural processing of touch and taste signals. These allow them to determine if an animal is good to eat or is toxic, says Nicholas Bellono at Harvard University. That is useful because octopuses tend to "blindly" hunt, sticking their limbs into holes and crevices to find hidden prey.

Bellono and his colleagues found that some of the sucker cells of California two-spot octopuses (*Octopus bimaculoides*) respond to touch and others to the "taste" of chemicals in the water. The suckers' taste and touch receptors reacted to water-soluble chemicals, like bitter chloroquine, as well as to chemicals that don't dissolve well in water, such as those emitted by toxic prey, says Bellono (*Cell*, doi.org/fgjz).

Octopuses do possess a tongue-like organ in their mouths called the radula, but it doesn't seem capable of taste. The radula acts "more like teeth", says Bellono. **CL-L**

# Views



Comment

# Online learning's big issue

Now is the time for educational technology to shine, but it simply isn't good enough and is unlikely to be so soon, says **Justin Reich**

PROPONENTS of education technology have made remarkable promises over the past two decades: that by 2019, half of all secondary school courses would be online; videos and practice problems can let students learn mathematics at their own pace; in 50 years only 10 mega-institutions of higher education would be left; or that typical students left alone with internet-connected computers can learn anything without the help of schools or teachers.

Then in 2020, people around the world were forced to turn to online learning as the coronavirus pandemic shut down schools serving more than 1 billion students. It was education technology's big moment, but for many students and families, remote learning has been a disappointment. When the world needs it most, why has education technology seemed so lacklustre?

Educational software has a long history, but throughout there have been two major challenges. The first is that most people depend on human connection to maintain their motivation. When a student closes their laptop in frustration in a classroom, someone can see it and respond. When the same thing happens while using an education technology product, human connections are shut down with it.

Well-designed online learning environments can encourage meaningful relationships, and online learning has the potential to transcend typical classroom boundaries, but in practice, many online students struggle to stay focused.

MICHELLE D'URBANO

The second challenge is that curricula are complex. On any given day in a school, one teacher may introduce a new sound-letter mapping in phonics, another finish a unit on plate tectonics, and a third facilitate a seminar on *Don Quixote*. Many teachers can walk down the hall into a new lesson to teach different subject material. But for every new curriculum area for education technology, new content, tools, resources and assessments need to be developed and disseminated.

Assessments are also a thorny challenge. In some domains, like mathematics and computer science, education technology can instantly detect when a student solves a problem or creates a correctly functioning computer program. We can reward students for getting answers correct, nudge them towards resources when they get things wrong, and create the feedback loops of instruction, assessment and iteration that good learning requires.

Unfortunately, the same approach doesn't work so well in other areas. We can ask students to calculate how far a tectonic plate might move given a certain speed and time and computers can instantly evaluate a correct numerical answer. But if we ask students to write a paragraph that explains how plate tectonics work, computers can't reliably identify correct, partially correct and incorrect responses. Computers cannot reliably evaluate how humans reason from evidence, and reasoning from evidence is the very core of schooling.

Education technology has long promised to transform education, but at best, the field has developed individual tools for niches of the curriculum. For large swathes of school learning, we don't have online tools or resources that are any better than a printed textbook.

Every technological solution is also a human capital problem: integrating technologies into learning requires giving teachers and students time to play with and get acclimated to new tools, routines and pedagogies.

For most teachers, the road to more effective teaching with technology looks less like a transformation, and more like tinkering: a slow and steady process towards identifying the right tool or approach for particular students in a particular context. ▮


Justin Reich is director of the MIT Teaching Systems Lab, and author of *Failure to Disrupt*

Field notes from space-time

# Inside the nothingness

Space-time may seem empty, but the expanse between stars is filled with more interesting stuff than you may think, writes **Chanda Prescod-Weinstein**

Chanda Prescod-Weinstein is an assistant professor of physics and astronomy, and a core faculty member in women's studies at the University of New Hampshire. Her research in theoretical physics focuses on cosmology, neutron stars and particles beyond the standard model

## Chanda's week

**What I'm reading**
Cosmology's Century: An inside history of our modern understanding of the universe *by Nobel laureate P. J. E. Peebles.*

**What I'm watching**
*I am an LA Dodgers fan, and hopefully by the time this is published, they will have won the US's World Series!*
Editor's note: They did. 4-2

**What I'm working on**
*A paper on simulations of a hypothetical dark matter particle.*

This column appears monthly. Up next week: Graham Lawton

SPACE-TIME is mostly empty. Though there are at least 100 billion galaxies – each home to around 100 billion stars – and lots of galactic dust, the universe is so vast that there are huge tracts of space-time between every star and more still between every galaxy. Even the nearest star to Earth (the sun) is nearly 150 million kilometres away, meaning the fastest thing in the universe (light) still takes 8 minutes to get from there to here, despite travelling at 300,000 kilometres per second.

It seems like most of what is between Earth and the sun is two other planets – other than that, there isn't much else that we can see. But is space actually completely empty? Not really.

There are a few senses in which we can think of space-time as being teeming with stuff. One is quantum-mechanical in nature. Quantum field theory, the tool we use to study particle physics, says particles flicker in and out of existence, even in a vacuum. In other words, once quantum effects are taken into account, there is no such thing as completely empty space-time. Importantly, these random particles pop in and out of existence quickly and are unable to have a meaningful impact on phenomena that we might notice. And they aren't something big, like a star suddenly appearing and then disappearing.

There is another way in which the universe is fundamentally full of things. For almost 80 years, we have been getting to know an all-pervasive type of light that we scientists call the cosmic microwave background radiation, or CMB. Like many things in science, the CMB was first detected by accident. The first hint was from Andrew McKellar's 1941 observations of the region around a star. He noticed that rather than being a temperature of absolute zero on a Kelvin scale, which is what you might expect from empty space, it was about 2.3 Kelvin, or -271°C. About a decade later, theoretical physics caught up, using simple cosmological models to predict the existence of a radiation that is everywhere in the universe.

Then, in the 1960s, Arno Penzias and Robert Wilson were taking some measurements using a radio telescope when they noticed a background noise in the signal that wouldn't go away. The structure of the signal meant that its wavelength could be associated with a temperature. They found the temperature to be about 3.5 Kelvin, in effect rediscovering McKellar's original measurement. In the decades since that moment, we have launched multiple space telescopes to measure this radio signal more closely, and the CMB has become an incredibly important tool in observational cosmology.

> **"Once quantum effects are taken into account, there is no such thing as completely empty space-time"**

These instruments include the NASA Cosmic Background Explorer, or COBE, which found that the CMB's temperature is about 2.73 Kelvin and is around the same temperature everywhere in the sky no matter what direction we look in. In other words, the universe is filled with photons from the CMB. COBE also first verified an idea from cosmological theories suggesting there would be extremely small variations in the temperature.

These variations are part of what makes the CMB so important as a tool. Our theories tell us that the CMB originates from a time when the universe was so hot that it was filled with a plasma of light and matter particles. This plasma was so dense that light couldn't travel very far without colliding with a particle. As the universe cooled, the light and particles decoupled and the universe became transparent to the light.

The CMB is that light, stretched over time, providing us with information about what the universe was like when it was only 400,000 years old. The little variations in the temperature are evidence of quantum fluctuations that we expect to be the source of how structures – dust clouds, stars and then galaxies – began to form.

Since COBE became operational in 1989, NASA has launched the Wilkinson Microwave Anisotropy Probe (WMAP), which studied those small fluctuations in more detail until 2010. Most recently, NASA supported the European Space Agency's Planck space observatory, which shared WMAP's mission but completed it with more sensitive instruments.

Today, CMB measurements are important evidence that confirms our theoretical models about the history and timeline of structure formation. The measurements are consistent with our observations of the presence of dark matter and the mysterious dark energy phenomenon too. Importantly, Planck information is also playing a role in the debate about the measurement of the Hubble-Lemaître constant that I mentioned a few columns ago.

As such, it is a good thing that while the universe looks mostly empty to the human eye, it is, in some basic sense, teeming with light – and useful light at that!

# Signal Boost

Welcome to our Signal Boost project – a weekly page for charitable organisations to get their message out to a global audience, free of charge. Today, a message from **Estuarine & Coastal Sciences Association**

ECSA promotes estuarine and coastal sciences, and celebrates it 50th anniversary in 2021. We are an international society and our mission is to promote and advance multidisciplinary research into all aspects of estuarine and coastal environments, and to support the application of science and technology for their sustainable environmental management. To achieve this our main aims are:

- To promote excellence in estuarine and coastal marine science, technology and management
- To focus on promoting young scientists and early-career academics
- To actively engage in global outreach with an emphasis on developing countries

We run science meetings at local and international scales to promote knowledge dissemination, and to provide young scientists with opportunities to present their work, and to network with more established scientists. We hope to have an international meeting in India in the next few years (recent ones have been in Australia, Germany and China). A joint meeting with EMECS (the International Center for Environmental Management of Enclosed Coastal Seas) due to be held in Hull, UK this year has been postponed to 2021 because of covid-19. We have run many workshops, and also produce handbooks and other publications. ECSA members, and members of ECSA Council, come from a wide range of academic, regulatory, consultancy and other backgrounds. The covid-19 crisis is likely to mean changes to how we all operate, and we are further developing our website to extend online communications and resources.

We are keen to encourage the next generation of scientists in a range of disciplines and career areas, particularly workers in developing countries. To do this we have a range of membership fees. We have a range of awards to support members' attendance at our conferences. For our most recent international meeting in Australia we awarded 32 grants to cover travel and fees. We can support research work where individuals need small grants to support their work, for example en-abling the purchase of sampling equipment.

We have a student/early career representative on ECSA Council, and are actively engaging with student members.

The world needs to address major threats to marine and coastal ecosystems – climate change, sea-level rise, ocean acidification, ecosystem shifts, plastic pollution, mineral resource exploitation, biodiversity loss and more. To help do this we need to share knowledge and ideas, and ECSA actively promotes this type of knowledge gathering and exchange. We all need to rise to the challenge.

## Want to help?

Join the ECSA community to help understand and protect our coastal and estuarine ecosystems for a better world. To find out more, please visit **ecsa.international**

# Red monster

**Photographer** **Mofeed Abu Shalwa/ Luminar Bug Photography Awards 2020**

THIS spectacular but terrifying close-up of a red palm weevil exposes every detail of the insect's rusty-coloured exterior, which is usually hard to spot by eye.

Mofeed Abu Shalwa, who took the image, says he began photographing insects partly as a way to overcome his childhood fear of them. He spotted this weevil (*Rhynchophorus ferrugineus*) next to a date palm tree in the forests of Qatif in eastern Saudi Arabia. The image won him Luminar Bug Photographer of the Year 2020 in the inaugural Luminar Bug Photography Awards.

At between 2 and 4 centimetres long, red palm weevils are relatively large insects. Originally from South-East Asia, they have spread to parts of Africa and Europe, including the UK.

While the weevils pose no direct threat to humans or animals, how they act on young palm trees makes them a formidable pest. They have been estimated to cost growers in the Middle East millions every year due to their destruction of date palms cultivated for their fruit, for example.

So far, 26 species of palm tree are known to be targeted by the red palm weevil, whose larvae bore holes up to a metre deep into the trees after hatching, weakening and sometimes killing the plant. Insecticide and traps keep some of the insects at bay, but more sustainable and comprehensive measures are needed to fully control this pest.

The winners of the Luminar Bug Photography Awards can be found at photocrowd.com/bugs.

**Gege Li**

## Editor's pick

### Trudeau must take note of the Gettysburg Address

**17 October, p 45**

*From Martin Jenkins, London, UK*

**As a linguist, I, er, found David Robson's article quite, uh, interesting. But, mmm, maybe starting from Justin Trudeau was, like, not a good idea.**

**Language has evolved with a range of expectations. We expect private conversations to be punctuated with meaningless sounds, as they are an indication that we are taking the other person seriously. They are saying: "I am processing what you said. In responding to it, I do so with some hesitation because I am still thinking about it." On the other hand, we expect public figures standing up to speak on a major issue to have already reflected on it and to have organised their thoughts into a coherent whole. There are no uhs or ers in the Gettysburg Address.**

**So Trudeau wasn't, in fact, speaking like a pro. He was treating a public occasion like a private conversation and using the wrong linguistic register.**

### Monoculture can create a frying pan effect

**3 October, p 24**

*From Miles Clapham, Mairena del Alcor, Spain*

James Wong rather gently argues for the necessity, at times, of monocultures, his argument being designed to take the wind out of the sails of those who rail against them.

