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INSPIRING THE NEXT GENERATION

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HOW TO TEACH THE FUTURE

NADIA WHITTOME: THE UK'S YOUNGEST MEMBER OF PARLIAMENT IS CAMPAIGNING FOR TEACH THE FUTURE'S CLIMATE EDUCATION BILL

ALSO IN THIS ISSUE

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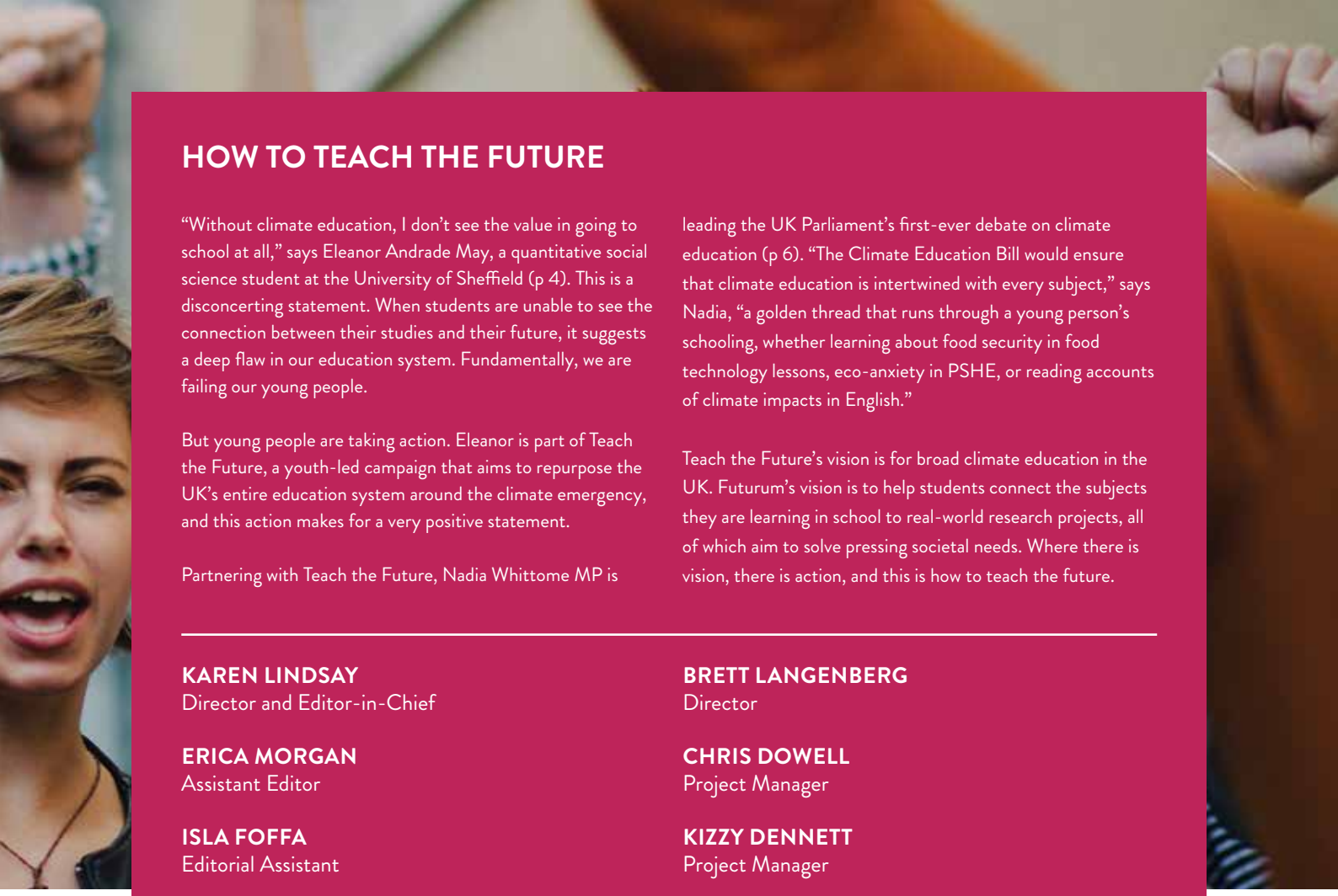

HOW TO TEACH THE FUTURE

"Without climate education, I don't see the value in going to school at all," says Eleanor Andrade May, a quantitative social science student at the University of Sheffield (p 4). This is a disconcerting statement. When students are unable to see the connection between their studies and their future, it suggests a deep flaw in our education system. Fundamentally, we are failing our young people.

But young people are taking action. Eleanor is part of Teach the Future, a youth-led campaign that aims to repurpose the UK's entire education system around the climate emergency, and this action makes for a very positive statement.

Partnering with Teach the Future, Nadia Whittome MP is leading the UK Parliament's first-ever debate on climate education (p 6). "The Climate Education Bill would ensure that climate education is intertwined with every subject," says Nadia, "a golden thread that runs through a young person's schooling, whether learning about food security in food technology lessons, eco-anxiety in PSHE, or reading accounts of climate impacts in English."

Teach the Future's vision is for broad climate education in the UK. Futurum's vision is to help students connect the subjects they are learning in school to real-world research projects, all of which aim to solve pressing societal needs. Where there is vision, there is action, and this is how to teach the future.

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CONTENTS

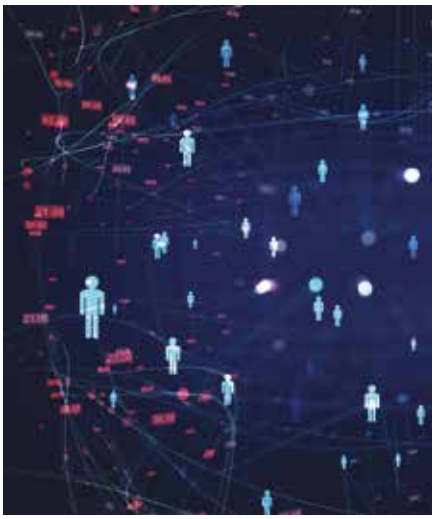
RESEARCH ARTICLES

INTERVIEWS

ELEANOR ANDRADE MAY p 4

NADIA WHITTOME MP p 6

RACHEL MUSSON p 32



THE MISSING MILLIONS p 48

"WITHOUT CLIMATE EDUCATION, I DON'T SEE THE VALUE IN GOING TO SCHOOL AT ALL."

