Imperial/48

THE MAGAZINE FOR THE IMPERIAL COMMUNITY
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LIQUID ASSET

WHY DETECTING WATER ON JUPITER'S MOONS COULD HOLD THE KEY TO LIFE

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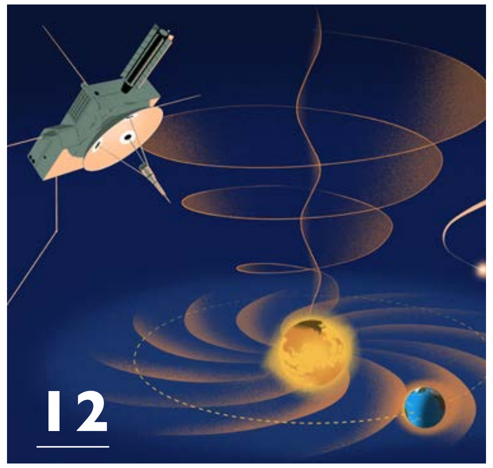

Regulars

Features

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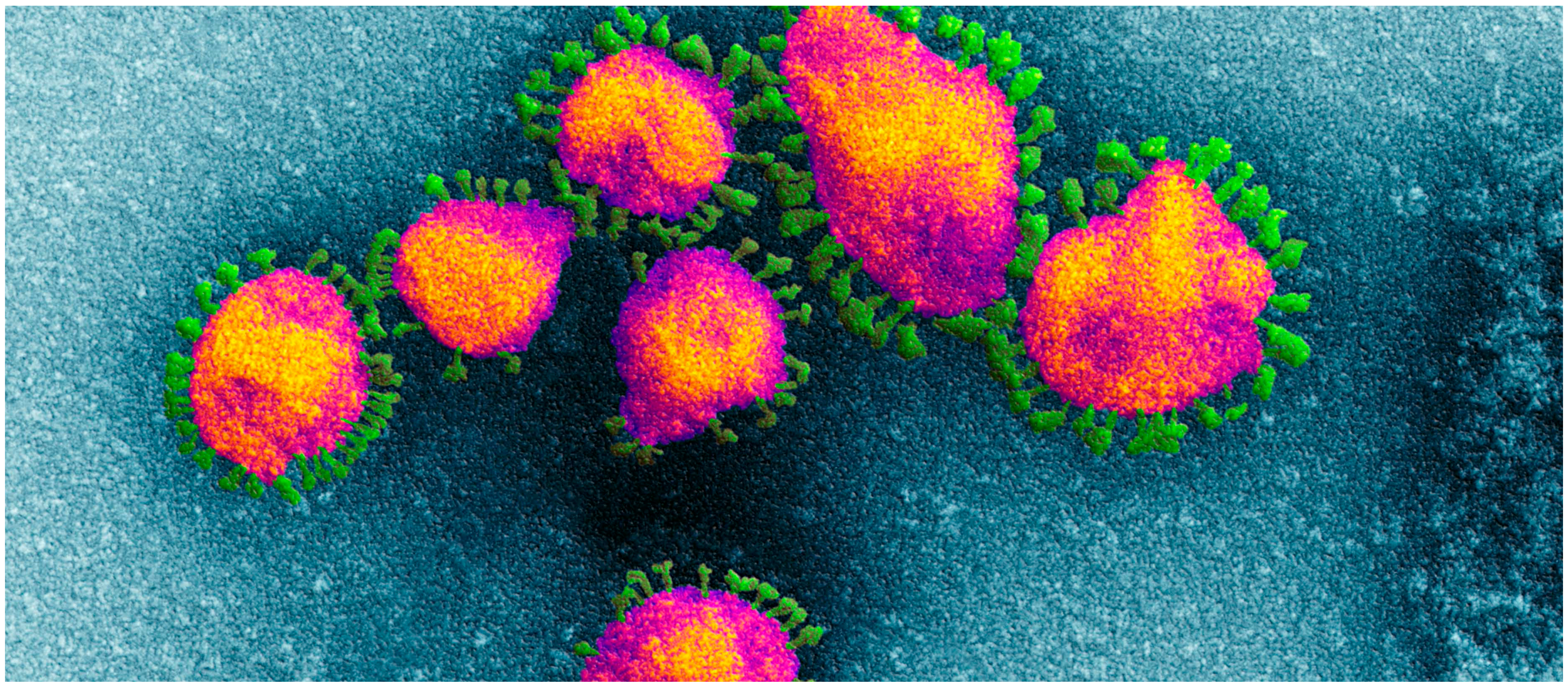

PANDEMIC

Imperial leads on coronavirus response

Imperial researchers continue to be at the heart of the global response to the coronavirus pandemic.

Throughout the crisis they have been playing key roles: epidemiologists are informing global policy makers; immunologists are trialling a COVID-19 vaccine and developing potential new therapies to tackle the disease; virologists and respiratory specialists are analysing the virus and how it affects patients; biomedical engineers have developed high-performance ventilators, as well as rapid-result coronavirus tests; data scientists, AI researchers and health economists are among the many Imperial researchers redeploying their expertise to fight the pandemic; and a multidisciplinary team has set out key regulations for safely designing and building new innovations to tackle COVID-19.

As well as receiving more than £40m worth of support to help fast-track the development of a vaccine, Imperial's own COVID-19 Response Fund provides rapid support to projects with the potential to make a major impact in the fight against the virus.

According to Professor Nick Jennings, Vice-Provost (Research and Enterprise): "The impact of Imperial's COVID-19 work can be seen in labs, newspapers and hospitals across the country, and the support of our alumni, friends and donors will greatly enhance our efforts." ◆

> *www.imperial.ac.uk/covid-news*

Coronavirus particles
The coronaviruses, shown here through a coloured scanning electron micrograph (SEM), take their name from their crown (corona) of surface proteins (green) that are used to attach and penetrate their host cells.

ABOVE PHOTO: SCIENCE PHOTO LIBRARY. ILLUSTRATION ABOVE RIGHT: MIKE LEMANSKI

Letters

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Please mark your letter 'For publication'. Letters may be edited for length.

Tree fellows

Arian Arjomandi Rad's My Imperial story (*Imperial* 47) reminded me of the days when a society with more than ten members got a grant from the Student Union for an amount matching the sum of all membership fees. A group of us formed the I.C. Tree Climbing Soc, membership fee half-a-crown (the cost of a pint of beer in those halcyon days!). We could climb a tree (an easy task) and retire to The Goat, where the treasurer would disburse the fees and the grant by buying each one of us two pints – so we got a 2-for-1 deal. The Union cottoned on after the first year.

Bernard Liengme
(BSc Chem 1960, PhD/DIC 1964)

Newsroom camaraderie

As an ex-editor of *Felix*, I was naturally interested in your article (*Imperial* 47) celebrating its 70th anniversary.

Several of the issues highlighted in the article chimed with me, but none more than the camaraderie of the newsroom, located at the time right at the top of the Union building staircase.

And thanks to the online archive, I have been able to jettison my deteriorating collection of old paper copies and cringe at the witterings of my earlier self from the comfort of my armchair.

David Cooper
(Physics 1967, Chem Eng and Chem Tech 1970)

Antifungal resistance

My thanks for the excellent article on antifungal resistance (*Imperial* 47), a timely and cogent reminder that the fight is against not just bacteria, but fungi too.

I would also like to point out that any of your retired readers can still get involved in the battle against biological resistance by contacting the charity Antibiotic Research UK (www.antibioticresearch.org.uk), where even senior citizens such as myself can still play a useful role!

Keir Hartley
(Life Sciences 1979)

Beware groupthink

In response to your piece on net-zero emissions (*Imperial* 47), I should point out that the mathematical models used to support the conclusions of the IPCC, and the output of most of the media, have been shown to be extremely inaccurate. Yet they and the data are still being artificially manipulated to produce a worldwide political agenda. Honesty, supported by peer group experimentation, can be trusted. Groupthink still awaits justification one way or the other.

Sean Galbally
(Mechanical Engineering 1962)

> ***Keep up with the latest news from the College as it happens,*** *and share your thoughts and news on our Imperial alumni Facebook page and LinkedIn group.*
facebook.com/alumni.imperialcollegelondon
www.linkedin.com/groups/87488

FROM THE PRESIDENT / PROFESSOR ALICE GAST

Towards a better world

Last November, when we were planning the content for this issue, we wanted to cover the critically important and ground-breaking work our colleagues were doing on 'Disease X' – that next great unknown new virus. Little did we know that before the issue went to print Disease X would be upon us, and we would be in a most extraordinary world of lockdowns, social distancing, prevention and protection. There has been terrible loss, and our hearts go out to members of our community, their family members and friends who have experienced death and suffering.

Amid all of this sadness, there have been triumphs. People rallied to support one another in amazing ways. We opened our doors to NHS workers, and our community volunteered to serve in the wards, made face shields and hand sanitiser and designed new ventilators. Our academics doubled down to produce insightful models, create new diagnostics and develop a vaccine. These are the moments when the determination and spirit of our Imperial community really stand out. Our talent, our capacity to innovate and improvise, and our collaborative approach to addressing complex problems come together to produce solutions with global benefits.

On 17 January, a report from Professor Neil Ferguson's group in the Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA) and the MRC Centre for Global Infectious Disease Analysis took the news of the detection of three cases of COVID-19 outside China and calculated, based on flight and population data, that there were far more cases in China than originally thought, that human-to-human transmission was probable and that this was a virus to contend with locally and globally. They recommended "heightened surveillance, prompt information sharing and enhanced preparedness". The swift spread to Europe and beyond brought us to unprecedented worldwide efforts to reduce the impact of the virus on people.

Meanwhile, Professor Robin Shattock was working on a novel vaccine for Disease X. He presented his work on a new self-amplifying RNA

> **Little did we know that before the issue went to print, Disease X would be upon us and our world transformed**

vaccine at Davos in January 2019, and, by January 2020, was in possession of the sequence of COVID-19. With remarkable speed, he and his team were able to generate a candidate vaccine in the laboratory 14 days after receiving the sequence. You can read about this work and other Imperial breakthrough research on page 24.

At my sixth President's Address at the beginning of March, I talked about improvisation and what we could learn from jazz masters. I said that "… three elements – foundations, collaborations and risk-taking – are central to great jazz performances, and, indeed, central to many human acts at the epitome of excellence. I believe that they will make all the difference for us personally, collectively and institutionally."

Jazz improvisation, like any lasting improvisation, does not arise from making things up as you go along. It is a highly disciplined process of building upon what came before, with the goal of finding a new approach that will lead to an improved solution. As we look at the uncertainty before us, our ability to improvise, to be creative by thinking outside the box, is all the more pertinent. Today, dealing with a global pandemic, we 'improvise' based upon our values, our intellect, our experience, our adherence to robust scientific method and our ability to imagine a better future.

Hundreds of my colleagues are improvising as you read this. You will see how they are pursuing solutions to global challenges – from the coronavirus and dark data to net zero emissions in the UK and helping people with dementia. They are also creating exciting ways to transform teaching at Imperial through the innovative use of technology that will provide a safe and high-quality education in the COVID-19 world. Our cover story on the Imperial magnetometer and its great discoveries, from the Sun to Saturn, with a much-anticipated visit to Jupiter, is a chronicle of great collaboration, intellect and persistence.

These stories are a sample of what we see at Imperial every day. I hope that you find them inspiring and uplifting. We are moving towards a better world, even during these difficult days.

All of us greatly look forward to a time when we can meet, in person, once again. ◆

> ***Professor Alice Gast** is President of Imperial College London and is an internationally renowned academic leader and researcher.*

PHOTOGRAPHY: IMPERIAL COLLEGE LONDON/THOMAS ANGUS. OPPOSITE PAGE: PHOTO: BBC. ILLUSTRATION: MIKE LEMANSKI

WINNERS

Challenge accepted

Imperial College London has been crowned this year's champions of the BBC quiz show *University Challenge*, only the third Imperial team to win since 1996.

The team, led by captain Caleb Rich and made up of members Brandon Blackwell, Richard Brooks and Conor McMeel, beat Corpus Christi, Cambridge by 275 points to 105 in the final.

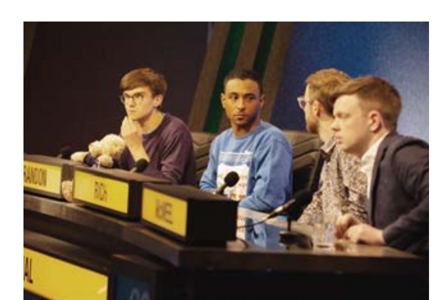
"Our win has been the culmination of many months of practice and hard work," says Caleb, "and I am so pleased to have played with an amazing team of quizzers.

"Brandon really came into his own and shone in the last couple of episodes, but in the final we all played to our strengths and demonstrated a really good team effort.

"It takes a lot to trust one another when you can't confer about the answers, and I think the confidence we had in each other helped us to get this far and, ultimately, to win."

The next team to represent Imperial are in training, with help from the Imperial College Quiz Society and this year's winning team.

> **It takes a lot to trust one another when you can't confer about the answers, and I think the confidence we had in each other helped us to get this far and, ultimately, to win**



42

The Hitchhiker's Guide to the Galaxy says 42 is the answer. But what is the question? Dr Tilly Collins thinks it's whether we should eat more insects.

Want to reduce your environmental footprint? Try eating insects – or at least adding them to our food supply – says Dr Tilly Collins (PhD Biology 2000), a Senior Fellow in the Centre for Environmental Policy.

"Not only do insects grow very rapidly, they are high in micronutrients, so very nutritious, and they produce protein very, very fast – a 21-day life cycle, where for a cow it is three years. By turning our agricultural waste into densely nutritious protein, quickly and in a small space, they are the ultimate recyclers."

The challenge she's tackling now is how to make entomophagy, or eating insects, acceptable in places where it's taboo, while encouraging its expansion in other areas. "We are working on increasing the contribution insects can make to diets in tropical regions, especially West Africa. Entomophagy was an important component of ancestral diets and crop pests are still a high-value item there, but there's less availability because of chemical pesticides."

Alongside Vincent Savolainen, Professor of Organismic Biology in the Department of Life Sciences, Dr Collins is leading a consortium of African scientists to integrate palm weevils into the agricultural cycle. "We hope to help the palm industry become more sustainable, using the agricultural waste for poor and disadvantaged people to grow delicious insect protein."

The team is working on the design of a cartoon guide to weevil farming so that people with different languages and literacy levels can set up simple home farms using a bucket and lid. While British palates are typically less appetised by insects, there are hidden ways to consume them, such as nutrient-rich cricket powder, which can be added to shakes and brownies. They are also increasingly being used as animal feed for fish and poultry, with flies grown on brewery waste such as hops.

Dr Collins is pleased with the progress that's been made so far, and feels optimistic about the future. "Insects aren't a huge source of protein yet, but people are starting to recognise how brilliant they can be for our diets. The amount they contribute to our protein consumption will just keep rising."

> *For more on Dr Collins's research, visit imperial.ac.uk/people/t.collins/publications.html*

IN BRIEF

Gross to lead new research centre
Dr Rob Gross, from the Centre for Environmental Policy, has been named as the new Director of the UK Energy Research Centre, helping the UK towards its net zero target. For more on net zero, see our feature on p30.