The contribution of industrial monoculture agriculture to climate change, biodiversity loss, pollution by agrochemicals and soil erosion by wind and water is vast and complex. Monocultures can also increase local heat. I write from southern Spain, where an enormous hectarage of land lies bare in the summer awaiting autumn sowing, its topsoil blowing away in the wind, soil life dying and releasing carbon dioxide, and causing local heat effects. These are difficult to measure, but undoubtedly contribute to why the region around Seville is called "the frying pan of Europe".

Polycultures can be very productive – perhaps they don't match industrial monocultures, but they are more labour intensive. In many rural areas, there are few jobs, so young people leave. A more people-intensive agriculture that is actually good for the planet can't really be a bad thing.

### Surely automation will lead to fewer jobs

**10 October, p 44**

*From Sam Edge, Ringwood, Hampshire, UK*

Having worked in automation all my life, I hoped for a little more evidence and less speculation from your article on it.

If the interviewed experts think automation doesn't reduce the number of staff required to produce a given amount of output, can they explain why businesses do it? Assembly-line workers are a lot cheaper than cryptographers or drone operators.

### Drake equation still just a guesstimate at best

**3 October, p 36**

*From Phil Stracchino, Gilford, New Hampshire, US*

In your article on the chances of finding intelligent life beyond Earth, you suggest that the error bars on estimates of this produced by the Drake equation are huge, that we are essentially plugging best guesses into the equation and have been doing so for decades.

This is a very welcome admission – but it doesn't go far enough. I put it to you that the Drake equation is flimflam, mummery and handwavium with no predictive or determinative value whatsoever. If you have an "equation" that is fundamentally a chain of unknown terms multiplied together, you don't have a scientific tool, you have a science-flavoured Ouija board.

### For a slice of what life in 4D could be like, try this

**17 October, p 40**

*From John Spivey, Thorverton, Devon, UK*

You write about complex electric circuits used to represent a fourth physical dimension. For a lighter take on a fourth dimension, read *"–And He Built a Crooked House–"* by Robert A. Heinlein. It is a story about a house built in the shape of a 4D cube, or a tesseract.

This gives an entertaining – but not necessarily scientific – view of problems when interacting with a physical fourth dimension. There are many video representations of the tesseract online, which show how a cube can turn itself inside out by moving within the fourth dimension.

### Tabletop games trump video games for choice

**10 October, p 32**

*From Elizabeth Belben, Nettlebridge, Somerset, UK*

Jacob Aron says "video games offer something unique among media: choice". I disagree. As he points out, if you are playing a shooter in a video game, you can't decide to host a tea party instead – but in a tabletop role-playing game, you can do precisely that.

I speak as someone who, in my first ever *Dungeons & Dragons* session, derailed the dungeon master's carefully plotted story of demonic possession via a magic ring by choosing to have my character chop her finger off.

### Let's talk about quantum computing

**10 October, p 17**

*From Alan Baratz, CEO of D-Wave, Bellevue, Washington, US*

There are several points that I would like to address in your coverage, both in your magazine and online, of D-Wave's claim that it has the world's most powerful quantum computer.

It is wrong to characterise quantum annealing as being limited to optimisation. With more than 250 early applications, D-Wave's systems are also well-suited for material simulation, quantum chemistry and a broad array of computational challenges known as NP-hard problems.

Though not yet a universal computer, D-Wave's Advantage can, in principle, be programmed to solve any classical problem. We are also progressing towards the universal annealer.

There are peer-reviewed papers in *Physical Review X* in 2014 and *Science* in 2018 that demonstrate the quantum-mechanical effects of superposition and entanglement in our quantum systems. D-Wave has shown significant speed-up on important physics problems. Researchers have also published results showing superior performance of D-Wave quantum processors compared with classical alternatives in the journals *VLDB*, *IOP Science*, *Journal of the Physical Society of Japan* and others.

It is time to move away from antiquated perspectives and work together to bring quantum computing to waiting industries.

### Life on two legs is for these birds, too

**10 October, p 34**

*From John Humble, Taroona, Tasmania, Australia*

You report that humans are the only species that uses bipedalism as its primary mode of transport. This must be worrying news to ostriches and their ilk.

**Want to get in touch?**

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# Must
# ~~Nice to~~ have this holiday season

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# Unlocking the Arctic's hope

A new exhibition reveals exquisite artefacts from Indigenous people who have thrived in the Arctic for millennia, says **Shaoni Bhattacharya**

**Exhibition**

**Arctic: Culture and Climate**
**British Museum**
**Until 21 February 2021**

THE TRUSTEES OF THE BRITISH MUSEUM

AN ANIMATED globe on the wall shows a lovely, generous white ice cap over the North Pole and Arctic in 1979 that shrinks and shrinks again until, by 2100, it is a mere fingerprint, skimming the top of Greenland and the furthest tip of the Canadian archipelago.

This apocalyptic introduction at the start of the British Museum's Arctic: Culture and Climate exhibition is a sobering reminder of the other emergency we face, but the show is more about the hope found in human resilience and adaptation, and cultural change in the face of disaster.

Nearly 400,000 Indigenous people live within the Arctic. Over 30,000 years, their ancestors survived extreme and fast-changing conditions, including the end of the last glacial maximum and colonialism.

Amber Lincoln, the exhibition's lead curator, wants visitors to emerge with a fresh appreciation for the people who live in the Arctic – beyond the statistics to the lives affected by climate change.

The show's historical artefacts, artworks, starkly beautiful photos and immersive videos combine seamlessly to tell those stories. All this is set against a light and soundscape that recreates the changing light and sound of the Arctic year: each "month" lasts 2 minutes and fades into the next, producing a sense of flux.

Indigenous communities are found from the northern reaches of Scandinavia and Siberia to Greenland and the northern vistas of Canada and Alaska. Their way of life faces upheaval because the Arctic has lost 75 per cent of its sea ice in the past 50 years, and the soil permafrost that acts as bedrock has started to melt.

One photo shows an ice cellar deep in the permafrost, used by the Inupiat of northern Alaska to preserve whale meat. Once the permafrost melts, such "fridges" may no longer be available.

**"Most striking is the incredible sustainability and respect for nature of the communities"**

Elsewhere, a 19th-century belt, a knife and hanging bags for amulets and tobacco that would have belonged to reindeer herders serve as springboards to talk about the less expected effects on shrinking Arctic ecosystems. For example, in 2016, 2350 reindeer on the Yamal peninsula in Siberia died after eating anthrax spores released by melting permafrost.

Even one of the most beautiful exhibits – a commissioned work by Sakha artist Fedor Markow showing the spring solstice celebrations of the Sakha people of north-east Russia – resonates with this theme. The miniature model is chiselled from mammoth ivory (with special permission). Ivory from mammoths is becoming more available as the Arctic's frozen treasures are exposed by the melting permafrost.

Most striking is the incredible sustainability and respect for nature of the communities. While caribou, walruses, seals and whales are still hunted, every scrap of flesh, bone, baleen, skin and sinew is used.

A whaling suit that belonged to a Kalaallit hunter in Greenland in the 19th century – the only one of its kind – shows what people could do with sealskin. Waterproof and inflatable, it would have provided warmth and buoyancy to the wearer as he jumped (according to the caption) from his boat onto a sleeping whale to harpoon it.

**Left: an Inughuit sledge made from bone, ivory, sealskin and driftwood; right: a Sami woman's "horn hat"**

Arctic: Culture and Climate is a great exhibition. For a few hours, I could feel something of Arctic life, through the sounds of an ice-bound world, light like nowhere else – and by marvelling at some incredibly clever clothes fashioned from sealskin and fur.

The exhibition has clear lessons about the mindset of people for whom everything, from animals to the ice, is a living, connected part of the daily world, not a separated-off area mostly fit for exploitation.

Such shows are the more valuable for reminding us that there is a real world out there to fight for. ▮

Shaoni Bhattacharya is a consultant for *New Scientist*, based in London

# The sound of solid science

While drowning in disinformation, how can children learn about science? By listening to *Tumble*, says **Simon Ings**

Podcast

**Tumble**

**Tumble Science Podcast for Kids**

**SHOULD we teach our children scientific facts about the world, or should we teach them to do science?**

**The answer, obviously, is both. Yet when physics, chemistry and biology struggle for independent spaces in the school timetable, it may be too much to hope that, along with the facts, children are being given any real idea of what science is like.**

**Teaching both the letter and spirit of science has always been difficult. I only acquired a love of physics and chemistry from popular science books such as Freeman Dyson's *Disturbing the Universe* and Gary Zukav's *The Dancing Wu Li Masters*. The BBC's *Horizon* and *Tomorrow's World* programmes also helped me catch a glimpse of science in action.**

**While books in this genre continue to sell well, how does science fare in the rest of today's fractured media landscape? On the internet, disinformation abounds. Vested interests sow doubt about climate change. Demogogues stoke conspiracy theories around proven medicine. The most outrageous nonsense sails under the false flag of spurious online journals.**

**For children, though, the virtual view is much brighter. Wikipedia, which turns 20 this year, is still a beacon of hope for an enlightened, fact-based and democratic internet. There is also YouTube, which – for all its failings – hosts a staggering amount of high-quality science entertainment, produced by young researchers desperate to engage with the public, and mostly directed at younger viewers.**

**There are also podcasts, of which *Tumble* is arguably the best: it is a series the whole family can get into. If gathering around the laptop sounds oddly old-fashioned, welcome to the strange world of podcasts – a form that, to everyone's surprise, revealed the lasting power of the spoken word and, to everyone's even greater surprise, is reinventing family listening.**

**Lindsay Patterson's podcast for kids began in 2015 and has just launched its family-friendly sixth season with an insightful and intermittently hilarious look at the human microbiome. Patterson and her husband and co-presenter Marshall Escamilla understand that facts can generally look after themselves. The trick is to inspire people to go looking for them in the first place.**

**Enter, in the new season's first episode, Lawrence David from Duke University in North Carolina. Here is a man who knows more than is healthy about how much it costs to mail human faeces around the world (buying it a plane ticket is cheaper, since you ask).**

**David also volunteered for a study that involved him collecting his own stool samples for a year. Not only that, he kept a diary in which he recorded around 300 data points concerning his health, activity, diet and well-being. Bit by bit, the sniggering dies away and the sheer enormity of the effort emerges: all this to understand just one aspect of human biology.**

***Tumble* entertains – that is how it ended up with more than 70,000 monthly listeners, as well as the good will and funding to expand into online education. *Tumble*'s inaugural "The Wildlife of Your Home" pod-course is a 10-episode series that promises to " train you to become an indoor wildlife investigator". What's more, *Tumble* also inspires – last year, the American Association for the Advancement of Science awarded it a children's journalism prize.**

**As scientific illiteracy scuppers the world's ability to act on our most pressing problems, it is vital that projects like *Tumble* succeed. We desperately need a citizenry that knows what science actually is.**

*Tumble* is a science podcast aimed at children, but parents will enjoy it too

GETTY IMAGES/JOHNER RF

## *Don't* miss


**Read**

**The Comedy of Error** has evolutionary ecologist Jonathan Silvertown sharing old jokes and the latest science in his account of how humour evolved, why laughter is contagious and how being funny makes us sexier.

**Visit**

**Being Human**, the University of London's annual festival of the humanities, moves partly online this year with digital exhibitions, workshops, quizzes, talks and debates from 12 to 22 November. This year's theme is "New Worlds".


**Listen**

**The Seekers Podcast**, a playful and interactive series from theatre group The Wardrobe Ensemble, lets children aged 3 to 8 and their families join explorers Alph, Betty and Gammo for an adventure through space, time and beyond.

MIDDLE: BEING HUMAN

The TV column

# Who you gonna call? *Truth Seekers* comes from the duo who mashed keenly observed British comedy with horror to create cult hit *Shaun of the Dead*. Here's hoping the series rivals the success of the original *Ghostbusters*, says **Emily Wilson**

Emily Wilson is the editor of *New Scientist*. You can follow her on Twitter @emilyhwilson or email her at editor@newscientist.com

COLIN HUTTON/STOLEN PICTURES/AMAZON STUDIOS

**Elton (Samson Kayo, left) and Gus (Nick Frost) hunt ghosts**

COMEDY duo Simon Pegg and Nick Frost have specialised at writing and starring in movies (*Shaun of the Dead*, *The World's End*) that stir together warm, beautifully drawn British comedy and classic horror themes. Their latest outing, a TV series called *Truth Seekers*, arises from that same delightful tradition.