TEACH THE FUTURE IS A STUDENT-LED MOVEMENT, CAMPAIGNING FOR BROAD CLIMATE EDUCATION IN THE UK. THEY ARE ALSO ADVOCATING FOR GREEN VOCATIONAL COURSES AND CLIMATE-FRIENDLY EDUCATIONAL BUILDINGS. STUDENT VOLUNTEER **ELEANOR ANDRADE MAY** TELLS US MORE

HOW DID YOU GET INVOLVED WITH TEACH THE FUTURE?

My introduction to climate campaigning was through the school strikes and the UK Student Climate Network (UKSCN), which feels like a lifetime ago! UKSCN was campaigning for youth strikes, votes for 16-year-olds and above, and adequate teaching on climate education. Through the school strikes, Teach the Future became its own entity focusing on climate education.

I was in year 12 and getting to the point where I had to choose my own path. I'm concerned about the climate crisis, but I didn't pick A-level subjects that would teach me about it, like geography or chemistry. I felt I was missing out and if I wanted to make a difference in the world in terms of climate change, I wasn't going to be able to do it. That's why I joined Teach the Future.

WAS TEACH THE FUTURE SET UP BY STUDENTS?

Yes, Teach the Future is entirely student-led. We're supported by a handful of staff from SOS-UK, which helps students organising for sustainability. They help with things like banking and finance, legal issues and safeguarding.

WHY IS THE TEACH THE FUTURE CAMPAIGN IMPORTANT TO YOU?

If we're not being taught the skills and knowledge we need to equip us to face the effects of climate change and to not have careers that will have horrible consequences for the world around us, then what is the purpose of education?

For me, realising this brought on despair as well as eco-anxiety. I felt helpless about not being able to act against climate change. I felt we were doomed. I felt that certain things in my life weren't worth the effort because they didn't help to solve climate change.

Climate education means that no other student has to feel this way. All students would feel prepared and that their education has a purpose. Climate change impacts every aspect of our lives so it should be mentioned in every aspect of our education because there's no part of the curriculum that it doesn't affect. Without climate education, I don't see the value in going to school at all.

WHAT DO YOU DO FOR TEACH THE FUTURE?

I help with communications, pretty much. There are a handful of us who run several different social media channels: Twitter, Instagram and Facebook. We create posts a few times a week to engage other young people with climate education and why we need it, hopefully to inform them about how impactful it can be.

I also help write emails and turn them out for our mailing list. We connect with other organisations to spread our message further and reach out to their supporters, as well. A few months ago, I ran a communications

"IT ISN'T NECESSARILY ONLY ABOUT TAKING ACTION; IT'S ALSO ABOUT BEING SURROUNDED BY PEOPLE WHO FEEL THE SAME WAY".

ABOUT ELEANOR

AGE: 19
STUDYING: Quantitative Social Science, University of Sheffield, UK

www.sheffield.ac.uk/undergraduate/courses/2022/quantitative-social-sciences-sociology-bsc

WHAT IS THE COURSE ABOUT: Polling and research for societal good
THOUGHTS ABOUT THE COURSE: "I'm still in my first year but it's absolutely what I want to be doing."

campaign for a fundraiser. We managed to raise £8,300 plus another £1,000 or so in gift aid, which was incredible. This involved emailing people and getting our message across through social media and influencer activists.

One of our posts featured on Emma Watson's Instagram story, which was possibly more bizarre than going to Parliament! [Earlier this year, Teach the Future's Climate Education Bill was proposed by Nadia Whittome MP for its Second Reading in the House of Commons. The Bill was first proposed in Parliament in the form of a 10-minute debate in November 2021.]

HOW MUCH TIME DOES THIS TAKE YOU?

It comes in waves. Volunteers put in as much or as little time as they can or want. I was doing about eight hours a week or so, working up to the second reading in Parliament, but it's easy to take a break. The meetings take place after school because almost all our volunteers are still in formal education.

HOW HAVE YOU BENEFITED FROM BEING INVOLVED IN THIS CAMPAIGN?

I had next to no skills before joining Teach the Future, but one of the key parts of this campaign, aside from getting climate education into the curriculum, is providing skills and opportunities to young people who otherwise don't have them. I've come so far in the last few years. There are so many things I've done that I would never have imagined doing.

DOES VOLUNTEERING FOR TEACH THE FUTURE MAKE YOU FEEL BETTER ABOUT THE WORLD AROUND YOU?

Absolutely, it does. It isn't necessarily about taking action; it's also about being surrounded by people who feel the same way. When I was at school and starting to become aware of the climate crisis, it was as if no one else cared. Teachers weren't teaching it; it felt like no one thought about it or wanted to do anything about it.

WHAT WOULD SUCCESS WITH THIS CAMPAIGN LOOK LIKE FOR YOU?

For me, success would be to have climate education embedded within the curriculum. It would be to have skills training and vocational courses that prepare kids for green jobs. In the last few decades, certain trades have been severely undervalued, so we need to bring back vocational courses to have any kind of green transition.

WHAT MESSAGE WOULD YOU LIKE TO SEND TO YOUNG PEOPLE READING THIS ARTICLE?

If you're worried about climate change or any other issues that feel out of your control and too big solve, there are people who feel the same way and are looking to take action. It's not impossible, it's never impossible; you will be able to find people who are on your side and want to help change the situation if you look for them.

HOW TO GET INVOLVED WITH TEACH THE FUTURE

- Sign Teach the Future's petition: **www.teachthefuture.uk/action/petition**
- Write to your elected representative to ask them to support climate education: **www.teachthefuture.uk/action/rep**
- Ask your teachers to join the Teachers Network so that they can share resources with other teachers: **www.teachthefuture.uk/action/teachers-network**
- Donate: **www.teachthefuture.uk/an/donate**
- Subscribe to the mailing list: **www.teachthefuture.uk/an/mailing-list**
- Volunteer: **www.teachthefuture.uk/an/volunteer**

© David Parry/PA Wire

"THE CLIMATE EDUCATION BILL WOULD ENSURE THAT CLIMATE EDUCATION IS INTERTWINED WITH EVERY SUBJECT."

AFTER THE UN CLIMATE SUMMMIT COP26, **NADIA WHITTOME MP** LED THE UK PARLIAMENT'S FIRST-EVER DEBATE ON CLIMATE EDUCATION, IN PARTNERSHIP WITH THE STUDENT-LED TEACH THE FUTURE CAMPAIGN

THE CLIMATE EDUCATION BILL

Teach the Future has three demands for Members of Parliament (MPs):

1. Teach students about the climate emergency by embedding climate change throughout the curriculum, and by upskilling teachers and educators to be able to deliver this.

2. Include green skills in vocational courses to make sure students are equipped with the skills to help them tackle climate change and transition to a carbon neutral future.