Award-winning scientists
Professor Claudia de Rham (winner, Physical Sciences and Engineering) and Professor Matthew Fuchter (finalist, Chemistry) have been recognised in the annual Blavatnik Awards for Young Scientists.

Alzheimer's brain 'atlas'
The Multi-'omics Atlas Project (MAP) to create an 'atlas' of the brain at different stages of Alzheimer's disease has been launched by the UK Dementia Research Institute (UK DRI).
Full details at https://ukdri.ac.uk/news-and-events/mapping-the-alzheimers-brain-major-new-project-to-discover-disease-mechanisms

ALUMNI AWARDS CELEBRATE LEADERS

Inaugural awards ceremony
Game changers and problem solvers were celebrated in the inaugural Alumni Awards, part of Imperial's overall commitment to celebrate outstanding achievements within its community.

Distinguished alumni
Professor Angela Vincent (Westminster Hospital Medical School 1966) and Harris Bokhari OBE (BSc Mathematics 1999) won the Distinguished Alumni Awards, due to their "dedication to improving other people's lives and their ability to approach big challenges head-on".

Emerging alumni
Six of the next generation of game changers under the age of 40 were recognised in the Emerging Alumni Leaders Award, for their outstanding achievements or the substantial impact they are making on society.

> *Find out more at bit.ly/outstanding-alumni*

ENTREPRENEURSHIP

Imperial innovates

Lewis Hornby *(MSc Innovation Design Engineering 2018)* is the founder of Jelly Drops, offering a unique solution to dehydration in dementia sufferers.

Dehydration is one of the 'hidden' dangers of dementia and it can be life-threatening. Making sure people with dementia drink enough water is difficult, something I've seen first-hand with my grandmother. Many with dementia don't feel thirst, or might not associate being thirsty with needing to drink. They may not even recognise what cups are for, or struggle to grip them properly. It's a big problem – and because dehydration reduces cognitive ability, it also makes it more difficult to eat or communicate.

A couple of years ago, my grandma, who has dementia, was admitted to hospital – doctors told my family and me to expect the worst. However, after 24 hours on IV fluid she was back to her normal self. It turned out that she'd just been dehydrated. I was shocked that something so simple could have such a huge effect on her health.

I decided that my graduation project would be a great opportunity to try to help Grandma and others like her. I started by living in her care home for a month. I quickly realised that while many struggle to drink, they all loved sweets! After some experimentation on how to get as much water into a tasty treat as possible, I came up with Jelly Drops. They're sugar-free sweets that are 95 per cent water, with added electrolytes. When I first offered them to my grandma, she ate seven in 10 minutes – that's the equivalent of drinking a glass of water, which would usually take hours and require much more assistance.

There's huge demand for the product – a video of my grandma eating them went viral and led to a lot of media coverage. What people seem to like about Jelly Drops is that they don't carry the same stigma as some other products designed for people with dementia, which can be medicinal or infantilising.

My time at Imperial was fundamental to the project. They definitely push you to make ideas a reality, and give you the tools you need to start a business. Since graduating, I've been working on making a scalable commercial product alongside my former coursemates, Nick Hooton and Claudia Arnold. That's probably the biggest benefit of the course, meeting like-minded people who are willing to take a punt on an idea. It can be a bit overwhelming at times, but having a team means you're not trying to work it all out on your own.

When we started, we applied everything we'd learned from the Imperial Enterprise Lab about how to pitch and get investors on board. After graduation, we joined the Imperial Venture Mentoring Service, which means we have two great alumni advisors who are always available on email or at the end of the phone. We also received a Research Innovator grant from the Alzheimer's Society, which was a massive boost and helped us to finish our first factory ahead of the launch.

The potential for Jelly Drops is huge. The product can not only help the 850,000 people in the UK with dementia, but we've also had interest from many others, such as people with Parkinson's disease going through chemotherapy. The demand is also international, with about half of the 40,000 people on our waiting list coming from America. The plan for this year is to keep scaling up production to meet current demand and get into new markets as soon as possible. ◆

> *Find out more at www.jellydrops.co.uk*

PHOTOGRAPHY: HANNAH MAULE-FFINCH

A drop in the ocean
Lewis Hornby is working flat out to meet the demand for his Jelly Drops.

EDUCATION / DR KATHARINA HAUCK
READER IN HEALTH ECONOMICS

Our new online course is helping to give science a voice – and to show why it matters

PHOTOGRAPHY: IMPERIAL COLLEGE LONDON/THOMAS ANGUS

The first time we heard exactly what the COVID-19 pandemic would mean for our society was a truly chilling moment. It was in a video filmed in late January, originally intended to show what the Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA) was working on. But within a couple of days of being posted, the interview went viral.

In sharing the video, we showed that science matters – that knowledge can be a comfort for people. Amid all the confusion that was swirling around events in China at the time, here was a moment of clarity about what was coming. We could show that the virus was predictable in some ways – that it follows rules of mathematics and statistics. And if we understand these, we can forecast to a degree what will happen and put measures in place, instead of reacting as if a dark cloud is coming towards us.

We knew there would be a real and urgent need to show how science works, and that we could show the progression of the outbreak – and give people a real insight into the science – through a new, online course. Together with Professor Helen Ward, Oliver Geffen Obregon and a fantastic team from the Digital Learning Hub, we launched the free course, Science Matters: Let's Talk About COVID-19, on the online platform Coursera, featuring experts from Imperial who are analysing the disease.

We wanted to be authentic, to show the uncertainty, the trial and error as science develops – and then embrace it, learn and improve continuously. So, while in hindsight some of the videos on the course may have had the wrong emphasis or lacked precision, they were based on the best evidence at the time. Now we have further built the course and shown how we reached certain conclusions, how reality differed and where science provided good insight.

The course includes Situation Reports where researchers provided regular updates on the COVID-19 response. One module looks at how to model transmission dynamics,

> We wanted to be authentic, to show the uncertainty, the trial and error as it happened, and then embrace it

and another examines how to help healthcare prepare for a surge in demand. Another shows how important it is to communicate with and involve the community, both in person and on social media. We also look at the spread of misleading information, the 'infodemic'.

Participants include interested clinicians and policy makers, and people with an academic background. Rather than a practical course, it looks at the hurdles of dealing with a pandemic. It has a real documentary aspect – going beyond a fixed textbook. More than 100,000 people have signed up – it is Imperial's most successful course ever in terms of enrolment.

On the Coursera platform, it was the most popular course launched since our relaunch in March, and adds to a growing library of open content from the School of Public Health on Coursera's learning platform. The School has launched a number of open specialisations that form part of Imperial's first fully online public health degree – the Global Master of Public Health – which is also available via Coursera.

I think scientists have a duty to be impartial and inform debate as much as we can. There's a lot of information out there. We are providing estimates and forecasts of something that has never really happened before. The future is uncertain and we need to always communicate the uncertainty around our estimates. In 1918, people wouldn't have known what had hit them when the Spanish flu struck. But now science has helped countries make the decision to close their borders even before they'd experienced a single death.

Our insight is that we will be trying to control this epidemic until a vaccine is found. Countries differ in the control policies that they choose; science is there to provide unbiased advice. Science matters, as it helps people make decisions. ◆

> ***Dr Katharina Hauck** is a Reader in Health Economics at the School of Public Health and the MRC Centre for Global Infectious Disease Analysis (MRC GIDA), and Deputy Director of the Jameel Institute.*

Looking out
Dr Annalisa Alexander and her green van outside the Outreach classroom.

ADVENTURES IN...
DR ANNALISA ALEXANDER / HEAD OF OUTREACH

Spread the word

Former plant ecology student Dr Annalisa Alexander now cultivates talented young people wherever they may be – helped by Imperial's talented undergraduates.

Words: **Megan Welford** / Photography: **Emli Bendixen**

The Imperial Outreach team is on the brink of world domination. It has 700 schools on its books, astronaut Helen Sharman in its crew and a bright-green van ready to bring Imperial science to the masses.

But it wasn't always this way. When Head of Outreach Dr Annalisa Alexander (PhD 2004) joined the Schools Liaison Office in 2004, there was just one programme – the Pimlico Connection, a partnership with a local school. Now there are mentoring programmes, tutoring, numerous school partnerships, a summer school, science activities in schools, a dedicated lab, a community space ... and the van, of course.

As a doctor of plant ecology, Alexander was perhaps just the right person to grow Imperial's outreach. Although she had planned an academic career, when her PhD funding ran out in 2003 she took a job in Imperial's newly founded Volunteering Centre – and found her passion. "I discovered all these talented students who were not only academically gifted but wanted to share their knowledge. They were asking, 'How can I go and teach maths in schools?'" So, when the liaison job came up, she grabbed it. "It's not so different from plants – outreach is like a greenhouse. We have a hunger for nurturing things carefully, watching them grow."

Alexander cultivates using a sense of wonder. "As a scientist myself, I know how important and exciting it is to study science, but kids don't always see that. When final-year engineering students go into A-level maths classes, kids are asking, 'What's the point of imaginary numbers?' The student can say, 'Well, we use it for wing design', and straight away that's more engaging. You start the year with pupils who aren't that interested, but by March they're flying. And peer pressure is very strong for teenagers, so we work with teachers to pull under-performing students into the spotlight and see what they can do. It's about raising aspiration."

She gives the example of one student who came from a school in Holland Park, and a family in which no-one had gone to university – and who now works at CERN. "He was a quiet student but very bright and the school didn't know what to do with him. He wasn't getting the right nourishment. We tutored him and he ended up coming to study particle physics at Imperial before going to CERN. I smile when I think of it."

Alexander says she is "insanely proud" of Imperial's outreach. "My pleasure now is that students who came through our programmes come back to us and say they want to do mentoring. We're forming a big outreach family."

It's a growing experience for the Imperial students who volunteer, too. "They might know chemistry and be very bright, but being able to translate that for kids is quite a skill."

As well as having its own "incredible spaces" for school pupils aged five to 18 – the Wohl Reach Out Lab at the South Kensington Campus and the Reach Out Makerspace at the White City Campus – the Outreach team has also been able to provide a wealth of resources for families to learn at home during the recent lockdown period. For instance, Reach Out Reporter and Reach Out Continuing Professional Development offer an online primary school science news service and 30 pre-prepared courses for teaching five- to 11-year-olds.

"But as soon as we can we're looking forward to jumping in the van and getting back out there," says Alexander. "We're bringing outreach to your space, saying, 'We're Imperial, we do science and we're really cool.'" ◆

NEXT STOP: JUPITER

As Imperial's magnetometer team starts work on JUICE, the European Space Agency's mission to Jupiter's icy moons, due to launch in 2022, we explore the science behind magnetic fields and why they have the power to tell us so much about space.

Words: **Becky Allen**
Illustrations: **Señor Salme**

Is anybody out there? Answering the question about where life in our solar system does – or could – exist is one of science's biggest questions. But sometimes the answers to big questions come in the most unexpected places. It might look like something you could piece together in the kitchen, yet the fluxgate magnetometer has been behind some of the most astonishing discoveries of the space age.

Data recovered from magnetometers has revolutionised our ideas about where life might exist elsewhere in the solar system and beyond, revealed the structure of the Earth's magnetic field, and helped us understand how the solar wind – the charged particles that stream from the Sun – can have such a devastating effect on life on Earth.

"What makes magnetometers so fundamental is that most of outer space has a magnetic field linked to it," says Professor Michele Dougherty, Professor of Space Physics. "To have a chance of understanding the environment there, you need to understand its magnetic field – it's a fundamental quantity. If you don't understand the magnetic field, then you can't understand how the different processes that take place in the atmosphere and environment around other planets work."

Developed during the 1930s, fluxgate magnetometers were widely used during the Second World War to protect ships from submarine attack. Nearly 90 years later, the essential principles remain the same. Made from a doughnut-shaped magnetic core wrapped in two lengths of copper wire, an electrical current pushes the core into magnetic saturation – first one way, then the other – thus revealing the size and direction of a magnetic field. But, instead of hunting for the magnetic signatures of submarines, today's magnetometers are routinely launched into space in search of more interesting quarry.

Professor David Southwood (PhD Physics 1969), Senior Research Investigator and former President of the Royal Astronomical Society, explains: "Most objects – from the Sun to many of the planets – have either their own magnetic field, or interact with the solar environment in such a way that you get a lot of magnetic disturbances around them. So, a magnetometer is going to be required for almost any mission leaving Earth."

And some of the most high-profile missions in recent times have been heavily influenced by Imperial scientists such as Professor Southwood and, earlier, Professor Andre Balogh. Described as the "godfather of the instrumentation side of the group", Professor Balogh helped establish the College's stellar reputation for magnetometer science – he founded Imperial's Space Magnetometer Laboratory in the 1980s and paved the way for all future work, including the very latest mission, the Solar Orbiter.

In February, Senior Instrument Manager Helen O'Brien and her team oversaw the launch of the Solar Orbiter magnetometer, which blasted off from Cape Canaveral and is heading to the Sun to investigate the development of planets and how life begins.

"Although the technology has been around for a long time, the big difference now is the performance we're trying ▶

ULYSSES 1990

Ulysses was a joint ESA-NASA mission launched in 1990 on the Space Shuttle Discovery, and was the first spacecraft to traverse the north and south poles of the Sun. Imperial's Space and Atmospheric Physics Group had interests in two instruments on Ulysses: the magnetic field experiment and the Anisotropy Telescope.