The truth seekers of the title are a gang who rove around England investigating the paranormal. Given that, I queried with my editors at *New Scientist* why I was being asked to review a show about ghosts when I hadn't been allowed to review *The Witcher* on its release. Back then, I was told: "There needs to be science in it. We're a science mag. Witches aren't science." This time, they said: "Is it like *Ghostbusters*? Are there gadgets? Because if so, that counts. It's technology."

And indeed, this is a sort of amped down, English version of *Ghostbusters*, complete with home-made ghost-detecting gadgets that flash and make noises whenever spectres draw near. So, yes, of course it should be reviewed in a science magazine!

Our ghostbusters here are Gus (played by Frost), broadband installer by day, ghost-hunting vlogger by night, his nervous new sidekick Elton (Samson Kayo) and an extra sidekick Astrid (Emma D'Arcy), whom they pick up along the way.

This triumvirate are variously supported and impeded in their ghostbusting by Gus's father Richard (Malcolm McDowell), Elton's sister Helen (Susan Wokoma) and what really only amounts to a cameo from Pegg, playing Gus's boss (in a very strange wig) at a broadband company called Smyle.

**"The series' standout is Kayo. It is hard to play a cowardy custard and be genuinely funny, but he pulls it off"**

Frost, who co-wrote and is also a producer of the show, never puts a foot wrong, but for me the series' standout is Kayo. It is hard to play a big cowardy custard and be genuinely funny, but Kayo pulls it off. McDowell's presence of course adds extra class to the already classy ensemble, and there is a clever nod to *A Clockwork Orange*, the genuinely harrowing dystopian flick of his youthful career, in a plot line involving eyes.

As with everything filmed pre-pandemic, you will need to get used to how closely the characters sit together (especially when they have only just met) and how often they unnecessarily pat each other and take cups of tea from the hands of strangers with no apparent concern.

My worries about *Truth Seekers* are twofold. First, is it funny or scary enough, or both? For me, it was only mildly funny – although I loved the gorgeous writing – and it wasn't in the least bit scary. I wonder if that is enough, although perhaps the show is aimed at a much younger audience than I represent.

Second, the structure. Because the show isn't exactly densely plotted, the narrative arc advances little in each 30-minute episode. So you end up getting not much comedy and certainly little woo-woo scary for your episode buck, and then, on top of that, not much new story either.

Eventually, the plot does heat up rather nicely, and I ended the eight-episode season intrigued and ready for more. But will people still be watching? What I hope is that this proves to be the quiet first season, establishing who our new pals are and why we should care about them, and that this leads on to something a bit more unmissable – and potentially as much a smash hit as the first *Ghostbusters* in 1984. ▮

TV

**Truth Seekers**
**Jim Field Smith**
**Amazon Prime Video**

## Emily also recommends...

Film

**A Clockwork Orange**
**Stanley Kubrick**
*Kubrick's 1971 retelling of Anthony Burgess's dystopian novel is brilliant, visually stunning and very upsetting. It deserves to be called a classic, and I think Malcolm McDowell is superb in it, but I can understand why – because of the stylish and distanced way in which Kubrick delivers the horror and violence – it has always been controversial.*

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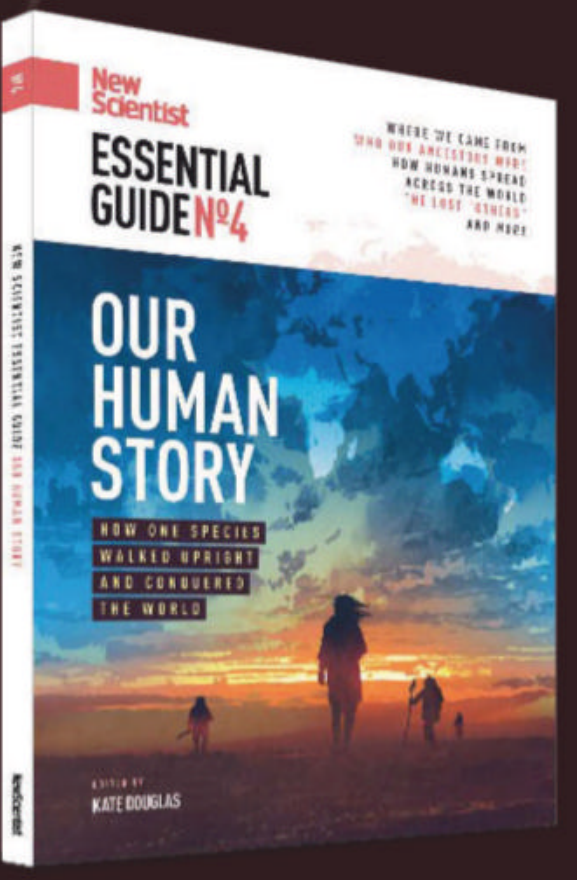


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# Dream power

The fictions we conjure while we sleep may do something far more profound than reinforcing learning, says neuroscientist **Erik Hoel**

HARDZIEJ STUDIO

IF ALIENS ever visited Earth, they might notice something strange. Nearly everyone, everywhere, spends a significant part of their day paying attention to things that aren't real. Humans often care fiercely about events that never happened, whether in TV shows, video games, novels, movies. Why care so much about fictions?

Perhaps, these aliens might hypothesise, humans are too stupid to distinguish between truth and falsehood. Or perhaps they pay attention to fake events for the same reason that they eat too much cheesecake: both are non-natural outcomes of evolved interests.

The aliens' confusion might deepen when they learned that humans fall asleep and dream. For dreams are also fictions. Dreaming takes time and energy, so presumably has an evolutionary purpose. The aliens might begin to wonder what they are missing about the importance of experiencing things that never happened.

As someone who grew up in my family's bookstore, and as a novelist, this question of the importance of fictions is especially dear to me. I think the imaginary aliens are in the same position as a scientist attempting to explain the evolved purpose of dreams – and if we can identify the biological reason for dreaming, we can ask if it applies to the artificial dreams we call fictions.

As a neuroscientist, I've been working on a hypothesis that draws on what we've learned about artificial neural networks to cast dreaming as a way to improve our performance in waking life, just not in the way we might think. If correct, it may also explain some of this strange human attraction to the unreal in our waking lives.

The study of dreams, also known as oneirology, suffered something of a false start in the first decades of the 20th century, when it was tainted by association with Sigmund Freud's ideas about psychosexual development. Freud argued that dreams are an expression of repressed desires resulting from traumatic experiences in early life.

These ideas have been discredited, but dream research never quite shook the association.

Luckily, over recent decades, neuroimaging and behavioural research have reinvigorated the field by giving us insight into the biological mechanisms underlying dreams. We now know that dreams are the result of localised firing of neurons that is probably induced by the brain's many feedback connections and not dependent on information from external stimuli. Dreaming represents a unique physiological state in which activity similar to that we see when we are awake is promoted while behaviour is essentially cut off by powerful chemical systems that induce paralysis.

Yet although we now know a good amount about the mechanisms of dreaming, we have little insight into its function. Some argue that we don't need to understand what dreams are for. Perhaps they are just a by-product of sleep, which may have evolved for some other reason, such as to clear the metabolic detritus generated by neuronal activity.

But this "null hypothesis" of dreams has been challenged by a slew of ideas about how dreams have an evolved purpose. After all, we spend hours every night dreaming in a distinct stage of sleep.

## Making memories?

Generally, these dream hypotheses have trouble accounting for the distinct phenomenology of dreams: their unique, highly specific nature, which is what sets them apart from waking experience. Dreams are sparse, in that they mostly don't contain the vivid sensory detail of waking life. Dreams are hallucinatory, in that they contain warped concepts and perceptions that are biased or unrealistic. And dreams are narrative, in that they are fabulist versions of the kinds of events we might encounter in real life, just rendered strange.

Consider the leading hypothesis, which is that dreaming is somehow involved in the process of memory storage. This idea draws on the metaphor of the brain as a ›

computer: explicit memories are created and then stored, the way one encodes data on a hard drive. Neuroscience has long drawn on such metaphors, even from before it was called "neuroscience", when the metaphors were pneumatic pressures or mechanical clocks. But sometimes metaphors can lead their proposers astray. In the case of sleep and memory, it is well known that various improvements can occur after a good night's sleep, such as performance on some tasks, but it is less clear that acts of pure memorisation, like lists of numbers, are actually significantly improved.

What would it even mean to help store a memory over a night? The clearest hypothesis about memory storage and sleep is based on studies showing that memories, in the form of the specific neural sequences of firing that are seen while we are awake, are sometimes "replayed" during sleep in mammals. Perhaps dreams are just that: replays of memories.

While neurons that learn do seem to increase in their firing frequency during sleep, two facts suggest the idea falls short. The first is that replay has been more strongly associated with non-REM sleep than the REM stage, where the most intense narrative dreaming occurs. The second is that it is unclear whether memories are actually being replayed during so-called "replay." Indeed, careful studies have demonstrated that the brain more commonly produces never-before-seen patterns during these periods rather than previously seen waking patterns.

Behavioural evidence is also a problem for the idea that dreams are somehow replays of memories, or even just by-products of the integration of memories. If this were the case, we would expect to dream actual memories, yet dreaming specific previous memories is actually so rare that it is considered pathological, often a sign of post-traumatic stress disorder.

Yet there is no doubt that dreams do play a role in memory and learning. Consider how I learned to juggle. As an undergraduate, I took a class on memory and as part of my homework I was assigned to learn to juggle

"Dreams may serve as 'noise injections' to counteract the risk of learning too narrowly"

**The purpose of dreaming remains one of the great mysteries of the brain**

TANG MING TUNG/GETTY IMAGES

SCOTT MACBRIDE/GETTY IMAGES

in one night and then demonstrate it in front of the class. I practised all evening, tossing tennis balls helplessly, but eventually fell into bed, certain of embarrassment the next day. On waking, I immediately jumped out of bed, picked up the tennis balls, and found I could juggle perfectly. It was an incredible lesson. It seemed that something had happened in my sleep that had built on my waking experience.

Even so, I find it hard to accept that I had stored or replayed memories of my juggling during sleep. When I went to bed, I couldn't juggle. If I had replayed my failures, what would be the gain? Most importantly, it is doubtful I dreamed of precise juggling events. More probably, if I dreamed of juggling at all, it was of sparse and hallucinatory fragments.

This is backed up by studies that have had participants play games like *Tetris*, which they were novices at, and found that they reported *Tetris*-like dreams – imagine falling hallucinatory blocks – but no replays of specific *Tetris* games. It seems that the best way to get someone to actually dream

**How can someone who went to sleep failing to learn to juggle wake up the next morning as a juggler?**

about something is to have them learn a difficult and novel task, and then have them overtrain on it, as with playing *Tetris* for hours and hours.

## Deep lessons

A new and growing trend in neuroscience might help explain why this is the case, and offer a clear explanation for why dreams possess their distinct phenomenology. This trend seeks to apply the lessons of deep learning and the study of artificial neural networks to the brain. These techniques are, after all, originally inspired by how the brain functions, and remain the only set of techniques by which machines can reach human-level cognitive performance on complex tasks.

From a deep-learning perspective, learning isn't like storing memories on a computer. Instead, it is about fine-tuning a huge, layered network of connections based on an inherently limited set of example data – the "training" data set. With every example that the system sees, the pattern and strength of the network's connections are tweaked until it can parse the training data set effectively, which would be things like classifying images, playing a game or driving a car.

The hope is that the performance generalises beyond the training data set to new, unseen data sets. But it doesn't always work so well because training data sets are often inherently biased in all sorts of impossible-to-notice ways. Often a network gets so fine-tuned to the specifics of the data set it is trained on that it fails to generalise to new ones.

This is called overfitting, and it is a ubiquitous problem in deep learning. A number of common techniques have been adopted to deal with this issue. Most involve exposing the network to some sort of stochasticity, introducing noise and randomness into the system.

One such strategy is "domain randomisation", wherein the inputs are warped in a highly biased way during learning, effectively inducing a hallucination in the network. This sort of thing has been found to be indispensable, for example, when the research company OpenAI trained a deep neural network to learn how to manipulate a robot hand to solve Rubik's cubes.