3. Make education buildings carbon neutral by reducing carbon emissions to net zero standards and adopting sustainable practices within the public educational estate.

Teach the Future's Climate Education Bill was in Parliament for its second reading in the House of Commons on March 18, 2022. It is a Private Members Bill written by students and young people aged 13-18 from Teach the Future. The Bill was first proposed by Nadia in Parliament in the form of a 10-minute debate in November 2021. A few of the students involved were allowed to attend the debate.

Tess, one of the students, has written a blog post about her perspective:
www.teachthefuture.uk/blog/i-sat-in-parliament-at-the-first-reading

You can also watch the full recording:
www.teachthefuture.uk/blog/climate-education-bill-first-reading-highlights

WHY IS TEACHING THE YOUNGER GENERATION ABOUT THE EFFECTS OF CLIMATE CHANGE SO IMPORTANT?

To tackle the climate crisis, the world has to transition to net zero carbon emissions, and this will require fundamental changes to every sector of our economy and every part of our society. Climate education prepares young people for this future. It will help them mitigate and deal with the effects of climate change and teach them the skills they need to thrive in a net zero society.

HOW DID YOUR COLLABORATION WITH TEACH THE FUTURE START?

I organised with youth climate strikers in Nottingham before I became an MP. Tackling the climate crisis has been among my top priorities from the start, so I linked up with climate strikers who had set up Teach the Future and brought them into Parliament not long after I was first elected. We've been working together ever since.

WHY IS THIS BILL SO IMPORTANT NOW RATHER THAN AT ANY OTHER TIME IN THE PAST OR FUTURE?

The science is clear: if we don't act fast, our future looks bleak. Our very existence is under threat. The UN Intergovernmental Panel on Climate Change has said that we need "rapid and far-reaching transitions" that are "unprecedented in terms of scale". Everything we do must be focused on achieving this, and climate education is an important part.

HOW CAN TEACH THE FUTURE HELP ENSURE THAT KNOWLEDGE IS SPREAD EFFECTIVELY ACROSS ALL SUBJECT AREAS, NOT JUST SCIENCE AND GEOGRAPHY?

The climate crisis and our actions to tackle it run through every aspect of our lives. By only teaching about it in geography and science, there's

Nadia Whittome (second from right), the youngest sitting MP, and Jeremy Corbyn MP (second from left) joined students aged 13-18 from the Teach The Future campaign on College Green, Westminster, London. © David Parry/PA Wire

Teach the Future's Climate Education Bill was first proposed by Nadia in Parliament in the form of a 10-minute debate in November 2021. Nadia is with Scarlett Westbrook (left), Teach the Future Campaign Coordinator. © David Parry/PA Wire

a risk young people will think that climate change is something that only geographers and scientists need to worry about.

The Climate Education Bill would ensure that climate education is intertwined with every subject, a golden thread that runs through a young person's schooling, whether learning about food security in food technology lessons, eco-anxiety in PSHE, or reading accounts of climate impacts in English.

WHAT EFFECT DID THE COVID-19 PANDEMIC OVER THE PAST TWO YEARS HAVE ON THE CAMPAIGN?

The pandemic has taken up a lot of time and focus for me as an MP, which meant there wasn't as much time for me to work on projects relating to other areas, like the Climate Education Bill. But Teach the Future never stopped campaigning throughout the pandemic, and I'm so pleased that in the last few months we've been able to make real progress with the Bill.

WHAT ARE SOME OF THE MAJOR ACHIEVEMENTS OF THE TEACH THE FUTURE CAMPAIGN IN THE PAST YEAR?

From my perspective, the level of support that we've built together around the Climate Education Bill has been a significant achievement. The Bill is supported by the three most relevant select committee chairs – Environmental Audit Committee, Education Committee, Business, Innovation and Skills Committee – two of whom are Conservative MPs. The Labour Party officially supports the Bill, and Green, Lib Dem and Scottish National Party MPs are also backing it.

ITALY HAS MADE CLIMATE EDUCATION A REQUIREMENT FOR ALL STUDENTS. WHAT WILL IT TAKE TO ACHIEVE THE SAME OUTCOME IN THE UK?

Making climate education compulsory requires enough pressure to be put on the government to make this a reality. Our campaign has built support from many different areas and over the next few months we will continue to increase the pressure.

GETTING SOME PEOPLE – INCLUDING STUDENTS AND TEACHERS – TO CARE MORE ABOUT CLIMATE CHANGE MAY REQUIRE SIGNIFICANT BEHAVIOURAL NUDGING. HOW WILL THAT BE ADDRESSED?

The whole point of the Bill is that whether or not you're taught about climate education will no longer depend on how passionate your teacher is about it. It will become part of the national curriculum. We are also advocating for schools and teachers to be provided with resources to help them feel confident about providing climate education.

WHAT ARE THE NEXT STEPS FOR YOU, THE TEACH THE FUTURE CAMPAIGN AND CLIMATE EDUCATION IN THE UK?

The Bill was back in Parliament for its second reading on 18th March. We'll be continuing to campaign and build support, and we'll be engaging with the government about their forthcoming education strategy.

ABOUT NADIA WHITTOME

Nadia is a British Labour Party politician and MP for Nottingham East. She was elected to Parliament in 2019 when she was just 23 years old, which made her the UK's youngest MP.

www.nadiawhittome.org

DOES LOCAL COMMUNITY ACTION HELP OUR SENSE OF GLOBAL CITIZENSHIP?

DR ELSA LEE IS A RESEARCHER AT THE **UNIVERSITY OF CAMBRIDGE** IN THE UK, WHO IS STUDYING THE LINK BETWEEN PARTICIPATION IN WATERWAY REGENERATION PROJECTS AND THE SENSE OF GLOBAL CITIZENSHIP IN YOUNG PEOPLE

GLOSSARY

EQUITY – fair distribution of resources based on the needs of the recipients

GLOBAL CITIZEN – a person who is aware of the wider world and understands their place within it

UBUNTU – a southern African philosophy that we are shaped by our relationship with others

WATERWAY REGENERATION – restoring rivers, wetlands and water environments

"By considering how our actions might affect people who live in a different country, we can support the health and well-being of people all around the world," says Dr Elsa Lee, a researcher in environmental sustainability education at the University of Cambridge. Elsa is investigating various projects that are working with young people to improve local waterways in England and South Africa. She is interested in understanding if and how participation in these community projects can help young people to feel like global citizens.

WHAT IS GLOBAL CITIZENSHIP?