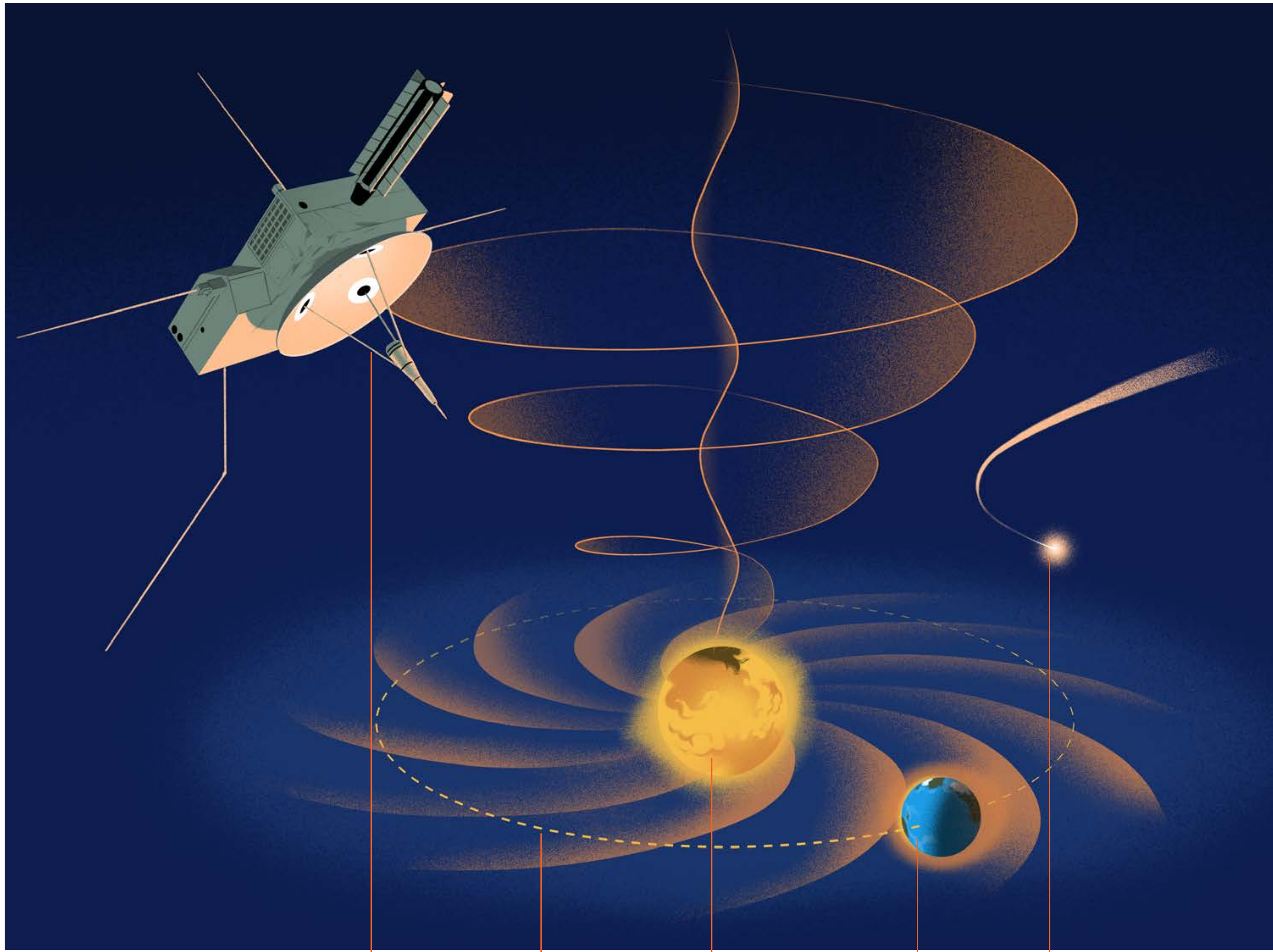


Illustration not to scale

Polar orbit
After its cruise to Jupiter, Ulysses' orbit over the poles of the Sun allowed the spacecraft to measure the solar wind flowing from very high solar latitudes, which had not been achieved previously.

Magnetic field
Ulysses found that the solar magnetic field at the Sun's poles is much weaker than previously thought.

The Sun
In more than 18 years in service, Ulysses made almost three complete orbits of the Sun and revolutionised our understanding of the heliosphere, the region of space surrounding the Sun.

Earth orbit
Since its launch in October 1990 to the end of the mission in 2009, the spacecraft travelled more than 5,400,000,000 miles.

Hyakutake comet
The spacecraft's May 1996 encounter with the comet Hyakutake revealed the tail was far longer than expected, providing unique information about the conditions within cometary ion tails.

CLUSTER 2000

Cluster was the first mission to study the magnetosphere in 3D. Since they were launched in 2000, these four identical spacecraft, flying in pyramid formation, have revealed a wealth of data about the Earth's magnetosphere and its complex relationship with the solar wind.

A TIMELINE OF MAGNETOMETER TECHNOLOGY AT IMPERIAL

"Developing magnetometers has been a flagship activity for Imperial for many decades," says Professor David Southwood, the original Principal Investigator on Cassini. "I've always felt the way we do things is special. As a mixture of scientists and engineers working together we get more out of it than we could alone." Here's a potted history of Imperial's role in magnetometer development.

1962: Imperial's Cosmic Ray and Space Physics Group builds the cosmic ray detector for Britain's first satellite, Ariel 1. Harold Macmillan named the satellite, deciding on Ariel, the spirit of the air in Shakespeare's The Tempest.

1967: Europe's first satellite ESRO 2 is launched with a trio of Imperial-built instruments.

1968: The launch of HEOS-1, the first European spacecraft to venture beyond the Earth's magnetosphere. The magnetometer, built by Imperial, makes a major contribution to mapping the Earth's magnetosphere.

1978: Imperial builds particle detectors for the NASA mission ISEE-3. Redirected to the comet Giacobini-Zinner in 1984, ISEE-3 performs the first fly-by of a comet by a spacecraft.

1990: The NASA-ESA mission Ulysses launches from the Space Shuttle Discovery with an Imperial magnetometer. The first spacecraft to traverse the north and south poles of the Sun, Ulysses discovered that the Sun's magnetic field flips from south to north every 11 years.

1996: The Cluster mission – four identical spacecraft with four Imperial magnetometers – blows up 40 seconds after launch, dealing a near-fatal blow to magnetometer science at Imperial.

1997: Cassini – the NASA-ESA mission to Saturn and its moons – launches. Cassini reaches Saturn in 2004 and the following year its magnetometer discovers water-rich plumes venting from the moon, Enceladus, allowing scientists to rethink their search for life beyond Earth.

2000: Partly re-built from flight spares in four short years, Cluster is relaunched successfully. The first mission to use four spacecraft flying in formation – an idea developed by Professor Jim Dungey, former head of the Space and Atmospheric Physics Group at Imperial – Cluster is able to study the Earth's magnetosphere in 3D. Thanks to Cluster, our model of the Earth's magnetosphere is now based on data rather than theory, and Cluster is helping us defend satellites and power grids against damaging space weather.

2020: Solar Orbiter launches on its long voyage to the Sun. The ESA mission is carrying ten instruments – including an Imperial magnetometer. Solar Orbiter will answer big questions about how the Sun creates and controls the giant bubble of plasma that fills our solar system.

2022: JUICE due for launch. When it arrives in 2031, its Imperial-built magnetometer will hunt for signs of life on Jupiter's moon, Ganymede.

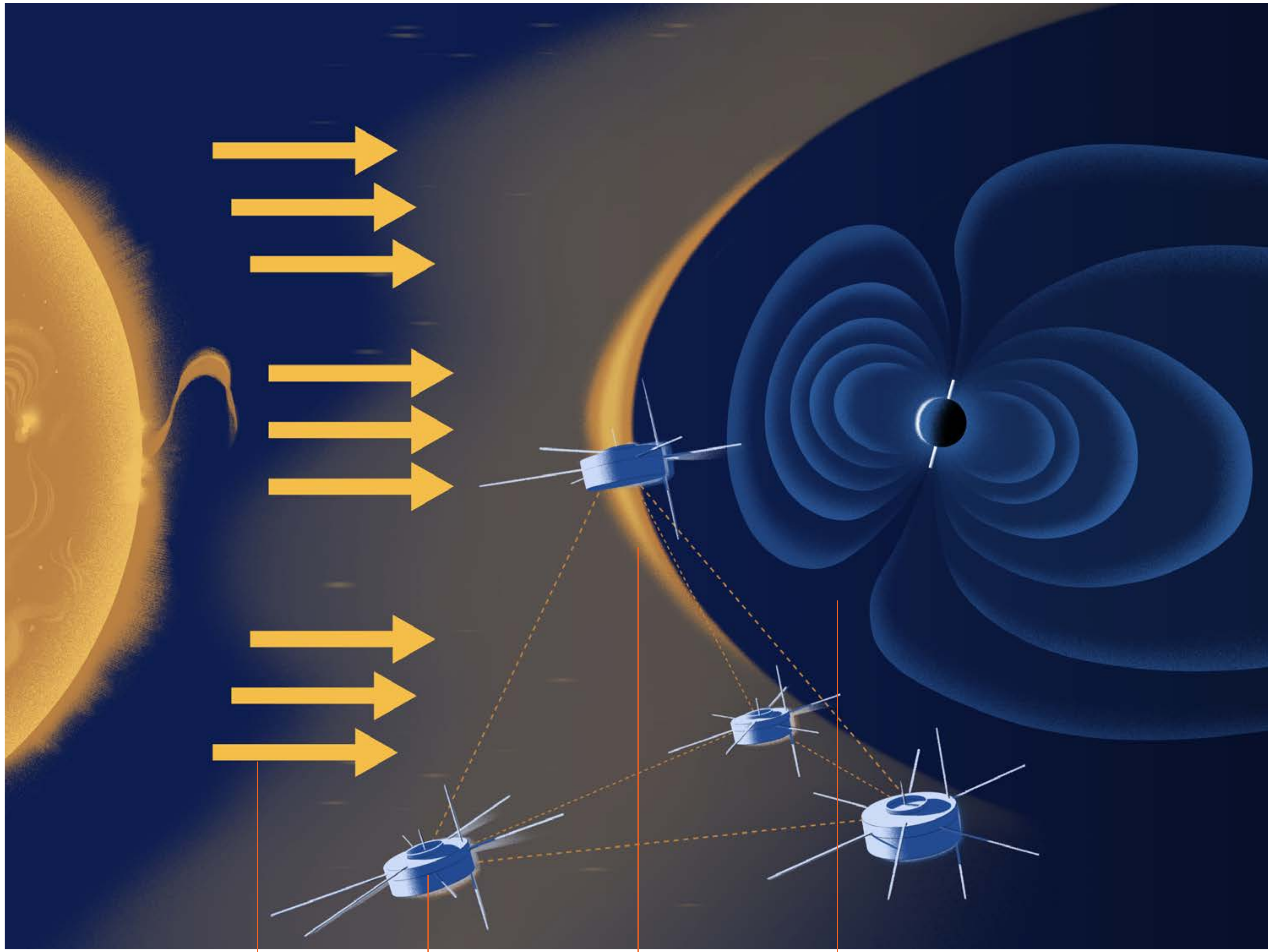
to squeeze out of them," says O'Brien. "We're working at temperatures and in high radiation environments that are breaking new ground. The fields we want to measure with Solar Orbiter, for example, are 50,000 times the equivalent we measure on the surface of the Earth. So, we're getting much better at extracting small resolution from the instruments we have."

Making major discoveries, including the unexpected, is in the Space Magnetometer Laboratory's DNA. The ESA Cluster mission – a quartet of spacecraft launched in 2000 to study the Sun's impact on the Earth's space environment – was the first to study the Earth's magnetosphere (the region of space surrounding an astronomical object dominated by its own magnetic field) in 3D.

Cluster provided the first 3D measurements of the structure and motion of the 'magnetic boundaries', which separate the magnetosphere from the impacting solar wind. This is important because the solar wind causes what's known as 'space weather', the climatic conditions that can have an effect on Earth by knocking out satellites and power grids, for example.

And, in 2005, another Imperial-built magnetometer, this time on the Cassini mission to Saturn, made its greatest discovery so far. Less than a year after launch, Cassini's magnetometer picked up strange signals from one of Saturn's moons. The data seemed to suggest that icy plumes were issuing from Enceladus, so Professor Dougherty, who was the Principal Investigator for the magnetometer, flew out to NASA to argue the case for a closer fly-by.

"After they agreed I was so excited. Then as the fly-by approached I was terrified," Professor Dougherty recalls. "If we hadn't found anything, no-one would ever have believed me again. The team took a chance. It was based on the science, but we weren't certain of what we were seeing. We were brave and it paid off." ▶



Solar winds
The Cluster orbit took it deep into the solar wind. It enabled the investigation of the Earth's magnetic environment and its interaction with the solar wind in three dimensions.

Cluster spacecraft
The four spacecraft were arranged in a 'pyramid' shaped formation so as to allow 3D measurements of the plasma.

Magnetosphere
Output from Cluster greatly advances our knowledge of space plasma physics, space weather and the Sun-Earth connection, and has been key in improving the modelling of the magnetosphere and understanding its processes.

Impact on Earth
The cusps are where Earth's magnetic shield is vulnerable to plasma from the solar wind leaking in to the magnetosphere, which drives effects such as the aurorae and potential disruption to communication and satellites on Earth.

Illustration not to scale

The fly-by revealed that beneath Enceladus's icy crust lay a liquid ocean, a discovery that has revolutionised our understanding of where else life might be able to form. Until 30 years ago, scientists assumed the only place in our solar system that you'd find water was closer to the Sun. Hence the hunt for life, or evidence that it once existed, on Mars.

But the fact that Cassini's magnetometer discovered liquid water on Enceladus – the moon of an outer planet – means life could form in lots of other places further from our Sun, and other suns.

Today, Professor Dougherty and a small team of engineers in the Space Magnetometer Laboratory are working on their biggest challenge yet – making the magnetometer for a new mission to Jupiter. Due for launch in 2022, the JUpiter ICy moons Explorer (JUICE) will explore the giant planet and three of its moons: Europa, Callisto and Ganymede.

JUICE will be the first spacecraft to go into orbit around an outer planetary moon and, although it will take more than eight years to get there, the prospect is tantalising. "I'm not renowned for my patience," she admits, "but it's essential if we're to understand whether life might be able to form in the outer solar system. For habitability, you need liquid water, a heat source and organic material, and for all three to have been stable for a long enough period. We think that could be happening on Ganymede."

Patrick Brown, Senior Instrument Manager on the JUICE magnetometer, is the engineer responsible for making it happen. Over the past 23 years at Imperial, Brown has worked on magnetometers for six missions, tailoring each for different environments. For JUICE, the challenges are hair-raising. To deliver Professor Dougherty's data, the magnetometer must be tough enough to withstand huge variations in temperature and massive doses of radiation, yet sensitive enough to detect tiny changes in magnetic field.

If we hadn't found anything, no-one would ever have believed me again. The team took a chance. We were brave and it paid off

"Jupiter has the largest planetary magnetic field in the solar system, and it has these big moons, one of which is full of volcanoes spewing out material that gets accelerated and trapped in the magnetic field. That means an intense radiation environment – like going through a nuclear reactor," says Brown.

While Brown is in the maelstrom of the design and build phase, O'Brien and Professor Tim Horbury (BSc Physics 1992, PhD 1995), Principal Investigator of the Solar Orbiter magnetometer, can only watch and wait as their instrument heads for the Sun, closer than any previous European mission. "We're going closer to the Sun than Mercury, so we'll be able to measure the solar wind when it's young and fresh," says Professor Horbury. "That will give us a better understanding of how it's formed – as well as the damage that space weather can do to satellites and electricity grids on Earth."

The list of scientific successes highlights what makes the Space Magnetometer Laboratory special. The small, close-knit team has championed magnetometers since the start of the space age. Its degree of specialisation – it typically only builds one flight instrument per mission – is unusual, and its experience unrivalled. And its combination of world-class engineering with world-class science sets it apart.

"Our unique success is down to the fact that, at Imperial, we're good at exploiting both the science and the instruments," says Chris Carr, now head of the lab. "It keeps us at the heart of missions and it lets us produce great science. It's a truly virtuous circle." ◆

> ***To find out more**, visit www.imperial.ac.uk/stories/mission-to-the-sun*

CASSINI 2005

Cassini was an international venture involving NASA, the European Space Agency (ESA), the Italian Space Agency (ASI), and several separate European academic and industrial partners. Its mission was to explore Saturn and its moons.