There is good reason to think the brain faces an identical challenge of overfitting. Animals' days are, after all, statistically pretty self-similar. Their "training set" is limited and highly biased. But still, an animal needs to generalise its abilities to new and unexpected circumstances, both in terms of physical movement and reaction, and cognition and understanding. It doesn't need to remember everything perfectly; it needs to generalise from the limited things it has seen and done.

This is the overfitted brain hypothesis (OBH): that animals, being so good at learning, are constantly in danger of fitting themselves too well to their daily lives and tasks.

I've recently been working on developing the OBH, exploring how dreams could be a way to beat back the tide of daily overfitting. Essentially, under the OBH, dreams are "noise injections" that serve the purpose not of enforcing what is learned when ›

awake, but rather counteracting the overfitting associated with that learning.

You can't do domain randomisation on an awake brain because most organisms are negotiating a high-wire act during daily life; they would certainly hurt themselves in myriad ways. However, you can use an offline period to do something similar by creating sparse and hallucinatory inputs, driven by top-down activity, that resemble the events and actions an animal might encounter, but that are corrupted and biased away from the drudgery of daily life.

According to the OBH then, dreams are exactly this: self-generated corrupted inputs. And the act of dreaming has the effect of improving generalisation and performance in waking life. This is how someone can go to sleep failing on their training task of juggling, and then wake up a juggler.

The advantage of this hypothesis is that it takes the phenomenology of dreams seriously, rather than as some sort of epiphenomenon or unexplained by-product of some other neural background process. Indeed, it is the strange phenomenology of dreams that makes them so effective at combating overfitting. While it may seem weird, experiencing events that are related to a task, but fundamentally different from it, can actually help performance. Dreaming of flying may help you keep your balance while running. And deep-learning practitioners should perhaps take a lesson from the brain and make their efforts to combat overfitting look as "dream-like" as possible for their networks.

## Waking dreams

Of course, this is still very much a hypothesis – and an untested one at that. There is much work that needs to be done to assess what the behavioural benefits of dreams are and whether they match the sort of reductions in overfitting that we might expect in humans and other animals according to the OBH. Additionally, dream physiology – how synapses change during dreams and when dreaming occurs during sleep – are all still being investigated more generally.

HARDZIEJ STUDIO

But by viewing dreams through this new lens, we can at least move beyond computer and storage metaphors and begin to think of learning as a set of trade-offs, where memorisation competes with generalisation, and learning the specifics of something too well can be as bad as not learning at all.

If dreams have this functional purpose, and the OBH is true, then the artificial dreams we call fictions might satisfy some of that same fundamental drive. I spent 10 years writing my first novel, *The Revelations*, which is about consciousness and murder. I can give all the standard cultural reasons for why fictions are important, entertaining, revelatory – but the OBH implies there is something more. Maybe art is also pleasurable for humans because we are constantly being overfitted to reality.

In this view, the sparse, sometimes hallucinatory, corrupted unreality put forward by authors, film-makers, and those first early shamans around some campfire, all help to stop our minds becoming too fixed in their ways. They don't just expand the "training set" that humans have access to, but do so in ways that assist with generalisation and therefore cognition more broadly.

Perhaps the hypothetical aliens wouldn't be so puzzled by our obsessions with fictions once they figured this out. They wouldn't be shocked either that as human civilisation developed, daily life became more complex, and so it became easier for us to overfit to it – until eventually we humans began to spend more time with artificial dreams than we do with biological ones. Just like how the invention of cooking essentially allowed us to expand digestion beyond our stomachs, maybe the invention of fictions allowed us to get the benefits of dreams when we are awake. ▮

Erik Hoel is a neuroscientist at Tufts University in Medford, Massachusetts. His debut novel, *The Revelations*, will be published in April 2021

# Into the deep

We are on the verge of a new era in deep-sea exploitation. Marine biologist **Jon Copley** considers the consequences

ON 2 AUGUST 2007, bright light shone on the ocean floor beneath the North Pole for the first time, as a van-sized submarine settled on the seabed. Inside, pilot Anatoly Sagalevich deployed a mechanical arm to erect a Russian flag. That act stirred up more than the yellow-tinged polar sediments.

"This isn't the 15th century: you can't go around the world and just plant flags and say we're claiming this territory," said Canada's foreign minister, Peter MacKay. Russia countered that the flag-planting was merely to celebrate their achievement – like taking a flag to the moon. "The goal of this expedition is not to stake out Russia's rights, but to prove that our [continental] shelf stretches up to the North Pole," said Russia's foreign minister, Sergey Lavrov. In 2015, Russia used data from the expedition to support a claim to seabed resources in 1.3 million square kilometres around the pole.

This may look like a latter-day land grab but it is actually a move in line with international laws built on a vision of the ocean floor being "common heritage". Russia isn't alone in claiming resources on the Arctic seabed, and nations are seeking to extend their rights to ocean resources elsewhere. Meanwhile, commercial enterprises are gearing up to mine deep-sea mineral deposits.

JASON FORD

We have come to a crucial moment for the future of our blue planet. As international bodies prepare to decide about the legitimacy of different mining ventures and how to protect biodiversity in the waters beyond national boundaries, the race is on for deep-sea biologists like myself to understand how these decisions will affect ecosystems on the ocean floor.

Working out who has rights to what is the easy part, at least in principle. The rules determining rights on the ocean floor are collectively known as the United Nations Convention on the Law of the Sea. UNCLOS was agreed through conferences that spanned decades, and has been signed by 167 nations and the European Union. It gives countries with a coastline a zone of "territorial waters" extending 12 nautical miles (22 kilometres) offshore. They own the resources within that area, such as fisheries and minerals, but ships of any other nation have the right of peaceful passage.

Coastal countries are also granted an "exclusive economic zone" (EEZ), with further rights to resources extending out to 200 nautical miles (370 kilometres) offshore. For both territorial waters and the EEZ, if there is an overlap with the zones for another country, the nations involved must agree a boundary. In practice, the ›


JASON FORD

area is usually divided down the middle.

All this helps explain disputes over the sovereignty of specks of land such as the Spratly Islands in the South China Sea. Any country that can claim an island potentially gets the territorial waters and EEZ around it – and may also reduce the zones of other countries if there is an overlap.

It doesn't explain what's happening in the Arctic, though. Rights to that territory are determined by additional rules agreed in UNCLOS. These allow countries to claim rights to sea-floor mineral resources out to either 350 nautical miles (648 kilometres) from their coast, or 100 nautical miles (185 kilometres) beyond the 2500 metre depth contour where the sea floor slopes away from the land, whichever applies first.

According to these rules, a country must submit a case with geological evidence and detailed sea-floor maps showing that the area is an extension of its continental shelf. In the Arctic, a relatively shallow stretch of sea floor called the Lomonosov Ridge runs across the ocean basin. Russia, Canada and Denmark, by way of Greenland, can all claim that this feature extends their continental shelves into the central Arctic. All three have submitted their cases to the UN Commission on the Limits of the Continental Shelf: Denmark in 2014, Russia in 2015 and Canada in 2018.

"What looks at first glance like this acquisitive scramble for the Arctic, with everyone just claiming what they can, is actually states doing what they're supposed to do," says Philip Steinberg, director of the International Boundaries Research Unit at Durham University, UK, "They are submitting the science that UNCLOS tells them to."

The areas claimed by Russia, Canada and Denmark overlap, so they will have to negotiate boundaries between themselves. But that is a problem for the future. Claims over the Arctic may have been making the headlines, but the same process is happening around the globe and there is a backlog of cases waiting to be reviewed by the UN. "It will be maybe 20 to 30 years before they get to all the submissions that are currently before them – and there are still more coming in," says Steinberg.

That still leaves a vast expanse of ocean beyond the reach of individual nations. This region, which covers about 46 per cent of Earth's surface, is known as the "high seas" or "the Area". In the 1960s, the UN designated the resources here as the "common heritage of mankind". This principle is the cornerstone of its International Seabed Authority (ISA),

**"Most resources on the sea floor are deemed 'common heritage' for all"**

created in 1994 to regulate deep-sea mining and ensure that lower-income nations benefit from it. "It is the only organisation that has such a broad mandate over a common property resource," says Michael Lodge, secretary-general of the ISA, which has its headquarters in Kingston, Jamaica.

Through the ISA, the UNCLOS signatories have devised rules for the extraction of three different types of mineral deposits in the deep ocean: polymetallic nodules (manganese nodules scattered across sea floor plains), polymetallic sulphides (deposits rich in copper, formed by hydrothermal vents) and cobalt-rich ferromanganese crusts (which form on undersea mountains). Nations can sponsor applications by contractors – either mining companies or research institutions – for exploration licences to map and study the value of a particular type of deposit in an agreed area.

The first exploration licences were issued in 2001. By last year, the tally had reached 30, of which 18 were for manganese nodules, seven for polymetallic sulphides and five for cobalt-rich ferromanganese crusts. Countries involved so far are Russia, South Korea, China, France, Japan, Germany, the UK, India, Poland, Brazil, Singapore, Tonga, Nauru and the Cook Islands. No deep-sea mining has taken place yet, however. That will require a new phase in which exploitation licences are issued.

**21**
billion tonnes of manganese nodules exist in the Clarion-Clipperton Zone

Containing:

**5.88** billion tonnes of manganese

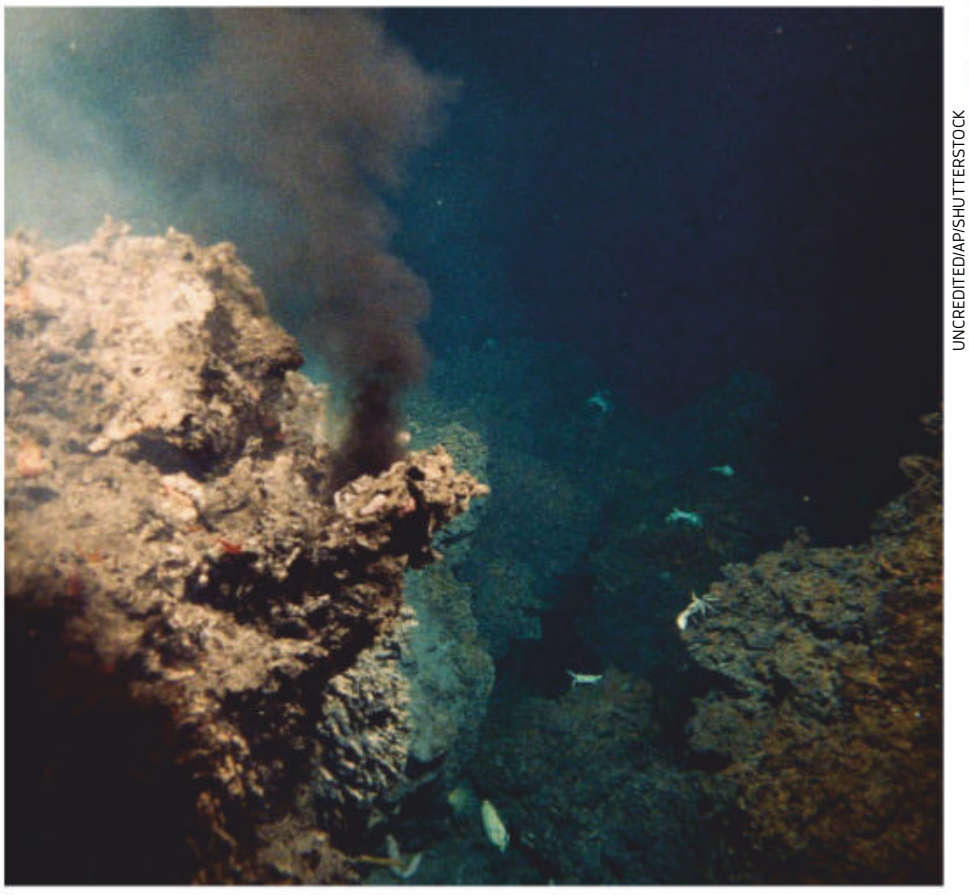
**273** million tonnes of nickel

**231** million tonnes of copper

**42** million tonnes of cobalt

**12** million tonnes of molybdenum

Some scientists are already calling for a ban on mining active hydrothermal vents – the "black smokers" of TV nature documentary fame. Cindy Van Dover, director of Duke University's Marine Laboratory in North Carolina, is one of them. In 2018, Van Dover and her colleagues published research calculating that the total sea-floor area of all known active hydrothermal vents is about 50 square kilometres – around half the size of Disney World in Florida, or less than 1 per cent of the size of Yellowstone National Park. "It is a super-rare environment," she says. Yet that tiny global area is home to more than 400 species of animal not found in any ›



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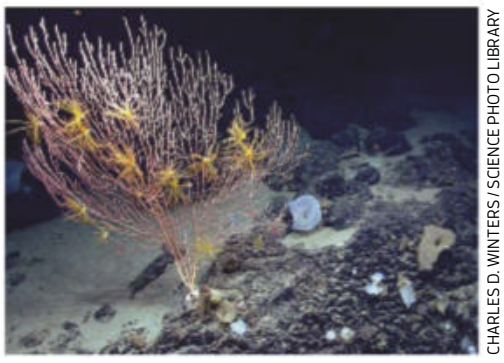

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CHARLES D. WINTERS/SCIENCE PHOTO LIBRARY

**Hydrothermal vents (left) and seamounts (above) could be mined for minerals. Manganese nodules (above right), found in abyssal plains, are also promising**

other habitat, which is why she says it needs protection from mining.