Global citizenship is an idea we are all part of one planet, so the way that we live in our communities and countries should also apply to the way we live as a member of a global community. We all have rights and responsibilities (such as the responsibility to care for others, and the right to be cared for when we are sick), and the goal of intergovernmental organisations like the United Nations is that everyone should have access to the same rights and share the same responsibilities. The concept of global citizenship is highlighted by UNESCO in their Sustainable Development Goals, and other terms with similar meanings include global awareness, world sensing and Ubuntu.

The idea is that if we consider ourselves as global citizens, we can begin to work towards equity for all. We should consider how our local actions might affect people who live elsewhere. For example, if we keep the water in our own rivers free of pollution, it will benefit people who live downstream, and even those on the other side of the world, when that clean water eventually reaches them.

"However, it's very difficult to live this way," explains Elsa. "It is a very big thing to ask people to keep the needs of everyone in the world in their mind when they make decisions about how to live their own lives." We must also consider how people across the world have different levels of access to water, food and other resources, so these choices are more difficult to make for some than others. And we need to think about how different countries' governing policies influence individual citizens' capacities to be global citizens.

But, if we focus on doing small, positive things in our own communities, we can eventually make changes on a much bigger scale. While we do not all have the same access to material resources, we do already have the mental, emotional and spiritual attributes needed to live like this, we just need to believe that our small, considered acts make a difference, and know that we are always only a small part of a greater whole. "If we work together and care for ourselves and those nearest us, we can reach a point where we make decisions that are community-minded without really thinking about it" says Elsa. "And then all those community-minded decisions come together to have a positive impact at a global level."

DR ELSA LEE

University of Cambridge, UK

FIELD OF RESEARCH

Environmental Sustainability Education

RESEARCH PROJECT

Investigating how participation in local waterway regeneration projects influences a sense of global citizenship in young people: Connecting Water to Global Citizenship via Education for Sustainable Development

FUNDER

Economic and Social Research Council (ESRC), UK, under grant number ES/S000151/1

ELSA'S RESEARCH METHODS

Elsa's research uses ethnographic methods, meaning she spends time alongside the volunteers and trainees who carry out waterway regeneration projects. "Before the pandemic, we visited these projects and walked alongside the rivers and water bodies where our participating organisations work, but restrictions prevented travel to field sites," Elsa explains. Now, Elsa and her project researcher, Dr Mary Murphy, talk virtually to members of the organisations about the work they do, carrying out interviews online.

After transcribing these interviews into text, Elsa and Mary look for themes that are common and themes that are unique across different sets of interviews. This process is known as thematic content analysis and is a common way of analysing data that is collected in social science research. It allows researchers to see how different people agree or disagree about different topics. Elsa and Mary then consider factors such as economic, social, political and environmental conditions where the participants live and work. "Knowing the background conditions can make a big difference in how you interpret what your interviewees are telling you," says Elsa. "It is also important to go back to your participants to ask them how they feel about your interpretations of what they are saying."

Elsa aims to understand why different people who are doing the same things (waterway regeneration) but in different places (England and South Africa) come to the same or different conclusions about the impact of their work. "This is a very exciting stage of academic research projects, and it can go on for years!" she says.

LINKING WATERWAY REGENERATION TO GLOBAL CITIZENSHIP

Elsa's data suggest that participation in community-based waterway regeneration projects influences young people's local environmental citizenship. "Volunteering on projects like these gives young people an opportunity to respond to the problems that are highlighted every day in the media," says Elsa. Young people are increasingly aware of the world's problems, such as climate change and environmental degradation, but can be unsure of how to solve them. Initiatives such as waterway regeneration programmes provide an opportunity for young people to take action and address issues in their local community.

"While this has obvious benefits for the environment, it also has benefits for the young people themselves," says Elsa. A sense of contributing to a solution has a positive impact on well-being, helping to overcome eco-anxiety, while volunteering also provides skills that can improve employment prospects and future economic well-being. These same impacts were reported by the young people in both England and South Africa.

However, Elsa has found that young people who are involved in community-based waterway regeneration projects do not necessarily identify as global citizens, and often feel uncomfortable with the idea. Some felt that the responsibility of global citizenship was too weighty, others felt that it was unattainable or unrealistic and some felt that it was inequitable. "If you live in circumstances where the challenges of meeting your responsibility to feed your family overwhelms your capacity to consider the impact of your actions on local waterways, let alone on global issues, then the notion of global citizenship heightens the sense of inequity," explains Elsa. It is therefore very important to be mindful of how ideas like this might impact on different groups of people.

While global citizenship raised some critical issues for the young people Elsa worked with, the opportunities provided by waterway regeneration projects have allowed them to become active local citizens. If everyone around the globe had a sense of community spirit (in whatever form was most appropriate to their circumstances) and took local action to protect their environment, then the world would soon become a fairer and more sustainable place. "This is something which environmental activists and researchers have known for a long time," says Elsa, "and it is very exciting to see how it works in the communities we studied."

PROJECT PARTNERS

FRIENDS OF THE LIESBEEK
www.fol.org.za

The Liesbeek River in South Africa flows from its source on Table Mountain through Cape Town, providing a crucial water source for the city and acting as an ecological corridor through the urban environment. "The river is an important area for biodiversity," says Sabelo. "Over 580 species have been recorded along the Liesbeek, many of which are endemic to the region." However, the river suffers from problems of pollution and rubbish dumping. Urban drains lead directly into the river so anything on the roads will be washed into the Liesbeek when it rains, and residents often throw their waste into the river.

Friends of the Liesbeek work to conserve and rehabilitate the river and its surroundings. "Sometimes we have to organise a river clean-up twice a week due to the sheer volume of waste that accumulates," says Phil. "We can remove 500 bin bags' worth of rubbish every time." They also remove invasive species, plant indigenous plants and are working to reinstate wetland environments by removing the walls from canalised sections of the river to allow natural flooding.

"People are disconnected from the river," says Sabelo. Many buildings have their backs to the Liesbeek, and so residents are not engaged with their local environment. Friends of the Liesbeek are helping to promote sustainable urban conservation by organising community activities that allow people to connect to nature through engagement with the Liesbeek.

THAMES21 **www.thames21.org.uk**

Flowing through the heart of London, the River Thames is the second longest river in the UK. "London is a river city," says Chris. "Its identity is permeated by the river. But today, the Thames is regarded as dirty and dangerous, and we want to change this attitude."

Thames21 is working to tackle pollution in the river by organising regular clean-ups, providing all the equipment needed for volunteers to remove rubbish (they have over 1,000 pairs of wellies available!). They also encourage residents to participate in citizen science projects, such as conducting litter surveys. One of these projects found that 45% of plastic bottles found in the Thames are single-use water bottles. These findings were used to support the #Oneless campaign to install more public water fountains around London.