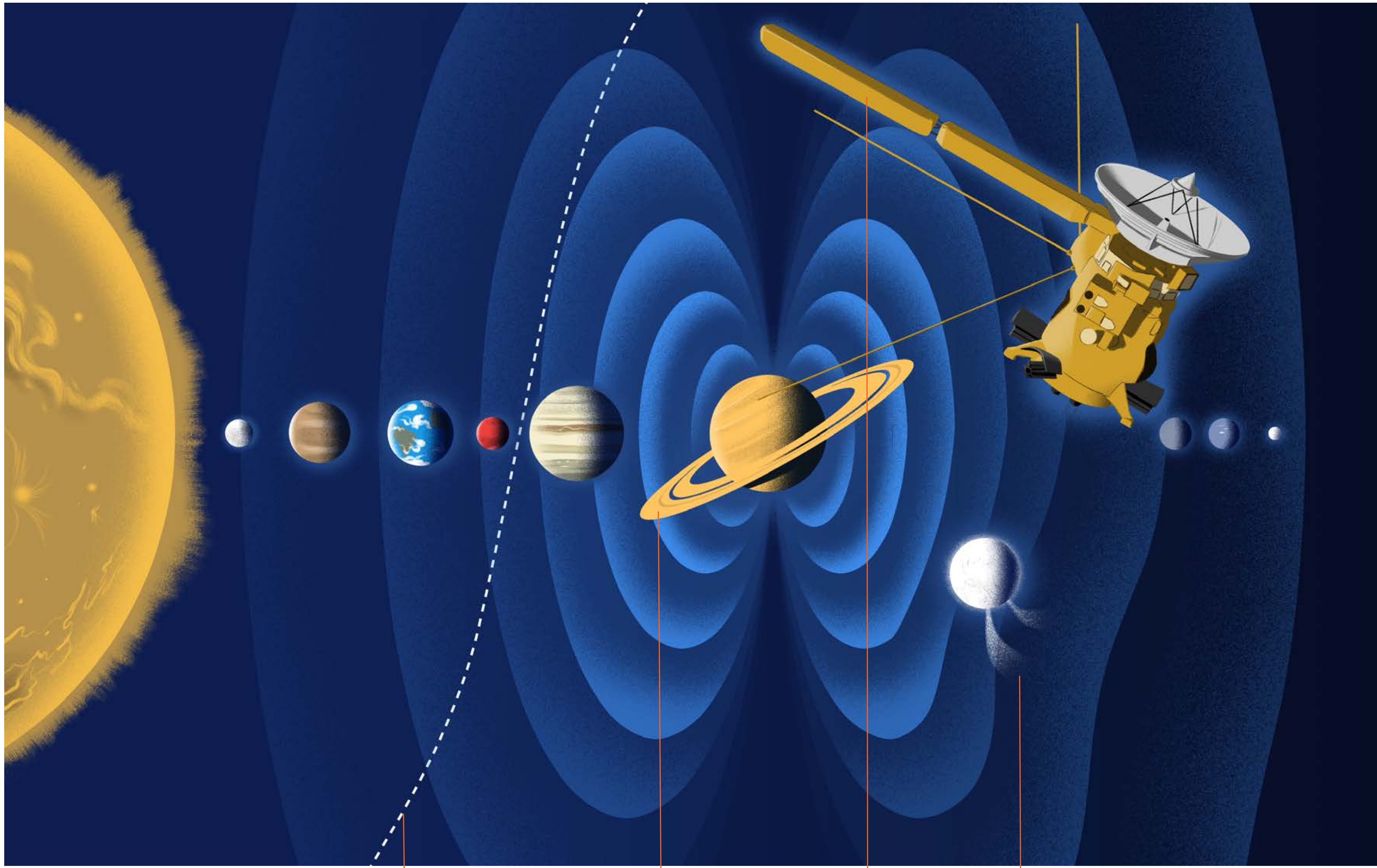


Illustration not to scale

The snow line
Cassini revealed that we should not simply focus on planets close to the Sun, where liquid water is found only on the surface, for potential habitability, but also beyond the 'snow line'.

Saturn
What Cassini found at Saturn prompted scientists to rethink their understanding of the solar system.

Cassini magnetometer
Before Cassini, scientists thought that to find life, they'd have to look much closer to the Sun. Cassini's magnetometer showed us that life might exist on moons orbiting outer planets like Saturn.

Icy plumes on Enceladus
The magnetometer found water vapour coming off Enceladus, one of Saturn's moons, revealing a liquid water ocean under the crust. It also discovered organic matter and a heat source – the remaining components for habitability.

Seeing is believing and believing is seeing

From hologram lectures to the gamification of pure maths, technology is transforming teaching at Imperial.

Words: **Megan Welford** / Photography: **David Vintiner**

Field trips to Mars. Hologram lectures and virtual anatomy lessons. Fluid dynamics experienced in real time, from within the flow. It sounds like science fiction, but for Imperial students it is becoming their everyday reality, as the College leads the way in blending the classroom and the digital world.

"Hologram technology has a very long history at Imperial," says Dr David Lefevre (MSc Computing 2002, PhD Management 2011), Director of the Edtech Lab at Imperial College Business School, "so when I read about a Canadian startup enabling holographic speakers, I immediately thought we could use that for education. We developed it and held our first event – a Women in Tech conference – in 2018 with holographic speakers, including Marily Nika (MSc Computing 2008, PhD 2014), Google's Computer Programming Manager. The new technology means the speaker can maintain eye contact with the audience – wherever they are – and respond directly to questions."

Blending teaching between digital and the classroom is all about finding the right medium for the right subject, says Dr Lefevre. "I never really liked the lecture theatre," he says. "Talking to a wall of students, there's very little interaction – it's quite a passive ▶

experience for the students. I used to think, I might as well show a video of myself. In a lab, or in the discussions we have around business case studies, it's different – it depends what you're trying to teach. But when I started teaching online, I found I was having very meaningful interaction with the students – I would set a problem and they'd work through it and ask questions. My job became to guide them through the material."

This approach has worked particularly well for mathematics. "To do an MBA you need at least A-level maths, but our students come from a wide range of backgrounds, with vastly differing experiences. We used to bring them in early for a week of intensive maths, face-to-face, nine-to-five. It didn't work. Now it's online, they go at their own pace. They have to study 15 hours of material over three months. We employ teaching assistants to answer their questions and they can book in for a tutorial. From the data, we get a strong sense of who's struggling, and we work with them one-to-one if we need to. We now have a 100 per cent pass rate – it's solved a significant problem for the Business School. I got an email from a father saying, 'That is the first maths test my son has ever passed!'"

Omar Matar (MEng Chemical Engineering 1993), Vice-Dean of Education in the Faculty of Engineering and a Professor of Fluid Mechanics, is developing a deeper understanding of fluid mechanics and maths by using virtual reality. "Have you ever dived into a swimming pool?" he asks. "We know how it feels and sounds, so watching someone else dive in just doesn't compare." Matar worked with a postdoctoral computer scientist to create 3D animations from equations and import them into a virtual environment. "We then created a platform where you could load different flows and then dive right in! If there's a bubble rising you can travel around it, look at the flow field, hear the pressure, experience how the liquid moves."

Students were, understandably, very excited. "It takes a few sessions to get used to it – some people get motion sickness! But we soon had people from all over the College hanging around the lab wanting to try it. There was a feeling of disbelief. Students said it didn't feel like 'education', it felt like a games arcade."

Matar and his team learned the gaming software language, Unity, to link the programme to learning outcomes. "So, you get points to unlock levels, and there is positive competition between players. You get sucked into the game and then find yourself doing more and more pure maths and equations. We're squeezing in the learning."

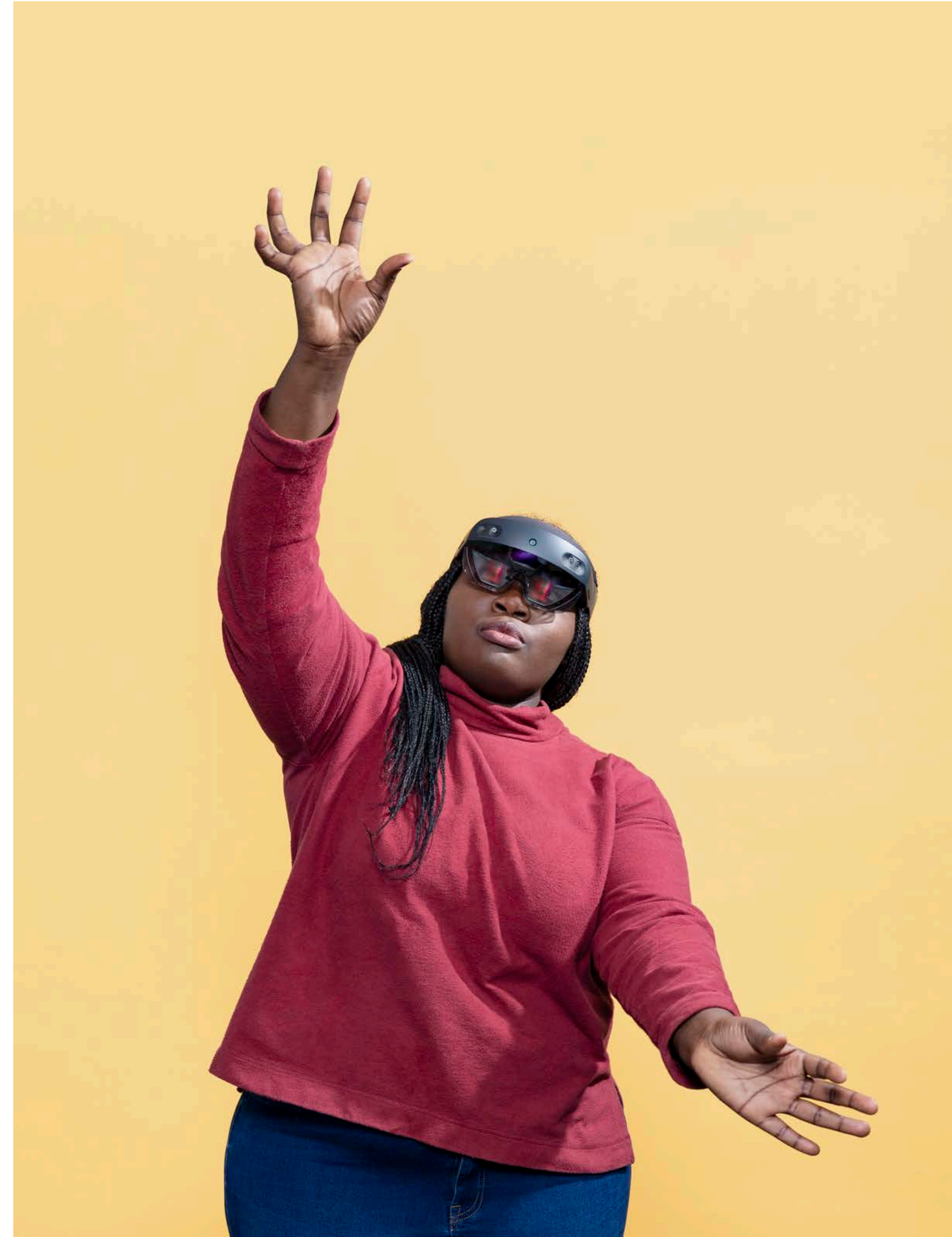
Mixed reality

As New Media and Innovation Lead at the Digital Learning Hub, Thomas Hurkxkens tests immersive technologies such as virtual and augmented reality and supports teachers in using these technologies for teaching and learning. Using smartglasses such as a HoloLens, for example, means medical students can study the anatomy of the human body in 3D and in motion, including carrying out a virtual biopsy.

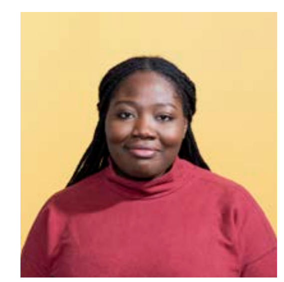
"A HoloLens is a good example of the strength of immersive technologies," says Hurkxkens. "It's a mixed reality, where students can work with the digital object and the real-world object at the same time. In the case of the biopsy application, students see a virtual torso and needle, projected over a real-world body-phantom. Using the real and virtual needle together, they can perform a biopsy without the need of a CT scanner. This gives students and trainees more time to practise when and where they want, and we expect that this gives a deeper, embodied understanding of the procedure. It's learning by doing."

Students can also use the HoloLens to project skin conditions on to each other's bodies, he says, which means they can examine each ▶

If there's a bubble rising you can travel around it, look at the flow field, hear the pressure, experience the liquid move



Aiman Binti-Ahmad-Dzulfakhar
Studying: MEng Chemical Engineering, third year.
What equipment? VR headset to explore fluid mechanics.
The experience? Incredible! I could experience the conditions of the fluid, such as pressure and speed, by being in the fluid virtually and not just seeing it in 2D. It's learning on another level.



Ayomide Ayorinde
Studying: Medicine, fifth year.
What equipment? Augmented reality smartglasses to explore a segment of a human spine model.
The experience? Once you really get into it you can easily get lost in the awesomeness of it all. Being able to view the model from all the different planes was very, very cool, and I definitely wish I had had access to it in my earlier years of medical school.

other, bringing social interaction into the learning experience. Medical and Chemistry students alike can get a 3D view of a molecule. And Earth Science and Engineering students can go on field trips… to Mars! "Together with Professor Sanjeev Gupta and team, we are designing a project where we use data from the Mars Rover," Hurkxkens says, "so students can explore the planet's surface together."

The use of these technologies in education is growing, but there are still many areas that need further exploration. At the Digital Learning Hub, for instance, the aim is to bring students, researchers and partners together to build on each other's expertise through things such as the Immersive Technologies Initiative, a web portal for students and teachers and partners to connect, learn and exchange ideas.

Experimental classroom

These technological possibilities mean there's a learning curve for teachers, of course, and even a change in the nature of teaching. "Teaching becomes less of an individual activity and more about co-creation, where teachers work with developers and even students to develop courses," says Gideon Shimshon, Director of Imperial's Digital Learning Hub. "One teacher said that she was surprised that, in the experimental classroom, there is no screen or lectern, so instead of using a PowerPoint presentation she had told a story and asked students to draw it – with better results than the traditional approach. It can lead to different kinds of teaching."

Digital tools can also scale up learning and make it available far beyond the physical classroom. "Online, we can give a lecture to 10,000, instead of 500," says Shimshon. "And with open content, we have hundreds of thousands of people taking our online courses. We are mission-driven at Imperial: we want to contribute to the global challenges of lack of access to education and healthcare. We have an online A-level maths course that is free, so anyone can do it. On our online Public Health Master's programme, students are in 24 different countries – we're building a global public health community."

Shimshon says not everything is scalable, though, and his team is still exploring the limits. "A book is scalable," he explains, "but the classroom experience of guiding you through the book, giving feedback and assessing, isn't. With tech, we are merging the classroom and the book. Continuous assessment is the best kind, and tools for this would free up teachers for better teaching and research.

"People like Dr Amir Sam, Head of the Undergraduate School of Medicine, are developing multiple-choice questions to a state-of-the-art level that will really test learning in healthcare. But how you test learning is the subject of scholarly work itself. We do need to be able to prove these new techniques work – we're training doctors here!"