The ISA is sympathetic. "If there is a need established for protection of active hydrothermal vents, I don't think that's a big problem," says Lodge. "It's something that we're working on." For every cluster of active hydrothermal vents on the ocean floor, gushing out mineral-rich fluid, there are several inactive ones, where venting has naturally ceased and the vent animals have moved on, but the mineral deposits remain for potential sulphide miners.

Most of the exploration licences aren't for sulphides at hydrothermal vents, however. They are for manganese nodules: nuggets the size of new potatoes that contain cobalt, nickel and rare earth elements, as well as manganese, that form over thousands of years on the sea floor. Exploration activity is primarily focused on the Clarion-Clipperton Zone (CCZ) of the eastern Pacific, which covers 4.5 million square kilometres of silty abyssal plains, punctuated by rolling "abyssal hills".

The CCZ is 90,000 times the size of the area of all the world's active hydrothermal vents, which could make mining here a very different prospect. Nevertheless, there is still much we don't know about it. Just as the environment changes over thousands of kilometres across a continent, the huge area of the CCZ is a patchwork of varied sea-floor environments. Different species flourish in these different areas, which requires a joined-up approach to manage the impacts of activities such as mining. We still don't know exactly what organisms live where or how they might be disturbed by mining.

For example, seven years ago, when researchers from the Natural History Museum (NHM) in London surveyed the eastern CCZ, they noticed white sponges, just a few millimetres across, on many of the manganese nodules. These turned out to belong to a new genus and species, which they named *Plenaster craigi*. It is the most abundant animal living on these nodules in the eastern CCZ, and has since been found across more than 1000 kilometres of the area. Being so widespread, it would probably not be threatened by mining, but other organisms are. Around hydrothermal vents there are 27 species listed as vulnerable or endangered on the International Union for Conservation of Nature's Red List of Threatened Species. These include four new species of snails, which I and colleagues recently described in published work. It remains to be seen whether any nodule zone species, whose populations cover much larger areas, will join them on that list.

"There has to be honesty and transparency about what will be impacted," says Adrian Glover, who led the NHM survey team that discovered *P. craigi*. He points out that large areas of the CCZ have already been designated as reserves, protected from any future mining. These total 1.44 million square kilometres, which is almost six times the size of the UK.

Research into the effects of mining across the CCZ is ongoing. In the next few years, Glover and Dan Jones of the UK's National Oceanography Centre will lead a project – in which I am also involved – to investigate what happens when a company tests one of its nodule-harvesting machines, which is permitted under current exploration licences. These machines work like a sort of underwater vacuum cleaner, sucking up nodules and stirring up sediment, which can have effects at least 10 kilometres beyond the mine site.

**21**
**million tonnes**

Annual global manganese consumption (2016)

**30**
**million tonnes**

Total copper and zinc at all the world's known hydrothermal vents

**31**
**million tonnes**

Annual global land-based extraction of copper and zinc

"No exploitation licences have been issued yet, so effectively deep-sea mining is banned until such time that we've worked out if it can be done environmentally, economically and legally," says Glover. Even if the ISA agrees the regulations for exploitation licences in the coming months, would-be miners then have to submit their licence applications for approval, which will include consideration of environmental impacts in each case.

Because deep-sea mining hasn't yet begun, the ISA also has time to consider how the benefits could be shared with the world's lower-income nations. One idea is to create a sovereign wealth fund for the ocean, using income from mining areas that each licensee has to release back to the ISA for its "common heritage" goal. "You could use it either to support underfunded global public goods, which could, for example, be marine scientific research," says Lodge. "Or you could use it to combat global public bads – climate change, for example, by putting it into a climate change adaptation fund."

This would only apply to profits from non-living resources, though: organisms in the Area aren't covered by the ISA. As well as fisheries, governed by regional organisations, these also include "marine genetic resources" – the gene pool of the oceans, which has huge potential for biotech and medical applications. This genetic resource is unregulated, but that is set to change. Next year – following a postponement because of coronavirus – the UN is convening the final session of an intergovernmental conference that began in 2018 to draw up a new treaty for biodiversity in the high seas.

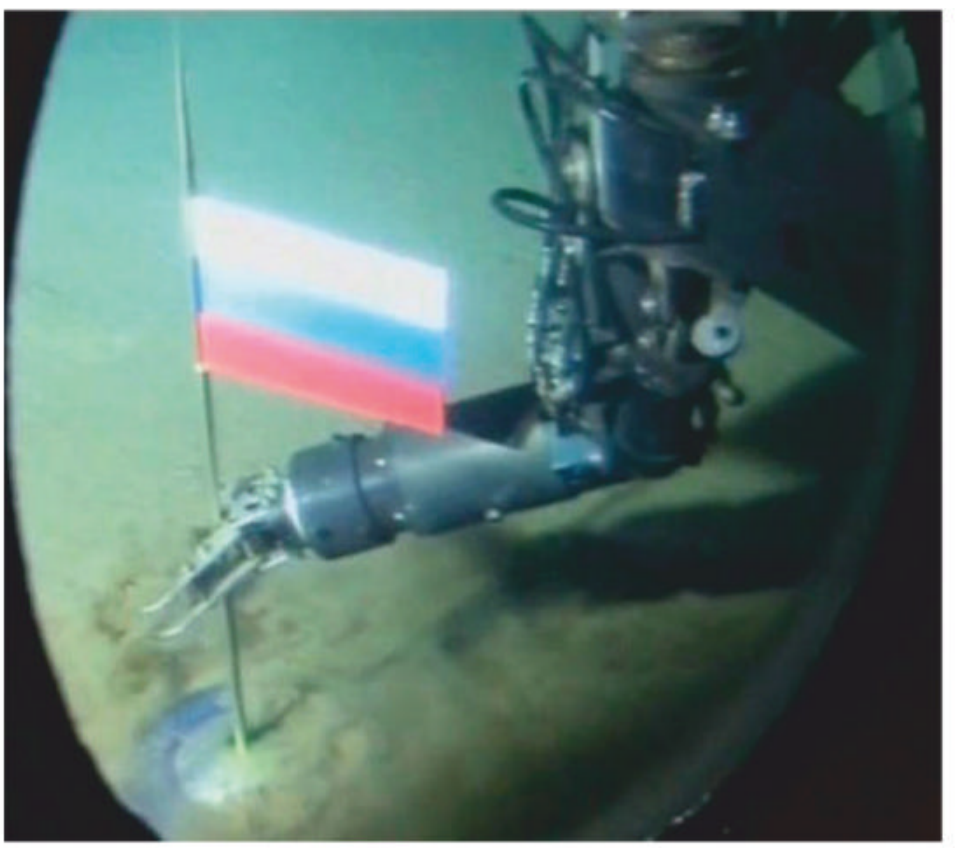
## Creatures of the deep

Unlike deep-sea mining, exploiting marine genetic resources doesn't involve large-scale harvesting: a single specimen of an organism can provide a genome for that species. So, sharing any benefits will depend on tracking biological samples and data collected from the high seas. "What you don't want is something that's going to end up hampering research," says Muriel Rabone at the NHM, who has attended the preliminary negotiations. But, she adds, tracking could also help other researchers to continue using collections of deep-sea specimens to answer new questions in the future.

Decades after it was proposed, the principle of common heritage could soon start to pay dividends. While that would be progressive, some scientists think the idea of the high seas as a resource to be exploited is outdated. "The Law of the Sea Convention was drafted in the 80s, on the back of negotiations that took place in the 60s and 70s," says Harriet Harden-Davies at the University of Wollongong, Australia. "Looking to the future, I think it's useful to draw some ideas from fresh inspirations."

In recent years, environmental legislation in some countries and US states has recognised that nature itself has rights: a few countries, such as New Zealand and India, have gone further and recognised rights for specific ecosystems such as rivers and mountains, making them legal entities akin to corporations or people. In June, Harden-Davies and her colleagues published a paper showing how this rights-of-nature paradigm could be used in developing a new treaty for ocean biodiversity.

"These laws wouldn't preclude use of ocean resources, but they would really reinforce the principle of precaution," says Harden-Davies. They would also ensure that some benefits of exploitation flow back into ocean conservation. "And you could have some kind of institutional mechanism, like a Council of Ocean Custodians, that would provide an opportunity for people to speak on behalf of the ocean," she says. In other words, instead of debating our rights to the oceans, the focus would be on our responsibilities. ▮



REUTERS/REUTERS TV

**In 2007, Russia planted a flag on the seabed at the North Pole**

Jon Copley is Associate Professor in Ocean Exploration and Public Engagement at the University of Southampton, UK

ALEX WILLIAMSON

# Code red

Outdated computer software underpinning much of the modern world is leading us into disaster, says **Edd Gent**

AS THE coronavirus pandemic swept across the US, it brought with it an unprecedented economic crisis. As firms shut down and people stayed home, the country's unemployment rate shot up from 4.4 per cent in March to 14.7 per cent in April, adding fuel to a political fire already raging in a tumultuous election year.

That much is well known. But the stories of many of those who lost their livelihoods and sought help exposed a slower-burn technological crisis. Outdated computer systems simply fell over as they attempted to deal with the flood of people applying for welfare benefits – and hardly anyone around knew how to fix things.

It is far from an isolated problem. Tangled webs of computer code built up over decades, often written in programming languages now rarely taught or understood, underpin IT systems across the world, in government departments, banks, airlines, hospitals and more. Coronavirus taught us a lot about how the systems we had assumed would assist and protect us can fail in a crisis. As the fallout continues, it is becoming ever clearer that we need to revisit the computer code that underpins many aspects of our societies before disaster strikes.

Thousands of different programming languages exist, performing the same basic job: translating real-world commands such as "import this data" or "run this calculation" into the strings of binary 1s and 0s that encode information in computer processors and memory chips. Certain ones dominate (see "Top five languages", page 46), but new languages pop up as requirements change. Google developed the Go language, for example, to streamline the development of massive applications running across hundreds of servers in the cloud. "There's still a rich space out there where people are exploring new ideas and trying to make things better," says Barbara Liskov at the Massachusetts Institute of Technology.

As new languages become favoured, so others fall out of use or find a different purpose. Fortran, for example, was developed by IBM in the 1950s for general business use. It went out of favour in corporate circles, but is still prized by physicists for its mathematical chops, thanks to its ability to run many operations in parallel at breakneck speeds.

Other languages stick around, unfashionable, but too deeply embedded in computing systems to get rid of. COBOL, or the common business-oriented language, is a prime example. When first released in 1959, it was aimed at allowing corporations to program business software on large mainframe systems. It was wildly successful. "The staying power of COBOL is the fact that it's easy to use," says Barry Baker at IBM in New York.

With the advent of personal computing and the internet, COBOL lost ground to newer, more flexible general-purpose languages, but roughly 220 billion lines of COBOL code still support the systems behind businesses and other institutions worldwide. Perhaps most significantly, it underpins huge chunks of the world's financial sector. According to Reuters, 43 per cent of the planet's banking systems run on COBOL and 95 per cent of ATM transactions still rely on the language.