Thames21 also organises outdoor learning activities, using the river as an educational resource. These activities are not only for schools, but also for community members, with events such as nature walks and music or photography workshops held by the river. These activities encourage residents to engage with the Thames and to value the river environment.

"It is important to connect young people with issues of water management," says Chris. "Young people are future decision-makers. They will be future water-consumers, waste-creators and environment-managers. If they understand the issues around waterways now, then they will make better decisions in the future."

DUZI-UMNGENI CONSERVATION TRUST (DUCT) **www.duct.org.za**

The uMsunduzi and Umgeni Rivers in South Africa are severely damaged and polluted. As part of its mission to establish an ecologically healthy river system, DUCT works with young unemployed people who want to protect the environment, providing training and job opportunities in ecosystem restoration.

"I was unemployed when I finished school, so, for me, joining the project was first and foremost a job opportunity, not because I was particularly passionate about the environment," says Portia. "But this quickly changed when I began to receive my training."

This training involved identification of indigenous and alien species during invasive vegetation clearances, inspections of waste management sites and using Google Earth to map out areas of different habitats. "We also receive individual training to help us with our vocational pathway, and I chose to get involved with waste management and recycling," she says.

With the help of DUCT, Portia founded her own recycling company where she collects waste from local schools, then separates out recyclable materials which she sells to make money.

In many residential areas there is no municipal waste collection service, so people dispose of their waste by dumping it in the river or wetland areas. Members of DUCT clear up this rubbish, and after receiving training in permaculture, they have been planting community gardens in areas that were once used as rubbish dumps. "These small actions motivate communities to be custodians of their own environment," says Pandora. "By working in a small area where practical impact can be observed, people believe that they can fix the problems and make a difference."

Read about some of the other waterway regeneration projects Elsa is working with:

LIBERTY NPO
www.libertynpo.co.za

NATURE CONNECT (formerly Cape Town Environmental Education Trust)
www.natureconnect.earth

THE SEVERN RIVERS TRUST
www.severnriverstrust.com and **www.unlockingthesevern.co.uk**

ABOUT ENVIRONMENTAL SUSTAINABILITY EDUCATION

As part of UNESCO's Sustainable Development Goals, all learners should be empowered with the knowledge, skills and values necessary to shape a sustainable future. Researchers studying environmental sustainability education want to understand how this can be achieved by placing sustainability at the heart of learning. Environmental sustainability education unbalances the three pillars of sustainable development (i.e. economy, environment and society, or profit, planet and people). "We put the emphasis on the environment, arguing that the environment is foundational, and then think about what emphasising the sustainability of the environment means for education," Elsa explains.

Elsa's research sets out to balance the needs of humans with the needs of other living and non-living components of Earth. "For me, the capacity to respond in some small way to understanding the challenges of human-generated environmental degradation is crucial, and fundamental to my way of life," she says. "I cannot choose to live any other way."

EXPLORE A CAREER IN ENVIRONMENTAL SUSTAINABILITY EDUCATION

"The very best way to get started on this career path is to find a local organisation and start volunteering," suggests Elsa. This could be with a local waterway regeneration project, a wildlife trust or local conservancy group. "Working with your local community will start you on your environmental education journey, and you can choose where to go from there."

Elsa also recommends citizen science projects as an opportunity to address large-scale issues through local action. The following organisations have many projects available:

- The Natural History Museum **www.nhm.ac.uk/take-part/citizen-science.html**
- EU Citizen Science **www.eu-citizen.science**
- National Geographic **www.nationalgeographic.org/idea/citizen-science-projects**
- The Nature Conservancy **www.nature.org/en-us**

PATHWAY FROM SCHOOL TO ENVIRONMENTAL SUSTAINABILITY EDUCATION

Elsa suggests that geography, the arts, economics, ecology and business are important subjects to study. But as a transdisciplinary issue, all subjects will be useful for addressing the challenges in the field of environmental sustainability education. It is really about what different disciplines of study can bring to support the search for solutions.

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UNCOVERING THE SECRETS OF THE AMAZON

DR GUILHERME OLIVEIRA, BASED AT THE **VALE INSTITUTE OF TECHNOLOGY** IN BRAZIL, LEADS A TEAM WORKING WITH AMAZONIAN BIODIVERSITY. TOGETHER, THEY CONDUCT GENOMIC ANALYSIS ON PLANTS, ANIMALS AND MICROORGANISMS IN A HABITAT THAT IS EXTREMELY DIVERSE AND STILL RELATIVELY UNKNOWN

TALK LIKE AN ENVIRONMENTAL GENOMICS AND BIOINFORMATICS TECHNOLOGIST

BIOINFORMATICS – a subdiscipline of biology and computer science concerned with the acquisition, storage, analysis and dissemination of biological data

DNA SEQUENCING – the process of determining the order of the four chemical bases that make up a DNA molecule

ENVIRONMENTAL DNA (eDNA) – DNA from environmental samples, such as soil and water

GENOME – the set of genes contained in a cell

GENOMICS – the branch of biology focusing on genomes

DNA BARCODING – a method of species identification using a short section of DNA

TAXONOMIST – a scientist who specialises in the classification of organisms

GENE EXPRESSION – the process by which information stored in DNA is activated to produce proteins and other molecules

GENE FLOW – the transfer of genetic material from one population to another

ENVIRONMENTAL STRESS – environmental conditions (natural or caused by humans) that can have a negative impact on species

NEXT-GENERATION SEQUENCING (NGS) – technology that allows detailed and fast identification of differences in DNA

NUCLEOTIDE POLYMORPHISMS – variations in DNA sequences among individuals

TRANSCRIPTOMICS – the study of the complete set of RNA transcripts produced by the genome – under specific circumstances or in a specific cell – using high-throughput methods such as RNA sequencing (RNAseq)

TROGLOBITIC – a cave-dwelling species

The Amazon is an area that spans eight countries: Brazil, Bolivia, Peru, Ecuador, Colombia, Venezuela, Guyana and Suriname, as well as French Guiana, which is an overseas territory of France. Its rainforest covers about 40 percent of Brazil's total area and is home to an estimated one in every 10 species found on Earth, which gives you an idea of its enormous size and the significant diversity contained within it.

The Amazon is one of the most remarkable areas on our planet and its vastness and the richness of life it contains are just two of the reasons why it is of keen interest to scientists across a range of disciplines. The rainforests situated in the Amazon contain between 90 and 140 billion tonnes of carbon, which helps to stabilise the global climate. Protecting this rainforest and understanding more about the life located within the Amazon region is of particular importance to researchers like Dr Guilherme Oliveira.