Matar has a plan to prove it, and to go a step further. He and his colleagues are beginning to collect data through specialised VR headsets equipped with eye-trackers and EEG electrode caps that could make teaching and learning a completely bespoke experience. "Through the headsets we can see what the students see," he explains. "With eye trackers, we see where they look, and we can track how they perform in VR. If we can link what they are seeing with their neural activity, through brain-computer interfaces such as EEGs, we can correlate behaviour with cognition. Then, with AI and machine learning, we can make content adjustments on the fly. So, the teaching would be tailored to the way the student learns." Matar and his team are going for a proof of concept this year. Watch this space – through your headset. ◆

Words: **Lucy Jolin/Becky Allen**
Photography: **Thomas Angus/Dave Guttridge**

TOGETHER, WE CAN

IMPERIAL'S RESPONSE TO COVID-19 HAS PUT DATA AND EXPERTISE IN THE HANDS OF POLICY MAKERS AND GOVERNMENTS AROUND THE WORLD, INFORMING DECISION MAKING AND SAVING LIVES.

Developing the vaccine
Professor Robin Shattock (left, shown here with research technician Leon McFarlane) heads one of the few labs in the world developing a coronavirus vaccine.

From taking a vaccine from bench to bedside in a matter of months to epidemiological modelling that has saved thousands of lives, Imperial is at the frontline of the response to the COVID-19 pandemic. Its experts are influencing policy, driving innovation, keeping the public informed and working tirelessly, work that has been central to governments and healthcare services around the world as they respond to the pandemic.

Back in January, the common assumption was that the coronavirus threat was animal-to-human and could therefore be contained. But using data from airports and airlines, Imperial researchers were the first to show that human-to-human transmission was probably at work, and that the then unnamed coronavirus was likely to be deadly.

It was a vital insight, but no accident. Imperial had been getting ready for this new challenge for years. "All the way back to the 2003 SARS epidemic, through avian flu, the influenza pandemic of 2009, and Ebola and Zika, we've been providing public health decision-makers the best possible analysis of what threat a new disease causes," says Professor Neil Ferguson of Imperial's School of Public Health. ▶

In 2018, the World Health Organization published its blueprint for research on priority diseases. Alongside the likes of Zika, SARS and Rift Valley fever, the WHO added a new threat – Disease X, a pathogen, still yet to emerge, that could cause the next human pandemic. In December 2018, Imperial and the Coalition for Epidemic Preparedness Innovations (CEPI) formed a partnership to protect against Disease X.

Then, in late 2019, the Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA) was set up to bring together the College's rapid response to emergencies such as pandemics, extreme climate events and natural and humanitarian disasters. The epidemiological response was led by Professor Ferguson and other world-leading researchers such as Nick Grassly, Timothy Hallett, Katharina Hauck, Christl Donnelly, Azra Ghani and Steven Riley from the Jameel Institute and Imperial's MRC Centre for Global Infectious Disease Analysis (MRC GIDA).

Throughout, Imperial researchers have sought to bring expertise and data to bear, sharing their research and methodologies in order to maximise the global response. Nowhere has that been more powerful than in the expert modelling – opened up by the College for scrutiny from some of the world's leading coders – that has helped to provide vital data and projections to scores of governments and policy makers around the world. "The Imperial model, as we've been following this for weeks, was the best, most accurate model," said Andrew Cuomo, Governor of New York State – one of the many governments around the world to use Imperial modelling to inform their response.

Now, as the world adjusts to a new normal, it is the vaccine work of Professor Robin Shattock that is in the spotlight. Over the past few years, Professor Shattock and his team of Imperial virologists have been steadily advancing a new concept in vaccine technology: a self-amplifying RNA vaccine. When COVID-19 emerged, they swiftly obtained its genetic code from China and, within 14 days, had a candidate vaccine to test on animals and prepare for human trials.

This astonishing speed is possible in part due to the revolutionary nature of the RNA vaccine technology developed at Imperial, where new genetic code, carrying an instruction to make, in this case, a protein found on the surface of coronavirus, is injected into the subject. "Your muscle becomes the factory that makes the vaccine that triggers your immune system to make protective white cells and antibodies," says Professor Shattock. Early findings have shown that animals given the vaccine are able to produce neutralising antibodies against the novel coronavirus SARS-CoV-2, the virus strain that causes COVID-19.

The team is currently developing the vaccine further to include human safety trials. While the UK government has provided more than £40m in total to fast-track this vaccine development, donations of more than £4m have been raised for Professor Shattock's vaccine work – with a further £29m in philanthropy required to carry out international clinical trials to enable widespread deployment of the vaccine by 2021. Meeting this timeline would break all records. However, with additional dedicated funding, it is achievable.

"We are working as fast as we can to determine the vaccine's efficacy and to get to a position where millions or billions of the vaccine can be manufactured rapidly," says Professor Shattock. "We are tremendously grateful to the UK government, the British people for their investment in this vital work. We are also thankful for the philanthropic support to the College itself that has helped us navigate funding blockages and which we hope will allow us to make this vaccine available worldwide, including to people in low- and middle-income countries."

While work continues on a vaccine, testing is critical to tracking the virus, understanding its epidemiology, informing how patients are treated, and to suppressing transmission. And here, too, Imperial's expertise is being harnessed across medical diagnostics, silicon-chip technology and materials science to deliver COVID-19 testing that can be affordably mass-produced and administered effectively at scale.

Professor Christofer Toumazou, founder and chief scientist for the Institute of Biomedical Engineering, is pioneering work that can deliver COVID-19 test results in just over an hour without the need for a laboratory. It's based on technology developed by Professor Toumazou for DnaNudge, an Imperial spinout that enables on-the-spot genetic test to be carried out for the first time, using a sample from a cheek swab. The technology has already been shown to be effective in early trials and is now entering larger trials with COVID-19 patients, with the ultimate view to roll out across the UK.

Understanding how the virus spreads will be crucial to its future management. COVID-19 is very likely to have jumped to humans from bats, though it's not clear if it then found its way into another animal with close human contact and crossed the species that way. How can the risk of animal-to-human virus transmission be minimised? Professor Wendy Barclay, Head of the Department of Infectious Disease, is working on ways to prevent novel viruses from ever reaching humans at all.

Visor production
Dr David Miller, Project Lead Support, was just one of many Imperial volunteers who made more than 50,000 disposable visors for Imperial College Healthcare NHS Trust hospitals.

Her fundamental research into influenza and how it spreads is likely to prove crucial to understanding how COVID-19 spreads – and how to stop it. Because of their simplicity, viruses need to use a raft of resources from the host cell in order to replicate. In 2016, Professor Barclay discovered the identity of one of these key resources. "It turned out that this protein is absolutely essential for influenza virus and, if you generate cells in the lab that don't make this protein, they can't be infected with influenza any more," she explains.

Then there are basic questions to be answered about how the virus actually behaves: who is most at risk? Why? What's the best way to diagnose it? What's the best way to treat it? What role does the immune system have in protection – and in potentially causing harm?

"This pandemic has highlighted a number of crucial questions for which researchers, healthcare professionals and, crucially, the public and patients, need answers," says Peter Openshaw, Professor of Experimental Medicine at the National Heart and Lung Institute. He's one of three national co-leads on the International Severe Acute Respiratory Infection Consortium study (ISARIC 4C) funded by the MRC.

Professor Openshaw and his team are working with colleagues to collect clinical data and samples from more than 15,000 patients with COVID-19 admitted to 166 hospitals throughout the UK. Some of these samples have already been analysed by scientists at Imperial. "We hope our work will underpin a huge range of research going on in the UK and provide a clearer picture of the illness and its risk factors," says Professor Openshaw. ▶

CORONAVIRUS VACCINE RACE

STAGE ONE Within weeks of the first cases of COVID-19, scientists in China sequenced and shared the genetic code of the SARS-CoV-2 virus.

STAGE TWO The Imperial team used this code to produce strands of DNA in the lab – these hold the building instructions for 'spike' proteins on the outside of the virus. The DNA is built into loops of genetic material (called plasmids) to produce copies of the self-amplifying RNA.

STAGE THREE The final vaccine is delivered as RNA strands in lipid droplets. To check if the vaccine is safe and effective, the team first needs to see if it produces an immune response in animals.

STAGE FOUR The vaccine can 'amplify' itself inside the body, meaning it makes copies of the instructions it contains (in the form of RNA). Once injected into muscle, the cells should produce copies of the coronavirus protein, which will be picked up by the body's immune system as a threat.

STAGE FIVE When immune cells come across these proteins, they will react by creating antibodies to fight off the danger. But they also create a lasting memory of the threat for any future attack.

STAGE SIX The hope is that the vaccine will train people's immune systems to recognise and defend against SARS-CoV-2. If they come into contact with the virus in future, they should be ready to fight it off, giving them some protection against COVID-19.

STAGE SEVEN Having an effective vaccine would enable us to protect the frontline health workers who are dealing with patients. But it could also be extended to the general population.

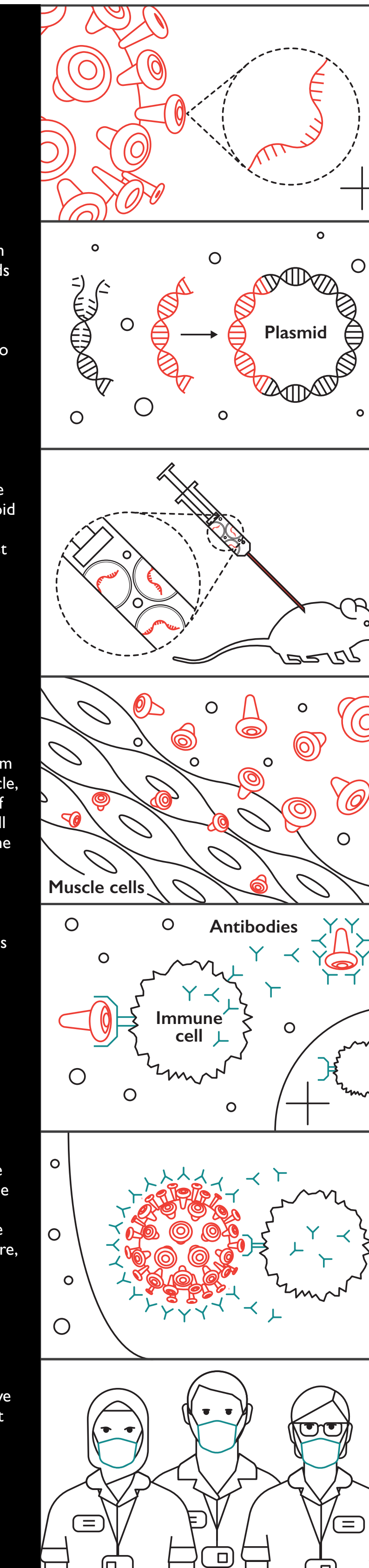


ILLUSTRATION: IAN DUTNALL

Imperial leads the way
Professor Wendy Barclay (left), Action Medical Research Chair in Virology, pioneers work into how respiratory viruses spread. The finger-prick antibody test (below) being developed by Professor Ara Darzi helps to improve understanding of virus infection rates and will inform future action to manage its spread.

And there is vital work being done outside the lab, too, combating the flood of misinformation and fake news that has spread along with the virus. Imperial researchers have partnered with the online learning platform Coursera to offer a free online course, "Science Matters: Let's talk about COVID-19". Currently the most popular course launched on Coursera in 2020, it's attracted 68,000 learners and 1.2 million page views so far. It features experts from the Jameel Institute explaining the theory behind the analyses of COVID-19 and its spread, and how to interpret new information using core principles of public health, epidemiology, medicine, health economics and social science. New content is being developed in real time as more information becomes available.

"Lockdown restrictions are having a dramatic impact on all aspects of life, and now more than ever we need to understand the science underpinning the response," says the Jameel Institute's Professor Helen Ward, Director of Education at the School of Public Health. "In this rapidly changing world, the Imperial College School of Public Health is doing its utmost to study the pandemic in real time in order to inform policy, and through this online course we are also sharing our learning and methods with tens of thousands of people across the globe." ◆

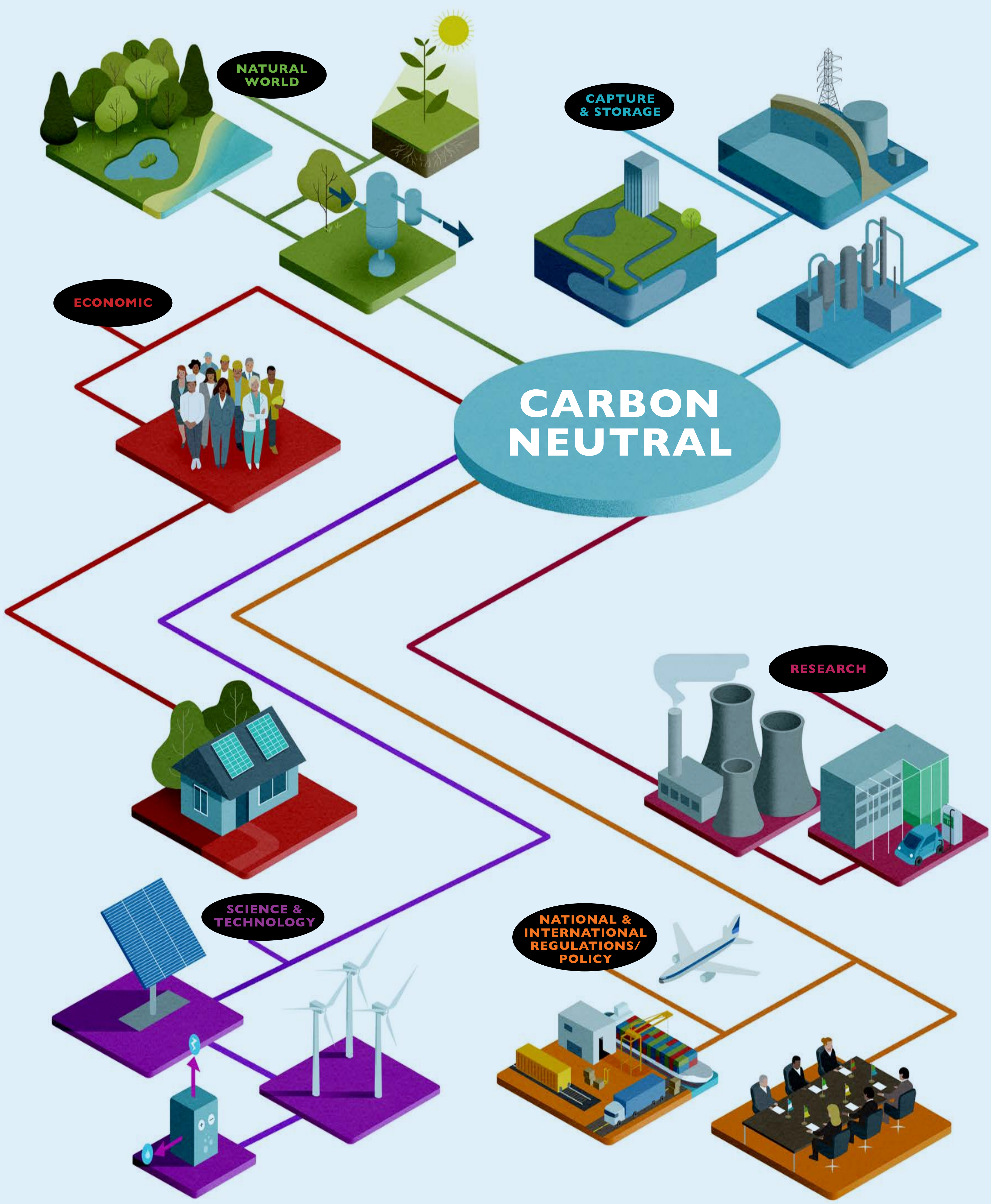
> *Imperial's critical work has been propelled forward by a combination of public funding and philanthropy. Hundreds of alumni, friends and staff have come together to provide rapid support for projects across the College through the Imperial College COVID-19 Response Fund and with specific funding for vaccine development and diagnostics. To find out more, please visit www.imperial.ac.uk/giving/covid-19-response-fund.*

WE HOPE OUR WORK WILL UNDERPIN A HUGE RANGE OF RESEARCH IN THE UK, AND GIVE A CLEARER PICTURE OF THE ILLNESS AND ITS RISK FACTORS

Turning convention on its head: how to reach net zero in the UK

BECOMING CARBON NEUTRAL BY 2050 WILL REQUIRE ALL PARTS OF SOCIETY TO COLLABORATE, AS IMPERIAL RESEARCHERS ARE DEMONSTRATING.