## COBOL cowboys

The extensive use of COBOL in welfare processing systems was seemingly behind the US unemployment benefit fiasco. Universities have stopped teaching this programming language, and when state governments needed to scale up their systems quickly to deal with the surge in demand, skilled labour was in short supply. New Jersey governor Phil Murphy made ›

## Top five languages

**Software consultancy company TIOBE publishes a monthly index of the world's most popular programming languages, based on factors including search engine results mentioning the languages and courses teaching them. This is October 2020's top five.**

**C 16.95 PER CENT OF LISTINGS**
**The go-to for programs requiring speed and efficiency, such as operating systems, robotics controllers and trading algorithms, C has been at number 1 or 2 of the most prevalent programming languages for at least the past four decades.**

**JAVA 12.56%**
**The leading language for most of the past two decades, Java is a child of the world wide web, and is a workhorse for mobile and web applications and games.**

**PYTHON 11.28%**
**Listed as only the 21st most popular language as recently as 2000, Python's versatile and easy-to-learn vocabulary has seen it gain popularity lately for everything from web applications to artificial intelligence systems.**

**C++ 6.94%**
**An extension of C, used to code operating systems, browsers and games, C++ was for a period in the 1990s the number 1 language, but has since slipped down the rankings.**

**C# 4.16%**
**Pronounced "c-sharp", this is another extension of C, developed to incorporate similar principles to Java, and it has similar spheres of application.**

an appeal for COBOL volunteers, and a group of ageing coders dubbed the COBOL Cowboys swung into action. IBM released a free COBOL training course. Despite this attempt to improve matters, a survey by the Economic Policy Institute think tank in Washington DC has found that reliance on COBOL caused real problems. For every 10 successful applicants in the initial phase of the covid-induced US jobs crisis, three or four others didn't receive their benefits. Many people went months without income.

Part of the problem is that, while most programmers could learn COBOL in a few weeks, picking up its vocabulary and grammar is only part of the challenge. Mastering how a coding language is used in practice, and its common styles and patterns or idioms, is no less important. Most computing languages have large libraries of ready-made snippets of code that streamline the programming process. Understanding how to draw on this literary canon is as much a key to fluency in a programming language as it is in any spoken language. Opaque turns of phrase, plus coding conventions that can vary significantly between domains or even organisations, make deciphering a specific bit of software difficult for an outsider.

"You hear these stories of people rehiring this old guy in his 70s who's retired," says Daniel Kroening at the University of Oxford. "You're not getting this guy back because he knows COBOL, you're likely getting someone who has worked on that particular piece of software in the past."

Building complex software from scratch is expensive and time-consuming, so code is also frequently reused and adapted. This means earlier decisions become deeply embedded in software that runs present-day systems. Over time, "dark shadows" start to appear in the labyrinths of code built up at large organisations, says Bill Scherlis, director of the Information Innovation Office at the US Defense Advanced Research Projects Agency (DARPA). "There's certain components that the programmers dare not touch," he says. "There's fear and superstition."

REUTERS/NICK OXFORD

**A queue of people filing for unemployment assistance in Fort Smith, Arkansas, on 6 April**

**"Over time, dark shadows start to appear in tangled webs of code built up at large organisations"**

## A glitch in the science?

**"Legacy code" (see main story) is also a big problem in academia, where old, poorly maintained computer programs can be prone to bugs that throw off results, says Caroline Jay, research director at the UK-based Software Sustainability Institute, which advocates for better programming training for scientists.**

**Researchers have to write software for everything from data analysis to modelling natural processes, but most learn these skills in an ad hoc way. They are perennially short of money and time to properly sustain their code. "Being a scientist is a full-time job," says Jay. "It's really difficult to be an expert in both of those areas."**

**The tendency to repurpose code written by other researchers can also cast a long shadow. Last year, scientists discovered a glitch in a tool to predict nuclear magnetic resonance spectra, a key method used to characterise chemicals. The tool, published in a 2014 paper, gave different results on different computer operating systems.**

**The software has been cited by other researchers more than 150 times. It isn't clear how many of those teams actually used the tool, or how many results were thrown out by the glitch.**

And the strain is showing. A 2019 report from the US Government Accountability Office (GAO) identified 10 ageing "legacy" federal IT systems whose creaking code is expensive to maintain and increasingly prone to serious failures or hacking. These include those that underpin the federal Social Security Administration, that keep the Air Force's planes battle-ready and even those that operate major dams and power stations. "Think about how many people, how much infrastructure, how much capital is downriver from a dam," says Carol Harris at the GAO, who wrote the report. "Imagine if that were hacked or went offline and the dam went through a catastrophic release."

It isn't just government bodies affected by this. Last year, the UK Financial Conduct Authority said it had received 853 notifications of IT outages at financial institutions in 2018/19 – a dramatic increase on the previous year as banks, trying to compete with finance start-ups, raced to add new features to their systems, some of which have code dating back to the 1970s. In the US in 2017, cybercriminals stole data on 148 million consumers from credit rating agency Equifax. The company forked out $700 million in fines and settlements and a US House of Representatives report accused it of relying on legacy systems with known security risks. Ancient, sprawling legacy systems have caused regular IT failures at airlines in the US and elsewhere, too.

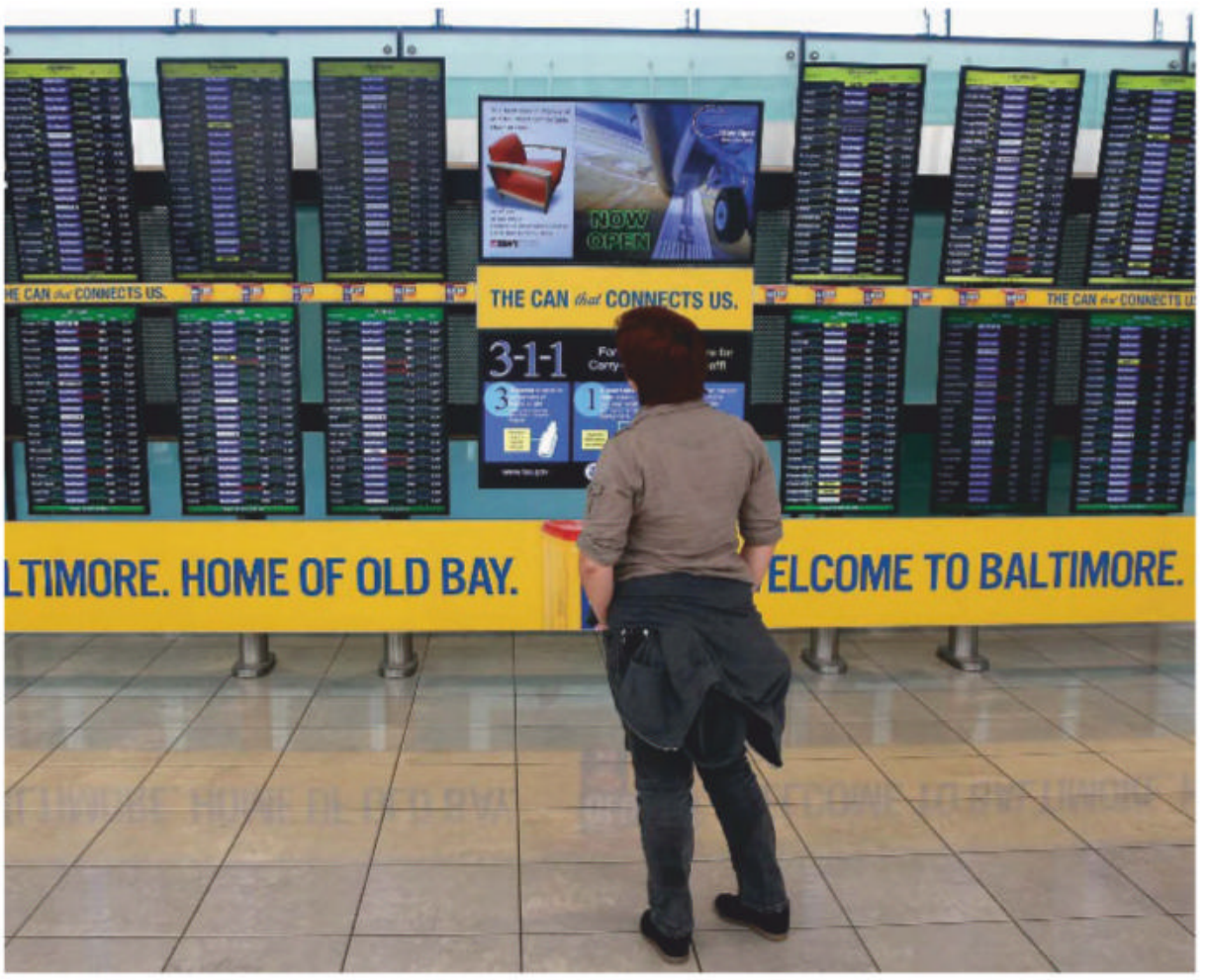
## Fake it till you make it

Fixing the problem isn't easy. When the Commonwealth Bank of Australia replaced its core COBOL platform with software developed by the German company SAP in its ABAP language in 2012, the switch took five years and cost $750 million. The GAO report highlighted a US Internal Revenue Service system in urgent need of modernisation. The upgrade would cost $1.6 billion, for an operation normally requiring just $5.5 million a year to run. "The payback period on that is just huge," says Harris. "This is why, in many cases, you wind up with these systems that just sit in the corner quietly and diligently doing their job until they break."

Then there is the risk factor. When the UK's TSB Bank attempted to upgrade to newer banking software in 2018, many customers were locked out of their accounts for a week, costing the company £330 million and CEO Paul Pester his job. Often, too, important business rules that govern how a company operates are embedded in software and, if not properly documented, can be forgotten as employees retire. "If you were to replace the system you might actually lose that corporate memory that is embodied in that code," says Scherlis.

That is why most "modernisation" efforts in corporate IT focus on surface details, says Tom Winstanley at NTT Data UK, which helps upgrade legacy software. Rather than updating core systems, many businesses adopt a "fake it till you make it" approach of adding new features such as e-commerce websites or flashy web apps – like adding new floors to a building that is crumbling rather than repairing the foundations.

The coronavirus pandemic has laid bare the short-sightedness of that approach, says Winstanley. As entire workforces shift to ›




ROB CARR/GETTY IMAGES

**Mass flight cancellations hit Baltimore/Washington International Thurgood Marshall Airport on 15 August 2015, in an incident attributed to outdated computer systems**

working from home, many of his clients are scrambling to enable remote access to ageing office computer systems, and dramatic shifts in business models are forcing painful overhauls. "It's only when you start needing to change fundamentally core policies that this stuff really comes to the surface," he says. "It's been hidden by a veneer of transformation."

Some help is at hand. Owing to the huge amounts of legacy software operating on its hardware, IBM has built a way for customers to map their sprawling systems, which spits out a visual diagram of how different software modules and components work together. It has also developed an AI-based tool that can recommend the most efficient strategy for modernising a company's software.

Such tools can help new IT staff get up to speed and shine light on those dark shadows in legacy code, says Baker. "It's shown to be really valuable for these clients that have maybe atrophied in their ability to keep doing the care and feeding of those applications," he says.

DARPA, meanwhile, has launched a program called V-SPELLS to develop ways to recover lost code knowledge. It has called for proposals for "advanced automated program understanding techniques", which analyse software to tease out the assumptions and architectural decisions that went into making it, and how individual modules are interlinked. That allows developers to tweak individual bits of a system without knock-on effects that might otherwise bring down the whole house of cards.

**"Choosing software or a programming language is a bet on how long it will stay in fashion"**

Heading off the legacy problem doesn't need fancy tools, though. Building software tests that check if later edits will introduce errors is an effective, but often neglected practice, says Scott Ford, founder of Corgibytes, a company that specialises in remodelling legacy systems. An even more rigorous approach is test-driven development, where developers build tests before they start coding. "You're building your safety net as you go," says Ford. Open-source principles, where developers share, reuse and modify each other's code, can give more people an incentive to maintain it.

Ford is part of a burgeoning movement of "menders" that aims to change a prevailing culture that regards code maintenance as second-rate work. But there is only so hard you can fight decay. Even the act of choosing a programming language or software product is tantamount to placing a bet on how long it will stay in fashion. "As soon as a developer pushes something out and somebody else has to come along and maintain it... it is legacy," says Baker.

Any system in regular use will face pressure to change, says Ford, sometimes in unpredictable and sudden ways, as with the US unemployment systems. "They assume that it was working yesterday, it'll continue to work tomorrow," says Ford. "But that pressure is going to show up; so if you don't have the human infrastructure in place to be able to respond to it, you can be caught by surprise."

There are no silver bullets. Staying on top of the legacy software problem means investing in maintenance and adopting best practices when building new systems. IT managers will always face trade-offs between the robustness of their software, its cost and how quickly they can deploy new services, says Winstanley. But every shortcut makes it trickier to modify code later, resulting in the build-up of "technical debt".