Guilherme is the Scientific Director of the Vale Institute of Technology – Sustainable Development. His field of research is environmental genomics and bioinformatics, which has seen him trawl through and across the Amazon to conduct genomic analysis of plants, animals and microorganisms. The chief aim of his research is to understand more about this beautiful region and uncover some of its biological mysteries.

WHAT IS GUILHERME WORKING ON SPECIFICALLY?

Guilherme's team participates in CABANA (Capacity Building for Bioinformatics in Latin America), a programme strengthening the field of bioinformatics in Latin America. CABANA involves an international consortium of organisations – one in the UK and nine in Latin America – and is focusing on the three areas of communicable disease, sustainable

DR GUILHERME OLIVEIRA

Scientific Director of Vale Institute of Technology – Sustainable Development, Brazil

FIELDS OF RESEARCH

Environmental Genomics, Bioinformatics

RESEARCH PROJECT

Conducting genomic analysis on plants, animals and microorganisms in the Amazon to understand more about this still relatively unknown area of the world

FUNDERS

Vale, CNPq, NovoNordisk, UKRI-BBSRC [grant no. BB/P027849/1], CAPES-SIU, The Research Council of Norway

food production and protection of biodiversity, with Guilherme focusing on the latter. His research uses DNA sequence data with the aim of describing and protecting biodiversity. However, alongside this, Guilherme is working on projects relating to species of importance to agriculture and health.

HOW DOES GUILHERME CONDUCT HIS RESEARCH?

Guilherme's team employs DNA barcoding, which uses a short part of the genome of a given species to establish a sequence that is unique to it. "We first determine the sequence for a specimen, identified by a taxonomist, in a particular group. We can capture the taxonomic knowledge in the DNA sequence and, for future specimens, we can identify species by sequencing," explains Guilherme. "This is an enormous advantage as we can produce DNA sequences and analyse them on a large scale, while the taxonomist can optimise their time to generate other references or resolve difficult issues."

As with the barcodes that you find in supermarkets that identify a specific product, DNA barcodes identify a specific species, but while you scan a specific barcode in supermarkets, Guilherme and his team are able to use a sample – which can be water, soil, faeces or even air (known as environmental DNA or eDNA) – to identify a species.

Guilherme is often in the field gathering data. As the leader of the institute, he is interested in identifying new species (his group has identified thousands of genetic references of fauna and flora to date). DNA barcoding is important as specialists like Guilherme can ascertain whether what they are reviewing has ever been identified before. "For some of the studies, we will process the samples to identify variations, sequence the entire genome, determine which genes are expressed, or find out which proteins are being produced," says Guilherme. "Once the data is produced, the bioinformatics team takes over. The analysis is conducted by the bioinformaticians in collaboration with the biologists and all sequences are deposited in public databases and published in open access journals."

WHAT CAN MOLECULAR MARKERS TELL US ABOUT PLANT HEALTH?

By using DNA barcodes and eDNA, Guilherme and his team can monitor any given species in an environment. "We can observe where DNA that was previously observed is no longer detected, which can show that the environment has been disturbed in some way," explains Guilherme. "If we have deeper knowledge of a plant at the genomic scale, we are able to verify if the genetic diversity of the species is being eroded by nature. Such findings can point to the diminished capacity of a species to adapt to its environment. Furthermore, if we have studies of gene expression of the species, we can correlate that with environmental stress and use the gene as a marker for monitoring the health of a species."

WHAT HAVE GUILHERME'S STUDIES SHOWN, SO FAR?

One of Guilherme's key findings is related to gene flow in the Amazon. Gene flow is fundamental to evolution. In Brazil, legislation indicates that the conservation of a species requires the maintenance of the genetic diversity observed in nature; determining the gene flow is essential to understanding the health and status of species in the Amazon. One of Guilherme's studies has, for the first time, discovered that cave environments within the Amazon are connected underground. "We observed that populations of certain cave dwellers are the same across long distances," explains Guilherme. "This observation has contributed to how we perceive the iron cave systems in the Amazon. They were initially taken to be individualised caves, such as islands, but now we know that there is gene flow between troglobitic species."

By using landscape genomics to study a particular species, Guilherme and his team are able to understand more about how a species is structured and how gene flow occurs between populations. Such understanding is essential to determining whether genetic diversity is being maintained in the Amazon. If it is not, then there is cause for concern, as without diversity, a species could easily die out over time.

Guilherme, his team and others involved in the wider CABANA project are working to establish a new standard for biodiversity work that enables conservation while industrial activities occur. "While we do not participate in decision making, we are able to provide the best science to support any decisions, at the same time as creating educational resources for society," says Guilherme. "We all need to respect the environment and the Amazon is a vast genetic resource that is essential to local communities and their livelihoods."

ABOUT ENVIRONMENTAL GENOMICS AND BIOINFORMATICS

If environmental genomics can be thought of as a means of collating knowledge of organisms and ecosystems through analysis, then bioinformatics is the method by which scientists are able to make sense of the data. Although the two fields are distinct, they complement each other, as is shown through Guilherme's research.

While we live in an age where it appears that everything we can know is at our fingertips (one only needs to perform a search engine query to find the answer to a given question), environmental genomics and bioinformatics help to demonstrate how much there is that we do not know. The biodiversity that is found within the Amazon region is truly staggering – and it is remarkable to think that there are still places on Earth that remain unexplored – but Guilherme's group is working through the detection and identification of plants, animals and microorganisms to help us better understand the world in which we live.

WHAT DOES A TYPICAL DAY LOOK LIKE FOR GUILHERME?

As you can imagine, field work in the Amazon is tough – there are no smooth roads or easy access to the areas the team is working in, and the area they are looking at is vast (most of the work the team conducts is in an area of over 1.2 million hectares). The temperature and humidity of the area can also be problematic! "The Amazon has distinct seasons, and it can be extremely hot in the dry season and very wet in the rainy season," explains Guilherme. "Generally, we start work at sunrise as we need to be back by sunset, except for some of the bat work that has to be conducted at night. Despite the environmental challenges, the region is gorgeous, and I never miss an opportunity to be out in the field."

WHAT ADVICE CAN GUILHERME OFFER?

Guilherme emphasises the importance of having a multidisciplinary approach to your work – not just for those interested in following a similar path to him, but for research in general. "Having a multidisciplinary approach will enrich your life, irrespective of the career path you take, so get your boots dirty, do some field work, experiment in the lab, talk to ecologists and do some programming!" he says. "Then, dive into one of the areas you are most interested in. The world is not divided into scientific specialisations that don't cross over, so talk to as many different specialists as needed to get a broader view of the subject of your study. This will give you a better understanding of how your work is connected and develop your analysis."