Words: **Lucy Jolin** / Illustration: **Andrew Lyons**



Natural world
Greenhouse gas removal methods in the natural world include forestation, habitat restoration, biochar and soil carbon sequestration, as well as enhanced terrestrial weathering and mineral carbonation (accelerating the conversion of silicate rocks to carbonates to provide permanent storage for CO_2).

Capture and storage
Some greenhouse gas removal methods have built-in storage, while others require a separate activity to store the CO_2, such as bioenergy with carbon capture and storage (BECCS), which utilises biomass for energy and captures the CO_2 emissions, and direct air capture and carbon storage (DACCS).

Economics
Many of the greenhouse gas removals methods in discussion are expensive to deploy. The rate of roll-out will need to be rapid, particularly in the 2030s and 2040s, and will require significant policy support. Economic mechanisms could establish markets and assist efficient resource allocation.

Research
A key action is to pursue research into the greenhouse gas removal potential of various activities not yet demonstrated at scale (for instance, biochar) as well as carbon capture and storage options, along with Imperial's own research efforts in the carbon and electric car industries.

Science and technology
Includes solar power and wind power, along with electrolysers. Cost, scalability, security and environmental impacts of greenhouse gas removal methods are often poorly understood, limiting their application and requiring research and development.

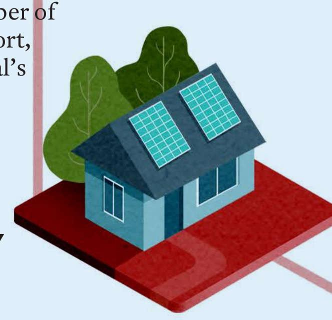
National and international regulations/policy
Emissions and removals (and their reporting) are governed under national and international legislation, and these will all have a significant impact on outcomes, particularly in terms of, for example, the supply chain of international trade. ▶

Last summer, the UK became the first G7 country to legislate for net zero carbon

– the state of overall balance between carbon dioxide (CO_2) emissions produced and emissions taken out of the atmosphere. An amendment to the Climate Change Act increased the target to reduce greenhouse gas emissions from 80 per cent to 100 per cent by 2050. It is an ambitious objective, and not one that can be reached by reducing emissions alone.

"Reducing emissions becomes harder and harder to do once we reach a certain level: in the UK (where total emissions were around 364 million tons in 2018), we might get to a low emissions economy with between 80 to 150 million tons of carbon dioxide equivalent still being released to the atmosphere," says Professor Nilay Shah (MEng Chemical Engineering 1988, PhD 1991), Head of the Department of Chemical Engineering. "To go from there to net zero means having technologies that will take in air and scrub out the greenhouse gases."

Carbon capture essentially means trapping carbon dioxide at its emission source, transporting it to a storage location – usually deep underground – and isolating it. But achieving net zero is a huge task. From the fine details of tree-planting to technical breakthroughs in underground storage, and from global financial implications to the details of translation, there are any number of problems, processes and pathways. In short, it's just the kind of challenge that Imperial's experts relish.



However, according to Professor Shah, the simplest solutions to carbon capture are right here now, all around us. "It doesn't require us to invent anything exotic. It's more a question of practical ▼ landscape management." Take trees, for example: along with getting rid of carbon dioxide, they also provide a multitude of other benefits, including improving the climate and biodiversity of an area.

"A well-managed forest with trees grown in rotation will produce wood that can be used in construction, and that's yet another way of capturing carbon. The carbon that was in the atmosphere goes into the wood. Then the wood goes into a building, and that carbon is locked away for a long time," says Professor Shah. "The only downside is that trees aren't going to be enough on their own. We'd need an awful lot of trees!"

Then there's biochar, a charcoal-like material produced when agricultural materials are partially combusted. It's carbon-negative: when biochar is used in soil, it traps carbon there while also improving the soil's quality. Restoring coastal wetlands and peatlands will also improve the landscape's ability to take up carbon dioxide, as will reducing ploughing in order to disturb the soil less.

"In the last two years, I've seen a big change in the attitude of large companies," says Professor Shah. He cites the example of the Drax power station, a large biomass and coal-fired power station in North Yorkshire that aims to get to net zero in 2030 by burning wood pellets from sustainable forests and utilising carbon storage technology. "We're also working with a very big company I can't name yet that has made a huge commitment in this area. For many aspects of science and technology, this will be a golden age. Carbon capture is a big and complex thing but it is also really exciting, enthusing and engaging."

Core carbon capture and storage technologies are nothing new, says Dr Niall Mac Dowell, Reader in Energy Systems. Most of them were first deployed between 1900 and 1930, and are used all over the world today. "But there's more to this kind of system transformation than just engineering technology," Dr Mac Dowell points out.

"Nobody is doing this for charity. The service being provided will be for removing CO_2 from the atmosphere. And to do that effectively, we need to develop the institutions and frameworks for the monetisation and commercialisation of these services, and for appropriately valuing them."

For example, a ton of carbon stored underground will eventually become rock. The risk associated with its removal is zero. Use trees to capture carbon, however, and the risk rises: trees can die from pests, disease or fire. "So how do we design a level of risk to that stored carbon, and price it appropriately? How many trees do you have to plan for to remove a ton of CO_2?"

Last year, Dr Mac Dowell's lab won a grant from the

EU's Horizon 2020 research and innovation programme to grapple with questions such as these, working out how this new system might be designed – and how to make it fair, equitable and, most importantly, practical. "We'll be looking into how deploying negative emission technologies interacts with the rest of the energy system," he says. "And we'll also be studying how we can make this transition in a way that benefits our broader society."

The transition is often framed in terms of trade-offs, Dr Mac Dowell points out, but it doesn't have to be that way. "I would argue that it's unlikely – even with the experience of the current crisis – to be broadly socially acceptable that we have to drastically and rapidly change our lifestyles. So, we need to design transitions that aim to maximise growth. "We are creating new industries and economies that will result in the creation and preservation of jobs and communities across the world."

The energy transition cannot happen immediately, points out Geoff Maitland, Professor of Energy Engineering – even by 2050, at least 20 per cent of our energy sources globally, and maybe up to 50 per cent, will still be fossil fuels. So how do we decarbonise these fossil fuels? Ten years ago, Maitland founded the Qatar Carbonate and Carbon Storage Research Centre (QCCSRC), a collaboration between Imperial College London, Qatar Petroleum, Shell and the Qatar Science and Technology Park, part of Qatar Foundation. It aimed to deepen understanding of how carbon can be efficiently stored underground in depleted oil and gas reservoirs and water-permeable rock formations called deep saline aquifers.

"This programme focused on how we can ensure both depleted oil and gas reservoirs and deep saline aquifers have the capacity to safely store the ten gigatons of CO_2 that we've got to store by 2050," says Professor Maitland. "The big concern with this method is that when you put the CO_2 down there, it stays there."

They used x-ray imaging tomography at both the micropore scale and the larger core scale to examine the fluids inside rocks. "And we identified the trapping mechanisms in a way people hadn't understood before," says Professor Maitland. "The natural seals of low-permeability rocks have kept oil and gas in place for millions of years. The CO_2 gets trapped by capillary forces in the same way that oil does; it's trapped by surface tension. Injecting it requires high pressure, but not too much, otherwise you fracture the rock, and we did a lot of work identifying this window." Once injected, the CO_2 gradually dissolves into the fluids in the rock, and eventually turns into carbonate minerals, trapping it permanently. ▼

Achieving net zero is a huge task – just the type of challenge that Imperial's experts relish

The project has already spawned numerous papers and take-ups in the field and paved the way for the large-scale adoption that will be needed by 2050. "We have 20 to 25 large-scale projects worldwide now, and by 2050 we're going to need about 5,000 or more," says Professor Maitland. "That's a big jump – but the technology exists."

Having practical knowledge and solutions to reach net zero is one thing: getting them out there into the real world is quite another. That's where the Grantham Institute for Climate Change and the Environment comes in.

"We are a bridge between the technical knowledge that we have at the university, the business and the policy community, and the general public," says Alyssa Gilbert, the Institute's Director of Policy and Translation. "We help them to make use of all that knowledge to make evidence-based decisions that can help deliver solutions today and in the future. We listen to those people so we can understand their queries and then we design information responses."

The recent Science in the City programme, for example, took Imperial's experts into different City firms to talk about the technologies that will need to be implemented to deliver net zero emissions goals. "We got some very good, insightful questions about the technology's strengths and weaknesses," Gilbert says.

"That informs a firm's ability to make investments in those technologies. And that's what we want to see – the shift of finance and investment from the things that damage our environment to the things that can solve our environmental challenges. It's really exciting when we're in the room with people who have access to funding decisions, asking us questions that we think can move the tide of money in the right direction."◆

DARK DATA. BRIGHT LIGHT.

PROFESSOR DAVID HAND SAYS THE 15 TYPES OF DARK DATA WE CAN'T, OR CHOOSE NOT TO, SEE COULD HAVE A DEVASTATING IMPACT ON OUR DECISION-MAKING.

A lot of stories about data – be they popular stories about big data, open data or data science, or technical statistical books about how to analyse data – are about the data you have. They are about the data sitting in folders on your computer, in files on your desk, or as records in your notebook. In contrast, this story is about data you don't have – perhaps data you wish you had, or hoped to have, or thought you had; but, nonetheless, data you don't have.

I believe that these missing data are at least as important as the data you have. Data you can't see have the potential to mislead, sometimes with catastrophic consequences. But, perhaps surprisingly, you can also use the dark data perspective to flip the conventional way of looking at data analysis: hiding data can, if you are clever enough, lead to deeper understanding, better decisions and better choice of actions.

So, what exactly are dark data? They might be blanks in a data set, they might be data you didn't think to collect, they might be the details in data that are too heavily rounded, or they might be data which are hidden from you for some other reason.

Some are very familiar, such as the non-respondents in surveys, or data from people who drop out of a clinical trial. Others are more subtle, such as selective dropout of companies from financial indexes, or abandoned phone calls to the emergency services, or ceilings on values from some measuring instruments, or the opinions of the man I came across who handed his phone to his five-year old son to complete a web survey. ▶

The fundamental problem is that the data you don't see might be very different from the data you do see. It means that basing your analysis solely on the data you have in front of you can lead to dramatically mistaken conclusions and poor decisions. And it affects both small and large data sets.

One of the most devastating small data examples is the well-known case of the Challenger Space Shuttle, where a calculation showing problems with the seals between the booster rockets' segments omitted data on launches that had had no problems. Including those extra data gave a dramatically different picture, and one which could well have led to a delay in the launch, with the saving of seven lives.

An early example of large data I encountered was a consultancy project involving many millions of financial transactions, with the aim of building a model to decide which customers were low risk and should therefore be given a loan. Statistical models of default risk are based on analysing previous customers, where their behaviour and outcome (whether they defaulted or not) is known. The problem is that previous customers have already undergone a selection process – they were presumably given loans because they were thought to be low risk. They are unlikely to be representative of the population of future applicants. A model based solely on previous customers could be seriously misleading.

These two examples illustrate the dangers of dark data: the data you see may not give a full picture. The same problem arises with econometric models built during benign economic periods. You don't have a full picture of potential variability, and when things deteriorate (the 2008 financial crash, for example), the performance of the models may degrade. Physicists use the term 'cosmic variance' to describe the same idea: since we observe only a part of the universe, and at only one time, making statements about the universe on a wider scale is difficult.

In scientific experiments, decisions must often be made about which data points to retain and analyse. We might be suspicious about departures from the ideal experimental conditions when some of the measurements were taken, and consider dropping some data. Different choices of values to include, with the excluded ones constituting dark data, can lead to different overall experimental results. The case of Robert Millikan and whether or not electric charge came in discrete quantities is a classic example.

Millikan asserted that he had included all his experimental results in his analysis ("This is not a selected group of drops but represents all of the drops experimented upon during 60 consecutive days"), but his notebooks told a different story. In fact, as I describe in my book *Dark Data: Why What You Don't Know Matters*, the truth seems to be that the values he excluded were obtained while he was calibrating his measurement procedure.

The Millikan case involves a small data set in modern terms, but as data capture and data storage have become easier and cheaper, so more and more larger and larger data sets have been kept. This often means that the data are accumulating without being looked at.

Indeed, the term 'dark data' is sometimes used in a restricted sense to describe data an organisation has collected but hasn't yet analysed – data stored in metaphorical filing cabinets gathering dust but possibly containing all sorts of treasures. But this is a fairly innocuous kind of dark data. Most dark data – data whose values you don't know or perhaps even data you don't know you are missing – are potentially much more serious. It is this kind of data which have led to business failures, as is illustrated by the fact that lack of data about the intended market is one of the prime causes of failure of startups. Sometimes data generation occurs at such a rate that it is impossible to store it all, and numbers can arrive so rapidly that selection is necessary on the fly, often using quick and dirty selection methods.

This means there is always the possibility that the discarded data might contain interesting discoveries. In the Large Hadron Collider, for example, about 30 million particle collisions occur per second. This is so many that data for only around 1,200 are saved. As an article by Ethan Siegel in *Forbes* magazine put it: "We may have collected hundreds of petabytes, but we've discarded, and lost forever, many zettabytes of data: more than the total amount of internet data created in a year." While the more interesting processes are selected, it inevitably prompts the question of whether the 99.996 per cent of the data which are dark contains useful information.

The term dark data comes from an analogy with astrophysics, when it was discovered that galaxies rotated more quickly than they should, according to our understanding of gravity. An explanation was devised in terms of 'dark matter': something which had mass but which was invisible to electromagnetic radiation, so we could not see it. It is now thought that 23 per cent of the universe consists of this dark matter.

Dark data come in many flavours. They might be the values not measured in an experiment because the instrument had a ceiling beyond which it could not register, or the events that occurred too rapidly for your detector to register them. They might be data missing from medical records because the topic was sensitive and people didn't like to mention it. Data collected about people often allows them to opt in or opt out of having their data collected, leading to potential distortion of the overall data set. In my book I give a taxonomy of 15 different types of dark data.

If dark data are ubiquitous and have potentially very serious consequences for understanding and for actions, what can we do about it? How do we know we have something missing? And does it matter? Is it misleading us, and how seriously?

Statisticians have developed tools to answer these questions. They are based on the general principle of using the data you do have to tell you about the data you don't. Again, dark matter illustrates this: it was the data on galaxy rotation that led to the detection of dark matter. But the critical thing is to be aware of the dangers of what you don't know.