"You need to find the space in your planning to pay down that debt just like any other debt that you're taking on as a business," he says. "If you just let that pile up, at some point, the debt is overwhelming and you go bankrupt." With our shaky computer systems, it is increasingly looking like payback time. ▮

Edd Gent is a freelance writer based in Bangalore, India. He tweets @eddythegent

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# The back pages



## Science of cooking

# Pairing flavours like a pro

From chocolate and strawberries to bacon and eggs, how well do we really understand food pairing, asks **Sam Wong**


Sam Wong is social media editor and self-appointed chief gourmand at *New Scientist*. Follow him @samwong1


## What you need

**Langoustines**
**A yellow bell pepper**
**Mayonnaise**
**Lemon juice**
**Vanilla essence**
**Freshly ground coffee beans**

WHY do some flavours go so well together? According to one school of thought, ingredients that pair well have key aroma molecules in common. Strawberries, for example, share aromatic compounds with chocolate, basil and balsamic vinegar – which may explain why they complement each other.

The idea has been embraced by chefs such as Heston Blumenthal, inspiring surprising combinations like white chocolate and caviar. On Foodpairing, a website created by chef Peter Coucquyt and Belgian food scientists Bernard Lahousse and Johan Langenbick, the chemical profiles of thousands of ingredients are used to generate molecular matches for chefs and the food industry. Now, their insights are available in a new book, *The Art & Science of Foodpairing*, containing suggested pairings for hundreds of ingredients, along with a few recipe ideas.

Chocolate is a suggested pairing for many ingredients in the book, reflecting the complexity of its aroma profile. Its roasted flavour works well with bacon, which also contains the chocolate-scented chemical 3-methylbutanal.

As much as I enjoyed chocolate mousse with crispy bacon and other combinations from the book, I am not entirely sold on the idea that shared aroma compounds determine which flavours pair well. Typically, dozens of volatile compounds contribute to an ingredient's aroma. If a pair of foods have two or three in common, it doesn't

STOCKFOOD/AKSAKOVA, VALERIA

mean that others won't suppress, overshadow or clash. What's more, don't the most interesting pairings work because they complement each other, offering difference rather than more of the same?

Barry Smith, a sensory scientist and philosopher at the School of Advanced Study, University of London, also finds the shared compounds idea too simple. "We need insights from food chemistry, sensory science and cross-cultural studies," he says.

Smith points out that some power couples of the flavour world work because of taste, not smell. Bacon and eggs, ham and cheese, tomatoes and anchovies – these all provide two kinds of umami that act synergistically to heighten the intensity of flavours.

Whatever truly explains why some flavours work well together, the standard repertoire of pairings has only scratched the surface of the delicious combinations out there. The book is a welcome prompt to try new ones, which made me feel like I was eating at a fancy restaurant at home.

I heartily recommend this dish inspired by the book: roast a yellow bell pepper, blend it with some mayonnaise to make a smooth sauce, then add a squeeze of lemon juice and a few drops of vanilla essence. Pan-fry the langoustines, serve them with the sauce and sprinkle some freshly ground coffee on top. It tastes incredible – and you don't need to know why.

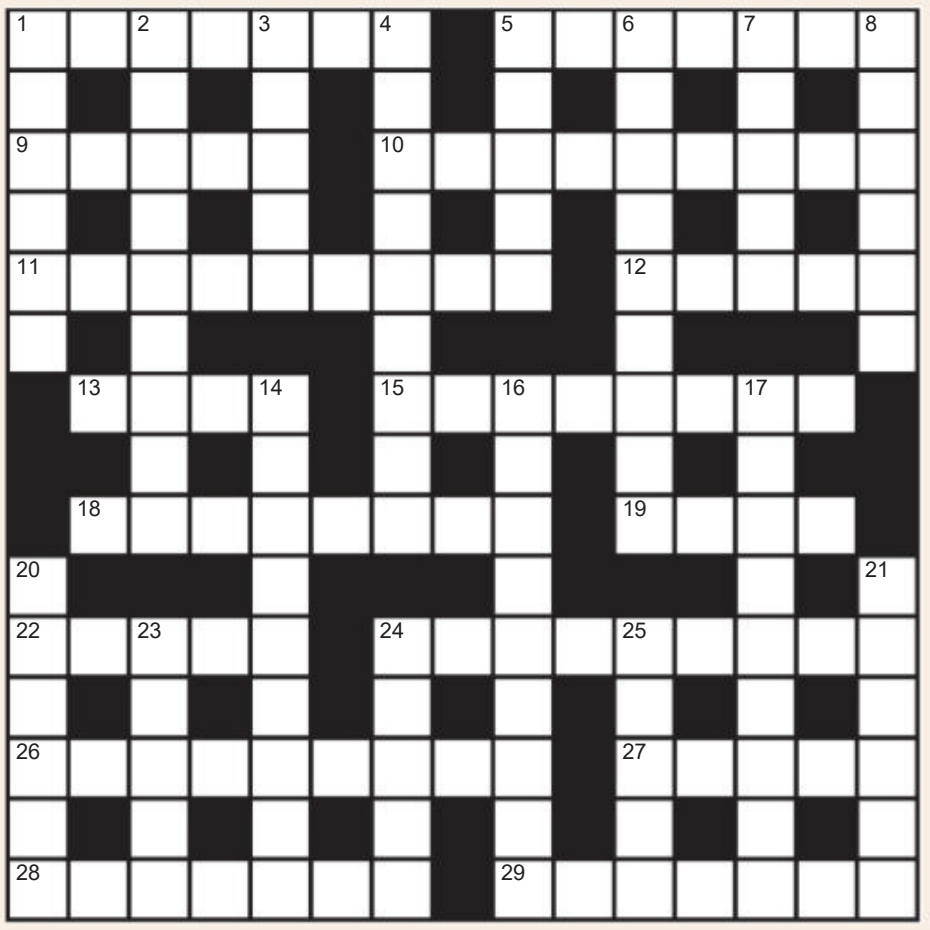
*Science of cooking appears every four weeks*

## Next week

Stargazing at home

**These articles are posted each week at newscientist.com/maker**

## Quick crossword #70 *Set by Richard Smyth*



### Scribble zone

Answers and the next cryptic crossword next week

**ACROSS**

**1** Place for esoteric online resources (4,3)
**5** System of transport by track (7)
**9** Flat side (5)
**10** Obstruction (9)
**11** Spiny marine echinoderm (3,6)
**12** Raised line; stretch of high ground (5)
**13** Fever (archaic) (4)
**15** Without Pb, like most modern petrol (4-4)
**18** Third (8)
**19** Ne (4)
**22** Body of accepted principles (5)
**24** #1 (6,3)
**26** Mars (3,6)
**27** Part of the hip bone (5)
**28** Distance across (7)
**29** Peninsula struck by an asteroid 66 million years ago (7)

**DOWN**

**1** Render harmless – a bomb, for example (6)
**2** Quadrilateral (9)
**3** $H_2O$ (5)
**4** 1984 work by ecologist E.O. Wilson (9)
**5** Toxin produced in castor oil seeds (5)
**6** Anti-inflammatory drug (9)
**7** ___ fiction, sci-fi subgenre (5)
**8** Y (6)
**14** Complicatedly interconnected – like knitting or electrons, say (9)
**16** Absence of correspondence (9)
**17** Student of living systems (9)
**20** Dung beetle (6)
**21** Like Heisenberg or Hahn, for example (6)
**23** 2008 book on "choice architecture" (5)
**24** Ordinal of 9 (5)
**25** First general-purpose electronic computer (5)



## Quick quiz #76

**1** What name is given to a hypothetical megastructure that encloses a star and captures most of its energy?

**2** How many neck vertebrae do most mammals have?

**3** What is the geologic era of the dinosaurs, encompassing the Triassic, Jurassic and Cretaceous periods?

**4** Mikhail Tsvet is best known for inventing which scientific technique?

**5** In 1820, which alkaloid used to treat malaria was first isolated from the bark of a *Cinchona* tree?

*Answers on page 55*

## Puzzle
*set by Catriona Shearer*
### #84 Squarebot

**"What's that you are holding, Squarebot?"**

**"Square."**

**I have met Squarebot before and am suspicious. "Are you sure, squarebot? I can see it must be a rectangle, because you have drawn it on squared paper. But I can't count the squares without breaking social distancing rules. How wide is it?"**

**"16."**

**"And its height?"**

**"16."**

**"Sounds like a square, then. Just to check: what is its area?"**

**"289."**

**"Hold on, that doesn't work: 289 is 17 squared. You are rounding every numerical answer you say to the nearest square number, aren't you? And if the answer isn't a number you just say 'Square'?"**

**"Square," chuckles Squarebot.**

**"So the width might actually be 17? Or 18? Or 15? Or even 20?"**

**"Square," grins Squarebot.**

**Can you think of a question to ask Squarebot to find out if the rectangle really is a square?**

*Answer next week*

## Double up

**Why is it that when I sneeze, I almost always do so twice?**

***Geoff Broughton***
*Abingdon-on-Thames, Oxfordshire, UK*
Only twice? My wife always releases a volley of six loud sneezes. There is palpable tension in the room if numbers five and six are momentarily delayed. How can her nasal system reliably count to six while under such strain?

***Taylor Rey***
*Suwanee, Georgia, US*
Almost every time I sneeze, I do so seven times in a row. The sneezes come in fast succession, but occasionally the last one lags behind by a few seconds.

***Harsha Kariyawasam***
*Royal National Throat, Nose and Ear Hospital, London, UK*
Sneezing is an underappreciated upper-airway event. It is a critical airway protection mechanism that prevents the entry and depositing of potentially hazardous agents into the nose.

It is normal to sneeze two or three times a day. This indicates that our nasal defences are active and working. Frequently, one sneeze isn't enough, so it is promptly followed by another to ensure that any inhaled threats are fully expelled.

In conditions such as hay fever or rhinitis, there is often irritation of the sensory nerves of the nose such that the sneezing reflex activation threshold is lowered. This results in anything from allergens to temperature change and even strong smells activating a sneeze.

The brain doesn't regulate or "count" sneezes, as sneezing is driven by a neuronal/muscular reflex. It is an involuntary act.

**"I saw nearly complete arcs of three rainbows in the Great Rift valley in Kenya after a band of rain had cleansed the air of dust"**

BEN HALL/NATUREPL

## This week's new questions

**Satellite limits** **To what extent can satellites have satellites? Could our moon have its own moon with its own moon, for example? Is there a limit? *Joe Roberts**, St Austell, Cornwall, UK*

**Frozen flight** **Birds fly at tens of thousands of metres high. Ice forms on the wings of planes at this altitude, so why don't the birds freeze? Jane Pickett**, *Hitcham, Suffolk, UK*

Why don't birds freeze when flying at extremely high altitudes?

## Rainbow riot

**I have seen many double rainbows, but can you get triple or quadruple ones? If so, where are the best places to see them? What is the maximum number that could occur at the same time?**

***Len Winokur***
*Leeds, UK*
We mostly only see rainbows when the sun is behind us. The reason is that light from the sun is internally reflected by the back of raindrops to re-emerge towards us. As it enters and leaves the drop, the white light is split into colours. Redder wavelengths emerge at wider angles than bluer ones, hence why red always appears as the outermost band of the primary bow and violet as the innermost.

Not all the original light escapes first time round, however. Some of it undergoes a second internal reflection before re-emerging. This has three consequences. Firstly, the secondary bow's colours now emerge at wider angles than those of the primary bow, so the second rainbow always appears above the first. Secondly, because it is formed by less light, the secondary bow is fainter. Thirdly, the colour sequence of the secondary bow is flipped, with red now being the innermost band.

Further rainbows do occur, but they are so faint that only in the past decade have these been scientifically confirmed. The caveat with the third and fourth bows is that they would be behind you, so seeing them would require facing the sun, and they would probably get lost in the glare.

From ground level, we never see a bow's full circle because the droplets projecting its lower section are below the horizon. But entire 360-degree rainbows can be seen from the air.

***Hugh Pumphrey***
*University of Edinburgh, UK*
The n-th rainbow is caused by light reflecting n times from the inside of raindrops before escaping. Until recently, there were a variety of claims to have observed a third bow, but few were credible. In the past decade, photographs of third and fourth bows have been taken, emerging when the contrast in the photograph is very strongly enhanced.