EXPLORE A CAREER IN ENVIRONMENTAL GENOMICS AND BIOINFORMATICS

- The European Bioinformatics Institute website (**www.ebi.ac.uk**) has a lot of training materials and opportunities.
- The International Society for Computational Biology (**www.iscb.org**) is a great resource for computational biology.
- Guilherme says that the International Barcode of Life events are fantastic for DNA barcoding: **ibol.org**
- The Genetics Society is also very useful: **genetics.org.uk**
- **Salaryexplorer.com** has the average salary for a bioinformatics technician in Brazil as 93,000 BRL annually.
- According to **glassdoor.co.uk**, the average yearly salary for someone in the field of Bioinformatics in the UK is £40,000, while in the US, it is $90,000.

PATHWAY FROM SCHOOL TO ENVIRONMENTAL GENOMICS AND BIOINFORMATICS

Guilherme is a strong advocate for developing basic knowledge in the life sciences. He is also passionate about the benefits of learning basic computer programming skills, particularly as he believes these skills will become increasingly important in the future.

To begin a career as a bioinformatician, you will need a master's degree. However, you will not necessarily need a degree in bioinformatics for a master's; life sciences, computer science, maths, physics and engineering degrees are possible pathways. A PhD in bioinformatics, computational biology, genetics or genomics is generally required to engage in advanced research.

More information can be found at:
www.degreesandcareers.info/stem/bioinformatics

www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/genetics

Photo courtesy of Catherine Brooksbank, EMBL-EBI

ASK GUILHERME

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

As a child, I was enchanted by nature documentaries, in particular, those from Africa. As a biology student, many professors were a source of inspiration – my university had a very strong human diseases department, specialising in parasitic diseases, which is where I focused my studies. Once genomics became my focus, I established a research group at my previous home, the Oswaldo Cruz Foundation. However, nature was always on my mind. My role at the Vale Institute of Technology was the perfect opportunity as it was a chance to combine genomics and nature studies!

WHAT ASPECTS OF CONSERVATION AND BIODIVERSITY WILL THE NEXT GENERATION OF RESEARCHERS BE FOCUSING ON?

Lives and communities depend upon biodiversity; young researchers have a huge challenge to contribute to its conservation. They do not have much time, so I think that prioritisation is necessary. This should be based on the level of threat an environment or a species faces, or on how society will benefit. As a consequence, one may need to work on a species that is not necessarily the biggest, the most beautiful, or the most scientifically curious, but the one that is most threatened or that will enhance the lives of people who are most vulnerable.

HOW IMPORTANT ARE ENVIRONMENTAL GENOMICS AND BIOINFORMATICS IN THE CONTEXT OF CURRENT GLOBAL CHALLENGES?

The COVID-19 pandemic has highlighted how important genomics is. We need it to understand our world today, and bioinformatics is a tool to make good use of genomics data. Being able to utilise basic computer programming skills is key to improving our understanding of the data we gather, but I expect artificial intelligence will play an increasingly important role; it permeates much of what we do already, but it will soon become an essential tool in overcoming environmental challenges around the world.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

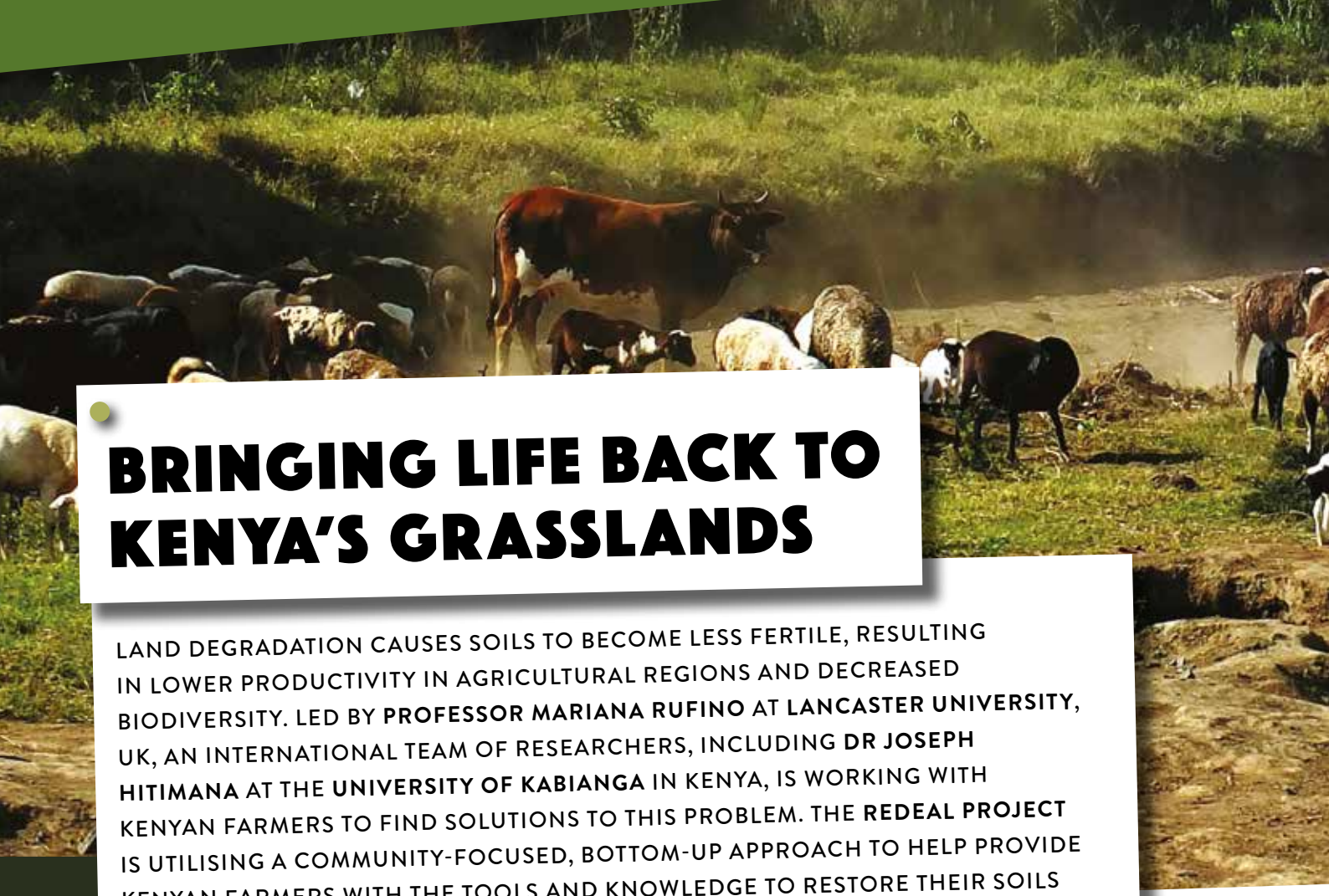
I am very proud to have established genomics and bioinformatics research groups at two different institutions. In one case, for the study of human infectious diseases and in the other, for the study of biodiversity. In both instances, I am certain we have produced works that have been important for the advancement of the field.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

Looking ahead, I would like to be involved in revealing the hidden resources within Amazonian biodiversity. I firmly believe that the use of genomics will unlock tools for biodiversity conservation, new nature-based solutions, and products for the benefit of humanity, with the focus on the enhancement of the lives of traditional peoples.