However, and here's the good news, it's not all downside. Surprisingly, you can actually use dark data to your advantage, enabling you to make better decisions and gain greater understanding – think blinding in clinical trials and blind analysis in physics to avoid bias, for example. I call this the strategic application of ignorance. The dark data perspective inverts the normal way of looking at things, so that the strategic casting of shadows can lead to greater understanding and greater illumination. ◆

> Dark Data: Why What You Don't Know Matters, *by David Hand, is published by Princeton University Press.*

Missing out: the 15 types of dark data

01: Data we know are missing

02: Data we don't know are missing

03: When you choose just some cases

04: Self-selection of data

05: Missing what matters

06: Data which might have been

07: Data which changes with time

08: Definitions of data

09: Summaries of data

10: Measurement of error and uncertainty

11: Feedback and gaming of data

12: Information asymmetry

13: Intentionally darkened data

14: Fabricated and synthetic data

15: Extrapolating beyond the data you have

IMPERATIVE / PROFESSOR NICK JENNINGS
VICE-PROVOST (RESEARCH AND ENTERPRISE)

Most big problems won't be solved by individuals. Our joined-up approach makes a difference

As I write this, the newspapers are full of reports of how Imperial's COVID-19 vaccine will shortly start clinical trial. It is a welcome ray of hope, but long before testing began, the multidisciplinary Imperial Network for Vaccine Research had been preparing for a possible new pandemic.

The Network's world-leading experts are at the forefront of every area relating to vaccine research, addressing knowledge gaps ranging from the extent to which particular infectious diseases affect people around the world, to how best to stimulate immunity using novel technologies and accelerate the licensing and uptake of vaccines.

It's a perfect example of Imperial's heterogeneity – and that's the essence of my job: to cut across all research and enterprise and bring people together.

Today, the most interesting science and research happens at the boundaries and confluence of disciplines and approaches. There was a time when many people thought the best work came from a lone scholar working in the dark, thinking deep thoughts. But most big problems won't be solved by individuals, they will be solved by people working collaboratively. You need different backgrounds, viewpoints, disciplines. From AI to synthetic biology to space science – in all these fields, engineers need to work with medics, business experts and scientists to make strides.

Luckily, we're not a traditional university, where everyone stays put in their departments. Instead, as the extensive work of the team of epidemiologists in the Abdul Latif Jameel Institute for Disease and Emergency Analytics (J-IDEA) has shown – mapping, predicting and advising on the spread of the COVID-19 pandemic – we can make a very real difference, both here in the UK and globally.

Each of the six global challenges we've defined has a dedicated institute that galvanises and focuses research. Our approach varies, from the top-down structures and institutes tackling the critical problems to the networks we encourage from the bottom up.

We have six global challenge institutes, 20 centres of excellence that have secured a certain amount of funding and 26 networks of excellence – these are the smaller, less formal groups. Between them they cover anything from fintech to robotics to dementia research. One centre for healthcare technology has more than 100 PhD students. What they add is so much more than the sum of its parts.

If you Googled 'food science at Imperial' when I first joined Imperial four years ago, for instance, you might think we had no-one in this field. Yet through some excellent community building we have a strong presence across the different faculties in our Centre for Translational Nutrition and Food Research – from business academics looking at sugar tax, medics looking at nutrition, and scientists and engineers searching for methods of evaluating food values and consumption. These are often virtual rather than physical spaces – even the largest institute might be a few meeting rooms and a few staff. We use digital spaces to enable people to 'bump into' each other, and that's very effective.

Having an impact is part of our founding charter. Our global institutes are intended to work on policy as well as research, and we expect great impact. For instance, Imperial scientists co-authored part of a report by the IPCC (Intergovernmental Panel on Climate Change) warning of the consequences of a rise in global temperatures above 1.5°C.

And when you're just 20 minutes from Westminster it can be easier to have an impact – there are opportunities for politicians to pop in and answer questions, or get a feel for what we're doing. And it helps, too, that I spent six years in government, as chief scientific adviser for national security. It means I understand how it functions, what the political drivers are, and what will and won't work.

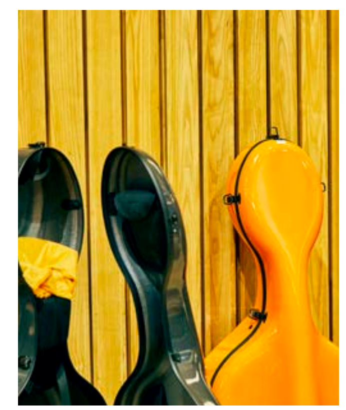
While AI is my area, if I had my time again I might look at the interface between engineering and medicine. So much can be done to help in terms of prevention of illness and looking after ourselves. Taking engineering and computing techniques and applying them to humans is fascinating. ◆

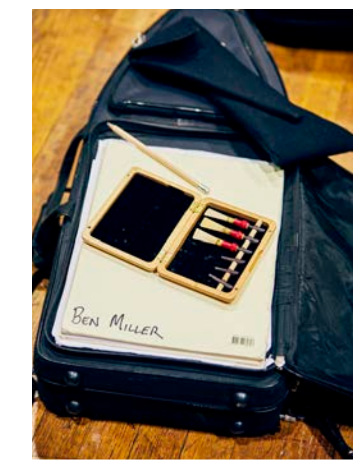
> *Nick Jennings is Professor of Artificial Intelligence and develops enterprise strategy across the faculties of Engineering, Natural Sciences, Medicine and the Business School.*











Practice makes perfect
Imperial College Symphony Orchestra at rehearsal in early February.

SOCIETY

Imperial College Symphony Orchestra

In tune

As a previous University Orchestra of the Year, the ICSO sets the standard for music at the highest level.

Words: **Helena Pozniak**
Photography: **Emli Bendixen**

When David Wheeler became chair of one of the finest university orchestras in the country, the third-year medical student and music scholar decided to ring the changes. "I've introduced a word of the week," he says. "The first one was 'family'. I stood up and said, 'Take a look around. Some of you are here for the first time, some of you are old-timers. These people will become your family away from home. We all have music as our common goal.' It went down really well."

Wheeler has played the French horn since the age of nine and performed in orchestras since he was 12, but has never experienced such intensity as at the helm of the Imperial College Symphony Orchestra (ICSO), which the university has hosted since 1948. For a science-focused institution, Imperial is rich in musical talent. "We have players who have won national competitions in the US, and ex-National Youth Orchestra of Great Britain players coming to audition. They set the standard – it's absurdly high." So high, in fact, that they are a previous University Orchestra of the Year, described by a member of the panel as "sounding like a professional orchestra".

The 80 musicians who make up the orchestra relish the challenge. Wheeler says: "We want to succeed, we want to experience what it feels like to play at the highest level. Everyone just wants to give the best of themselves." This year they had 20 'amazing' clarinets vying for just four spaces, so competition is stiff.

One of the orchestra's highlights comes each year with a performance at Sloane Square's Cadogan Hall, home to the Royal Philharmonic Orchestra. "You're on stage, blinking into the lights. You can't really see anybody, just silhouettes," says Wheeler. "But you know the hall is packed with people who care about music, and you feel the pressure. And you can't wait to perform what you've been practising in your own time and rehearsing together for so long. There's such a unique energy. It's nerve-racking but thrilling. Last year we performed Mahler's First Symphony. We got to the last page – a massive fanfare, with everyone playing their hearts out – and there was such a huge amount of energy and noise. It was pure euphoria."

Beyond the intensity of the performance, rehearsals, when they can again take place, are a release from academic pressure. "Some people have been slogging through lectures all day and come straight here – it's totally different. If that's what's required to create this level of intensity, they're happy to do it." There are also moments of levity and downtime. Traditionally, the orchestra tries to organise a weekend away, usually to Dorchester – "We rehearse and perform, then go for a drink and get to know each other."

Wheeler has considered making the orchestra's performances available on music-streaming services and inviting national critics to live performances. "But as Imperial students, we're constantly being assessed, and this is meant to provide relief from academic pressure, so it might be too much." The orchestra has a new principal conductor supported by Imperial's Blyth Centre for Music and Visual Arts, which this year celebrates 20 years of nurturing music and the arts at Imperial.

"This orchestra brings in people from different courses, backgrounds and beliefs. And we have a common goal – to make music with intensity and to perform to the highest standard. We're not pursuing perfection, we're pursuing emotion. We all need the time and freedom to pursue emotion, and the ICSO does that so well for so many." ◆

A WORKING LIFE

Patchwork Foundation: providing a sense of family for young people

Harris Bokhari OBE
(Maths and Management 1999)
on making positive change.

Interview: **Megan Welford** Photography: **Hannah Maule-ffinch**

It's easy to identify the inspiration behind my charity, the Patchwork Foundation – my father, Naz Bokhari. After his death in 2011, my sister, Hina, and I mapped out all that he had achieved and what would complement it. We started the Naz Legacy to promote education and integration, and the Patchwork Foundation came out of it. The aim is to connect disadvantaged young people, who are often locked out of society, with civic life.

My father was the first Muslim headmaster in the UK, at Ernest Bevin College, a secondary school in Tooting, and we were amazed at just how loved and respected he was. In the last two days he was in hospital before he died, we sent out an open invitation and a thousand people came to visit. He'd always been so low-key – he drove us into Buckingham Palace one day to get his OBE as if we were going on just another trip.

We grew up in Epsom, Surrey, where we were the only non-white family, and spent weekends in north London, Birmingham or Leicester setting up chairs in community halls or organising sports. We drank weak lemon squash and ate rice and mince from Tupperware containers. It was fun for us – we didn't know we were participating in community events and helping people. But our father brought us up to give back, to try to make positive change in our environment.

I am so lucky to have had my father's love and that my mother is my shoulder to cry on. In the Patchwork Foundation, we try to provide that sense of family for young people. Individuals provide the spark, but family is what allows you to achieve something. My dad advised me to become an accountant (rather than a teacher like everyone else in my family), and for that I am grateful. It allows me to do what I do, and I love it. I've always been comfortable with numbers – I like things to add up. Lots of things in society don't add up, like me having a full fridge when others don't.

Sometimes it can get a bit overwhelming, so I keep handwritten thank-you notes people have given me in my pocket. When someone says, "I'm alive because of you", you know why you do what you do. ◆

> ***Harris Bokhari OBE** won Imperial's inaugural Distinguished Alumni Award in 2020.*

Sometimes it can get a bit overwhelming, so I keep handwritten thank-you notes people have given me in my pocket

Back to school: Harris Bokhari at Ernest Bevin College in Tooting, where his father, Naz, was headmaster – the first Muslim head in the UK.

ILLUSTRATION: MIKE LEMANSKI.

PUZZLE

Test your brain power

Ready to test your little grey cells? Imperial's best minds set the ultimate puzzle challenge.

1: HARD

A farmer puts a heap of potatoes on his weighing scales, finding that it weighs 100lb. Unknown to him, it consists of 99 per cent water and one per cent solids by weight. He then carries out other farm work, leaving the heap in the sun so that its water content gradually evaporates, until it is 98 per cent water by the time he returns.
What is the weight of the heap when he returns?

2: VERY HARD

Noting their order, but hiding them from you, I place two aces and a jack face down in a row. You must identify an ace by pointing to one of the cards and asking me a single yes/no question. However, if you have pointed to an ace, I will answer truthfully, but if you have pointed to the jack, I will answer yes or no at random.
What card do you point to and what question do you ask?

3: FIENDISH

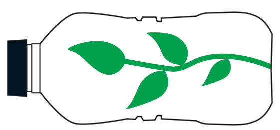
A computer glitch meant that all punctuation marks had been deleted from the following line of text. Replace the punctuation so that it makes sense:
Jane where John had had had had had had had had had had had the teachers approval

With thanks to Professor David Hand, Emeritus Professor of Mathematics and Senior Research Investigator, Faculty of Natural Sciences.

HOW TO ENTER:
Senders of correct solutions for two or more of the puzzles will be entered into a prize draw to win a signed copy of Professor David J Hand's new book *Dark Data: Why What You Don't Know Matters*.

Winners' names will be in *Imperial* 49 in November 2020, and solutions published at www.imperial.ac.uk/be-inspired/magazine/issue-48/brain-power. Entries close 31 August 2020. To enter, please email **imperialmagazine@imperial.ac.uk**

FOR ISSUE 47 SOLUTIONS:
www.imperial.ac.uk/be-inspired/magazine/issue-47/brain-power
ISSUE 47 WINNERS: Congratulations to: ***Peter Hewkin** (BSc Physics 1980)*, ***Dicky Yan** (BSc(Eng) Electrical Engineering 1986, MSc Statistics 1989)*, ***Patrick Schygulla** (Physics 2015)*, ***Desmond Lai** (BSc Mathematics 2014)*, ***Peter Ross** (PhD 1976)*, ***Céline Aussourd**, **Mohan Namasivayam** (Mathematics 1982)*, ***Ben Climer** (Physics 1957, PhD 1960)*, ***Kevin Ridout** (Civil Engineering 1979)*, ***Casper da Costa-Luis** (Physics 2014, MSc Computing 2015)*



OUR IMPERIAL

Plastic revolution

From small ideas grow big solutions: how members of Imperial's alumni community working in sustainability innovation are leading the way.

SUSTAINABLE PACKAGING

PIERRE PASLIER

MSc Innovation Design Engineering 2014

Co-founder: Notpla

Q. How did Imperial help develop the business?

The beauty of a Master's degree is it allows you the freedom to explore new ideas. My co-founder, Rodrigo García González (MSc Innovation Design Engineering 2014), and I come from different backgrounds, but we set out to find an alternative to the small plastic bottle that litters the world. We looked at many natural materials and chanced upon seaweed after reading about a technology developed in the 1930s by Unilever to make fake caviar balls using seaweed extract. We tried to recreate the process in our kitchen and, after a few iterations, were able to make the first prototype of Ooho, an edible water bubble.

Q. What happened next?

It was clear there were a lot of people out there looking for an alternative to plastic water bottles. We knew we had a good concept, but it took some time to articulate the business proposition, and we needed to acquire new skill sets. Through Imperial Innovations, we benefited from masterclasses on marketing, recruitment, fundraising and financial modelling, as well as access to mentors. After graduating, we continued to work from the South Kensington Campus, involving first-year chemistry students. When we started recruiting our own team, we spoke to members of the Innovation team to benchmark salaries and compensation. Now we are a team of 20.

Q. What are your plans for the future?

Our first product, Ooho, was very differentiating, but now we are moving on to looking at means of waterproofing cardboard and new products such as transparent film to protect dry foodstuffs and electronics. The potential is enormous – we aim to become the Tetra Pak for sustainable packaging. The Master's year we were in produced six or seven startups that have gone on to raise millions. It shows that combining people of different backgrounds who are not afraid to go beyond their training can be hugely successful. As for us, if we were experts, we would probably have said our idea was never going to work – but we thought, why not give it a go? And we got the support to make it happen. ◆

> ***Pierre Paslier** studied the MSc/MA Innovation Design Engineering programme jointly run by Imperial and the Royal College of Art before launching Notpla in 2014.*

HEALTHCARE

DR OLIVIA AHN

MBBS Medicine 2017

Co-founder/CMO: Polipop

Q. What gave you the idea for Polipop?

I have struggled with my periods for a long time and, back in 2016, asked my flatmate, Aaron Koshy (BEng Biomedical Engineering 2015, MSc Innovation Design Engineering 2017), to pop out and buy some sanitary towels for me. He came back with half the shop; he was shocked by the price and quality of the products available and didn't know what to buy. We had a long discussion, and for the first time I had to justify my periods and consider why they led to so much waste. Aaron was looking for a project on sustainability, so we set out together to create a biodegradable sanitary pad.