***Mike Follows***
*Sutton Coldfield, West Midlands, UK*
The use of laser light has revealed rainbows up to the 200th order in the laboratory, but nothing beats seeing rainbows in the wild.

***Peter Bursztyn***
*Barrie, Ontario, Canada*
Multiple rainbows are best seen in bright sunlight when the air is clear and free of dust. I saw nearly complete arcs of three rainbows in the Great Rift valley in Kenya about half a century ago. The conditions were perfect: a band of rain had cleansed the air of dust, the sun was low on the horizon yet still very bright and dark rain clouds formed the rainbows' background.

I have seen small portions of a third rainbow in various other places, but these never matched the nearly complete triple arc that I was treated to so many years ago.

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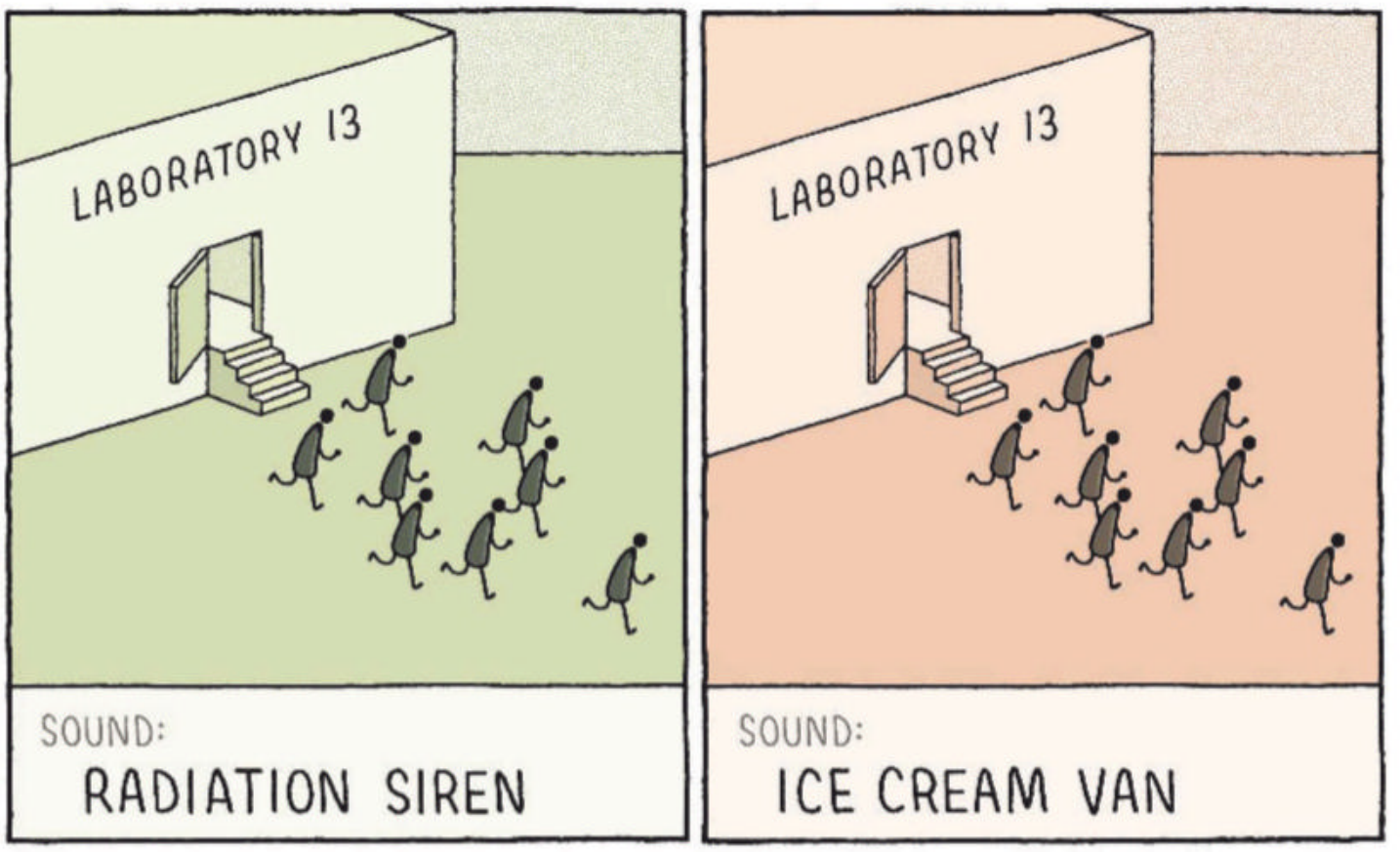
**Tom Gauld**
*for New Scientist*




***Geoff Piltz***
*Eskdalemuir, Dumfries and Galloway, UK*
I have seen a quadruple rainbow on the waterfront at Liverpool, UK. There was a double rainbow with a taller pair of rainbows above it. This second set started at the same apparent origins as the first set, but extended higher into the sky. After consideration, I have come to the conclusion that the first set was created by light directly from the sun, whereas the second set was made by light reflected off the river Mersey.

## Looking back

**Why hasn't evolution given us eyes in the back of our head or rear-view mirrors? (continued)**

***Eric Anderson***
*Wickford, Rhode Island, US*
While the previous answers to this question were good, they missed something.

Many vertebrates have a third or "parietal" eye at the top of their head, including some lizards, frogs, salamanders and sharks. This eye doesn't form images, but it is sensitive to light and dark. The parietal eye may even have developed from a more functional eye or pair of eyes that would have allowed true sight overhead or even to the rear.

**"Some swallowtail butterflies have rear vision. The male can sense light with its penis to help find the right mating position"**

The human pineal gland, which produces melatonin in response to light signals from our eyes, is thought to have originated from the parietal eyes of the non-mammalian ancestor that we evolved from.

Depending on how an eye is defined, it could be that scorpion fluorescence serves as a basic eye. It seems that a scorpion's glow is a by-product of its exoskeleton's ability to sense light – or "see" – hinting that it can tell whether it has left any part of itself visible to predators when it takes cover during the day.

***Peter Jacobsen***
*Davis, California, US*
One species of swallowtail butterfly has rear vision. The male has photoreceptors on its penis that help it position itself for mating. The female can also sense light with its genitals, probably to help her lay eggs in the right place.

***Mike Follows***
*Sutton Coldfield, West Midlands, UK*
Humans have few predators and can use our hearing and the eyes of fellow hunter-gatherers to detect many of them, so there is little evolutionary advantage to expending energy in order to have eyes in the backs of our heads.

Evolution doesn't always find the perfect fit to the environment. But if rearward vision were advantageous, then I think it would be more likely that we would have adapted to turn our heads 180 degrees like owls. ▮

## Answers

### Quick quiz #76
*Answer*

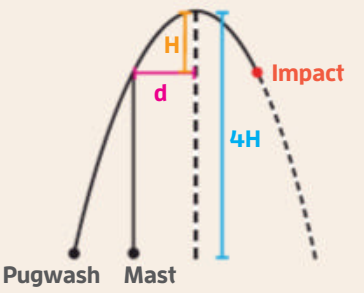
**1** A Dyson sphere
**2** Seven
**3** The Mesozoic era
**4** Chromatography
**5** Quinine

### Cryptic crossword #43 *Answers*

**ACROSS 1** Dog star, **5** Pique, **8** Charm, **9** Bus fare, **10** Faintly, **11** Ankle, **12** Format, **13** Despot, **16** Anode, **18** Lithium, **20** Braille, **21** Meant, **22** Shear, **23** East End

**DOWN 1** Decaf, **2** Glazier, **3** Time traveller, **4** Ribeye, **5** Postage stamps, **6** Quark, **7** Element, **12** Flambes, **14** Primate, **15** Allele, **17** Orate, **19** Muted

### #83 Albatross
*Solution*




If we call the height of the mast 3H, the stone climbed H above that to be 4H above the ground at its peak. A parabola is a "square" function, so the height increases with the square of the horizontal distance. If the top of the stone's path was d from the mast, Pugwash was 2d from the peak. The flight of the stone is symmetrical around the peak, so if the peak is d from the mast, it is also d from the point of impact. So the point of impact is d from the peak, 2d from the mast and 3d from Pugwash, and the stone was travelling at 3/2 or 1.5 times the horizontal speed of the albatross, or 15 knots.

## Heightened interest

Our hats, of which we have very many, are firmly off this week to Frédéric Bouquet and fellow inhabitants of the 15-metre-high Laboratory of Solid State Physics in Orsay, France, for their paper "61 ways to measure the height of a building with a smartphone" (arxiv.org/abs/2010.11606).

We are reminded of an urban legend about a physics student who later turned out to be Niels Bohr. When challenged during an oral examination to describe how he might do something similar with a barometer, he came up with several indubitably correct answers that contributed to getting him failed.

These included lowering the barometer from the roof to the ground on a long piece of string and measuring the length of string plus barometer, and throwing the barometer off the roof and timing how long before it smashed on the ground. The traditionalist within us is pleased to record that both of these methods appear on the team's list, although this does suggest that measuring the height of a building with smartphones, plural, would be a more accurate description.

A mere cavil. We can't fault the comprehensiveness of the research, which employs methods involving free fall, giant pendulums and various acoustic and optical techniques, as well as a section of the most interest to physicists, "methods that only work in theory". Nor can we fail to be impressed by the range of values recorded for the building's height, from zero ("Giant pendulum, using the accelerometer"), to 800,000 metres +/- 100,000 m ("Variation of the Earth magnetic field between the top and the ground").

The method "Variation of gravity between the top and the ground, determined by general relativity time dilation" also returned a value of zero, although with a margin of error of 3 million kilometres either way, leading the researchers to conclude, perhaps ruefully, that "on average, the simpler the method, the more precise the results".

Not consistently, however. Some methods were unable to deliver an answer at all, among them number 61: "Phone call to the building's architect."

## Twisteddoodles *for New Scientist*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## Lower!

"Scientists find new organ in throat while testing for prostate cancer", reports a headline on Sky News. Feedback is disappointed on further reading to find that this wasn't a result of the common doctor's injunction of people presenting with problems down below – "just cough for me" – one that always puzzled Feedback until we mindfully noted the muscular spasm that passes through those areas when we cough. It seems it was actually positron emission tomography that led to the breakthrough, which is real science, but far less fun.

## Bone of contention

A delightful exchange ensued on Twitter after Ben Rathe reported that his wife had fallen foul of software being used to censor language in submissions to a question and answer session at a conference. "One of the words it is censoring is 'bone'," he writes. "It's a palaeontology conference."

Happily, the organisers of this year's Society for Vertebrate Paleontology (SVP) meeting wrote back, tweeting: "Hi all, you'll be pleased to know that 'Hell' and 'bone' are now permitted on the Q&A function #2020svp Please use responsibly!" The tweet included a smiling face and three bone emojis.

Courtesy of our man with the old bones, Jeff Hecht, Feedback has been able to view a full list of words that the software blocked – all, we presume, included in participants' submissions to Q&A sessions.

Largely of a putatively sexual nature, they provide insight into the palaeontological mind. We can only assume that anyone enquiring about "erections" in that context would have unimpeachable intentions, but we are less sure about "enlargement". Also appearing on the list, eliciting varying degrees of polite nodding and smiling on Feedback's behalf, are "stroke", "stream", "knob" and "flange".

That last one causes us to wander down a byway of wondering how words can assume sexual connotations simply by sounding as if they should have them. Perhaps some expert in acoustolinguistics, a research field that we have just made up in hope, can enlighten us as to the quality of these words that makes it so.

But this is by the by. The whole thing reminds us of the recent story reported by the BBC of the Canadian seed and garden supply company whose picture of onions was rejected by Facebook's algorithms for being "overtly sexual".

AIs clearly aren't going to make it far in the saucy seaside postcard industry, but more generally, following recent discussions about artificial intelligence taking our jobs, we are glad of further evidence that, actually, our future jobs will be correcting the job that the AI did.

## Not (yet) in the bag

Allen Young writes in with an advert from our own esteemed organ for the *New Scientist* shop, and a special offer of a free tote bag on all purchases over £20. (Good offer, that, and the bags are very fetching.)

Too late, however – possibly. "Offer valid until 31st October", the advert trills, "or until stocks last".Well, it is past 31 October now, Allen, so we can only suggest you enquire whether stocks have begun to last yet, and if they haven't, claim your free bag. Just don't tell anyone we sent you. ▮

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