Q. How did you turn the idea into a viable business proposition?

As a medic, I had no experience of business, yet we were developing a consumer-facing product that would need marketing expertise. I heard about Imperial's Enterprise Lab WE Innovate programme for teams led by women with an early-stage business idea, and entered their annual competition. It was stressful, as my finals were the day after the WE Innovate final, but we won and the £10,000 first prize allowed us to develop the product and understand the marketplace. Fundraising aside, the Imperial Enterprise Lab has given us enormous support in developing business, marketing and PR plans, and introduced us to mentors, a few of whom have since become investors.

Q. What stage of development are you at?

Our first prototype used a crude thermosealing process. But we soon realised the issue was not biodegradability but flushability – every day in the UK alone, two million sanitary pads are flushed down the toilet. There are stringent flushability protocols and we worked with Johnson & Johnson to learn from their testing while also developing a novel manufacturing process. Our final prototype is currently awaiting independent flushability certification and UK and global patents are pending. We hope to launch in 2020. But I still practise as a locum doctor and I shy away from the word entrepreneur – I prefer to describe myself as a doctor who also has a business. ◆

> ***Dr Olivia Ahn** launched Polipop, the market's first safely flushable and completely biodegradable sanitary products, in 2017.*

RECYCLING

JAMES KUNG

BSc Physics 2018

Co-founder: Matoha

Q. How did Matoha get started?

One of our co-founders, Martin Holicky (BSc Chemistry 2019; MRes Nanomaterials 2019), went on a school visit to a recycling plant in Bratislava, Slovakia, and was shocked to find that, in an EU country, waste was still being hand-picked on a conveyor belt. The plastic-sorting process consisted solely of manual labourers taking out plastic bottles and incinerating the remainder. He came up with the idea of using infrared spectroscopy to build a simple machine that could provide better 'eyes' to a manual sorting system. But what really got us started was winning first prize in the Faculty of Natural Sciences's Make-A-Difference (MAD) competition for the best innovation in 2017.

Q. How did the Imperial environment help?

Without MAD I would not be here! After being selected to compete at the finals of the competition, the original team realised that changes to their idea required physics and data-analysis skills, and I was brought on board. However, much more importantly, this gave us not just funds but also our first validation. And the Imperial Enterprise Lab is the place where all the innovation I have experienced at Imperial has taken place. It has become one of my favourite places. When we can, we use it regularly, for work, meetings and filming video pitches, but also as a place to meet other entrepreneurs.

Q. What's next for Matoha?

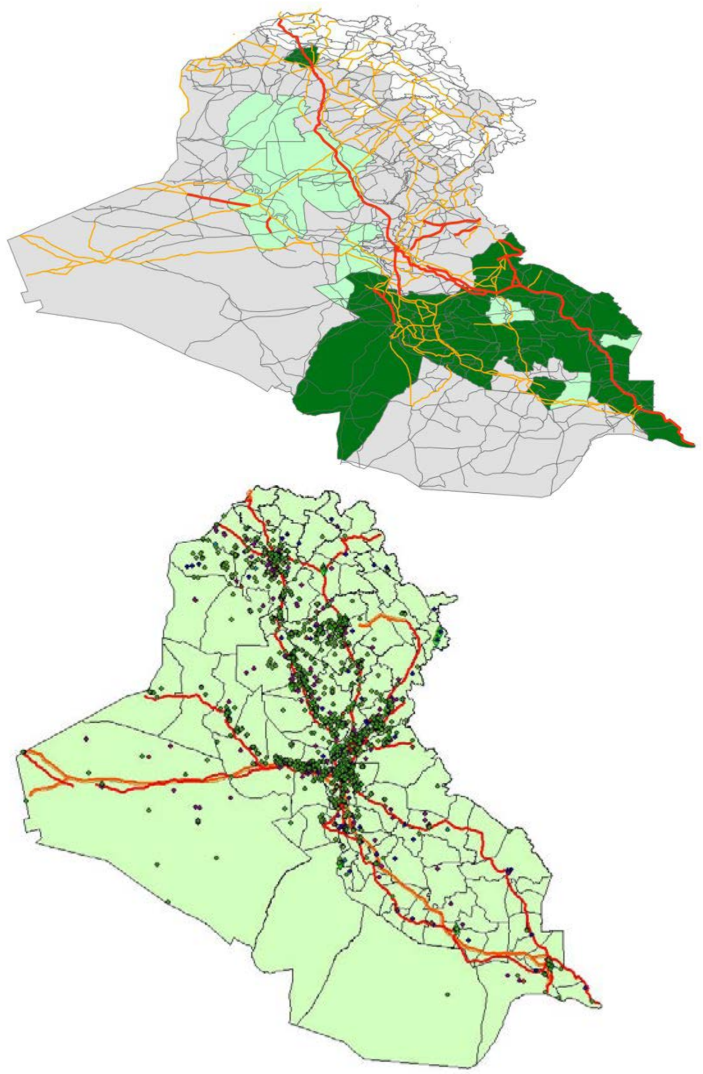
It is a difficult challenge to monetise the recycling industry while also maximising environmental impact and considering social values in an industry that, in many countries, is driven by manual labour. We are at a very exciting stage, though: our newest prototype is currently undergoing testing in facilities around the world; we are developing a fabrics-analysis device for those working in fabrics technology and manufacturing; and we're exploring new ways to bring our core technology to a wider audience. Although we still have challenges to overcome, we're confident that we'll keep up our current rate of progress and innovation for quite some time. ◆

> ***James Kung** is Co-founder of Matoha, the 2017 startup enabling plastics recycling worldwide that won the Institute of Physics' Startup Innovation Award in 2019.*

DATASET / TAMAR GOMEZ
RESEARCH POSTGRADUATE, IMPERIAL COLLEGE BUSINESS SCHOOL

Why does investment spark more violence?

Words: **Helena Pozniak**



Above, top: 2003 Iraqi road network overlaid on districts. Roads are coloured by road types (main, intermediary and other roads) and districts by their ethnosectarian split.

Above: 2012 Iraqi road network overlaid with geolocated violent events occurring the same year.

Context Over a beer with friends fresh back from Afghanistan, economist Tamar Gomez (MRes Imperial College Business School 2016) heard something that made her do a double-take. "They told me that when winter came and snow caused roads to be closed, Kabul became a less violent place." Gomez – who served in the Middle East as a reservist with the French armed forces – was intrigued. "Why should a lack of a good road network coincide with less violence? Shouldn't an investment in that network help ***limit*** unrest, rather than the opposite?"

Background Data is hard to come by in Afghanistan, but in neighbouring Iraq, violence is well documented by the US military and NGOs – and so that was where Gomez decided to focus. In the years following the 2003 US invasion of Iraq, the United States pumped around $11.9bn into the Iraqi road network, which expanded by 21 per cent. But violence soared and, at its peak, more than 1,500 civilians were killed every month.

Methodology It took nearly a year for Gomez to amass the granular information that would enable rigorous statistical analysis. She analysed how much US and aid agency money was invested in roads and infrastructure, and doggedly tracked down individuals working for NGOs in Iraq and government officials to interview. Then she compared records from Iraqi NGOs and information collated by the US-hosted Global Terrorism Database, looking at population density and economic activity, in order to plot trends in violence and eliminate inaccuracies.

Findings What Gomez discovered was completely at odds with the US doctrine that investment in infrastructure brought greater stability. Far from bringing peace and prosperity, building roads actually sparked greater levels of violence in Iraq. "We've proved this is a cause rather than a correlation," she says. But why is this the case? Gomez speculates that roads may allow violence to spill from one area to another more easily, or that the roads themselves become targets, especially when they are built by occupying forces. Harder to prove is the theory that cash investment increases levels of corruption, which could have a knock-on effect on sectarian violence.

Outcomes Since her discovery, Gomez's work has been picked up by *The Economist*, she has presented her findings to a European conference and been asked to address an international policy think tank in Washington. She is now working on a second Iraqi paper looking at the links between aid, corruption and development. "I believe there needs to be more research around investment in infrastructure in nations where there is a military presence – there's huge potential, for instance, to investigate within Syria." ◆

*> **Tamar Gomez** is a research postgraduate whose work focuses on development economics, game theory and conflicts.*

POLICY AGENDA / DR MATTHEW HARRIS
CLINICAL SENIOR LECTURER IN PUBLIC HEALTH
DEPARTMENT OF PRIMARY CARE AND PUBLIC HEALTH

We have to accept that west is not always best in healthcare and learn from others around the world

THE SITUATION

Even before the current pandemic crisis, which has put healthcare services around the world under unprecedented pressure, health services in the west faced enormous challenges – to create efficiencies and learn how to do more with less. Research shows there are lessons to be learned from research outputs and health systems of low-income countries. Traditionally, these countries have been passive recipients of expertise from developed nations, but now there is an opportunity to reverse the paradigm. "Existing western solutions to burgeoning healthcare demand are simply not working any more," says Dr Matt Harris, Clinical Senior Lecturer in Public Health Medicine. "We have not only the opportunity but the moral duty to create a win-win situation by learning from low-income countries."

THE ISSUE

Cognitive bias is slowing down the adoption of innovative practices from low-income models. A randomised, blinded, crossover experiment conducted by Dr Harris and colleagues among a sample of 347 English clinicians proved that changing the source of research from a low- to a high-income country significantly improved how it was viewed. "There are many empirical studies demonstrating this bias exists, highlighting the fundamental, morally debatable issues at stake," says Dr Harris.

"A postcolonial attitude of 'not invented here' and 'good enough for them but not for us' still lingers. Western healthcare services still have work to do, particularly at clinician level, for example, to advance attitudes and accept solutions that may not be technically cutting edge but are safe and cost effective."

THE OPPORTUNITIES

The scale of the overall opportunity is enormous, with outcomes specific to each innovation: using basic orthopaedic drills developed in Malawi, for example, could save the NHS an estimated £100m; mosquito-net mesh provides a much cheaper alternative to the synthetic commercial material currently used for hernia repair and is equally effective; and the delivery of blood products and essential medicines by drone is used at scale in Rwanda with great potential for rural areas in the UK.

"I first became interested in learning from other systems when I was working as a GP in a remote community in north-east Brazil," explains Dr Harris. "Through the Brazilian Family Health Programme, community health workers provide the backbone of the local healthcare system. When I returned to the UK after four years, I was shocked to see how fragmented community care was in comparison, with a complicated network of different services. The systematic deployment of community health workers in the NHS along the lines of the Brazilian model would have the potential to address apparent problems of fragmentation and inefficiency, while improving clinical outcomes through improved uptake of appropriate services." This, he believes, is just one example of the potential for reverse innovation.

FUTURE UPTAKE

Pilot studies are needed of innovations from low-income contexts. The NIHR Applied Research Collaborative in north-west London is an opportunity to translate innovative research into the local context.

"Overall, there are deeply entrenched attitudes to overcome," says Dr Harris, "but I believe that we can get to a level playing field. The attitude must be: if it works and is safe, it doesn't matter where the idea comes from." ◆

*> **Dr Matthew Harris** is an Honorary Consultant in Public Health Medicine in the Imperial College Healthcare NHS Trust.*

Hannah Lau (below), pictured at the garage in late February.

MY IMPERIAL

Nice and greasy does it

Hannah Lau, (*MEng Design Engineering, fourth year*) can't wait to get back to Jezebel, the 1916 fire engine at the heart of the RCS Motor Club garage.

Interview: **Lucy Jolin** / Photography: **Emli Bendixen**

When I get some spare time, I like to hang out at the Royal College of Science (RCS) Motor Club garage – with Jezebel. She's a 1916 fire engine that the RCS acquired from a soap manufacturer, Joseph Crosfield and Sons, back in 1955. The RCS offered £50 but the factory decided to donate her, and she's lived here ever since.

Not many people pass by the garage: it's tucked down behind a chemical engineering lab, next to the Royal College of Music's Britten Theatre. It's a bit messy and greasy because of the work we carry out on Jezebel, and there's plenty of clutter. Clem lives next door – she's the 1926 Morris truck that belongs to the Royal School of Mines Motor Club.

There's plenty of history and memorabilia here, too. We keep all the parts of Jezebel that we have replaced, and we have a board with plaques from the rallies we've attended with her. Someone made a sign for it: *Midnight Welding Since 1955.*

I've always enjoyed old things and engineering. Working on Jezebel is a great combination of the two. Fixing her is quite a technical job and I've learned a lot from my time at Motor Club, which is definitely enhancing my studies. It's not textbook learning: it's very hands-on. Sometimes it can feel almost like a job – especially when she breaks down just before an event, and we panic and try to get her back on the road. But most of the time we're pretty relaxed.

It's not just Jezebel who makes the garage my favourite place: my fellow club members are important, too. We sometimes have film nights and the like, but mostly we're working on Jez or taking her out, to the pub, or to Sainsbury's! We get a lot of interested looks when we do that, particularly from kids. We're a niche club and there aren't many of us. Our alumni are very engaged, though, and often come down to help out. It's great to gather in the garage for fun and a chat – I'm looking forward to the chance to enjoy that sense of camaraderie again soon. ◆

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Handprints on Hubble: An astronaut's story of invention

Kathryn Sullivan, the first American woman to walk in space, discusses her new book and remembers what it was like working with the team that launched, rescued, repaired and maintained the Hubble Space Telescope.
bit.ly/HandprintsOnHubble

The Schrödinger Lecture 2020: On coin tosses, atoms and forest fires

Professor Sir Martin Hairer presents the 32nd annual Schrödinger Lecture and discusses the mathematical objects arising in probability theory and how they helped to confirm the existence of atoms over 100 years ago.
bit.ly/Schrodinger2020

The Higgs: What is it good for?

Professor David Colling, Professor of Physics and e-Science, explores the Higgs mechanism, the search for the Higgs boson and how studying the particle sheds light on some of the most basic questions of the universe in his Imperial Inaugural Lecture.
bit.ly/TheHiggs20

Surgery, statistics and science

Professor Eric Lim, Professor of Thoracic Surgery at the National Heart and Lung Institute, shares how mathematics helped him to transform from bewildered medical student to international clinical opinion leader.
bit.ly/SurgeryStatisticsScience19

Staying in rhythm: the trials and fibrillations of a heartbeat

Professor Prapa Kanagaratnam discusses how his research and ideas have shaped diagnostic approaches to heart rhythm problems and explains how collaboration with industry partners, Imperial researchers and NHS Trusts has led to remarkable innovations.
bit.ly/TrialsAndFibrillations18

Chickpeas of iron: how primary care can influence children's health

The Head of Imperial's Child Health Unit and Professor of Primary Care, Professor Sonia Saxena, discusses the importance of the right data and how primary care could influence early life exposures to health risks, ultimately improving health later in life.
bit.ly/ChickpeasOfIron18

Professor Prapa Kanagaratnam, Kathryn Sullivan, Professor Eric Lim

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