GUILHERME'S TOP TIP

Every path is unique, but my advice is to trust people, ask for support and establish a strong network. Nobody constructs a career on their own.



BRINGING LIFE BACK TO KENYA'S GRASSLANDS

LAND DEGRADATION CAUSES SOILS TO BECOME LESS FERTILE, RESULTING IN LOWER PRODUCTIVITY IN AGRICULTURAL REGIONS AND DECREASED BIODIVERSITY. LED BY **PROFESSOR MARIANA RUFINO** AT **LANCASTER UNIVERSITY**, UK, AN INTERNATIONAL TEAM OF RESEARCHERS, INCLUDING **DR JOSEPH HITIMANA** AT THE **UNIVERSITY OF KABIANGA** IN KENYA, IS WORKING WITH KENYAN FARMERS TO FIND SOLUTIONS TO THIS PROBLEM. THE **REDEAL PROJECT** IS UTILISING A COMMUNITY-FOCUSED, BOTTOM-UP APPROACH TO HELP PROVIDE KENYAN FARMERS WITH THE TOOLS AND KNOWLEDGE TO RESTORE THEIR SOILS

TALK LIKE AN AGRICULTURAL SCIENTIST

BIODIVERSITY – the variety of life within an ecosystem

BOTTOM-UP APPROACH – in land management, an approach that involves empowering the users of the land, such as farmers, giving them agency to make their own decisions and to implement solutions

ECOSYSTEM – a biological community of organisms and the physical environment with which they interact

MONOCULTURE – a crop system that involves only a single species in a field at a time

LAND DEGRADATION – a decrease in the quality and productivity of soils

LAND RESTORATION – taking measures to return an area to its former state, such as through improving soils and/or promoting biodiversity

TOP-DOWN APPROACH – in land management, an approach that involves issuing legislation or regulations that land users must follow, which often does not consider the needs of local people

Around a quarter of all land in the world is degraded, and this amount is increasing. Land degradation is defined by a loss in soil quality, which can involve loss of organic matter, decline in nutrient availability and/or erosion. As soils become less fertile, biodiversity decreases and agricultural yields fall.

"Land degradation can happen as a result of various natural and human activities," says Professor Mariana Rufino, an agricultural scientist at Lancaster University. These include climatic changes, intensive agriculture and over-grazing of livestock.

Sub-Saharan Africa is a land degradation hotspot, making it a focal point for restoration projects. "The problem is particularly urgent here as land degradation reduces crop and livestock productivity, damaging the livelihoods of farming communities and making them more vulnerable to climate change," says Mariana. It also jeopardises neighbouring ecosystems. As existing agricultural land becomes degraded and therefore less productive, farmers may convert surrounding forests and grasslands into farmland.

PROJECT REDEAL: CONNECTING SCIENCE WITH COMMUNITIES

Mariana is leading the ReDEAL (Restoring Degraded African Landscapes) project, where an interdisciplinary team of researchers is hoping to reverse the trend of land degradation at two sites in Kenya: Kericho and Lower Nyando. As well as addressing the underlying science of land degradation, they are engaging with local farmers to understand the social and economic pressures faced by communities, ensuring the land restoration practices they develop will persevere far beyond the project's lifespan.

However, success of the project depends upon the researchers having the same objectives as the people they aim to support. "From household surveys, we learnt that farmers and scientists have different definitions for degraded grasslands," says Dr Joseph Hitimana, an agricultural and forestry scientist at the University of Kabianga. "Therefore, we need to ensure we build a shared understanding and work towards a common goal." The team is collaborating with farmers to understand what properties they require from a productive grassland, and how these can be integrated with key features of resilient grasslands.

"Farmers have different priorities to scientists," says Joseph. "In Kenya, farmers rely on grasslands to feed their cattle, which in turn feed their families and provide a source of income." Farmers, therefore, have a vested interest in avoiding land degradation. However, limited income often means farmers must prioritise the short-term picture, ensuring they have enough food and income for the current year, rather than considering the long-term picture of whether their land is degrading. "Farmers may overlook early signs of land degradation if they are not currently impacting their production goals," explains Mariana.

Another factor is the popularisation of a western style of agriculture, which typically involves large areas of monoculture crops or low-diversity grasslands. This style of agriculture, though it can lead to significant short-term productivity increases, can exacerbate degradation when soil nutrients are depleted and the biology of the soil is affected by the use of chemical fertilisers and pesticides.

"As scientists, we hold very particular views on degradation, founded in biophysical measures and indicators of soil functionality," says Joseph. "However, these scientific measures do not necessarily consider the important social and economic pressures that farmers face when making decisions about their land." Reconciling these two contrasting perspectives of land degradation between farmers and scientists is a key aim of the project.

ECOLOGICAL LESSONS

By working with local farmers, the team has identified that increasing plant biodiversity could be a potential solution for restoring degraded land in Kenya and other Sub-Saharan regions. "Manipulating plant biodiversity on degraded land can enhance soil functions and increase the resilience of farming," explains Mariana. "We have found that more diverse mixtures of plants rapidly enhance soil properties during the early stages of restoration, supporting the recovery of soils." Different plants have different functions in ecosystems, such as mobilising nutrients within the soil and as key sources of food for insects, some of the critical pollinators that fertilise crops.

Farmers provided the team with their knowledge of local plant species, and the researchers conducted experiments to grow these plants in different conditions. "Selected species were grown in pots with soils taken from our study sites in Kericho and Lower Nyando," says Mariana. "This enabled us to learn which traits allow plants to grow under different soil conditions." The team has now identified which selections of plant species grow most successfully in soils of various states of degradation.

At the study sites, the team is also investigating how these combinations of plants respond to different land treatments, such as tilling the soil and using manure as fertiliser. "We're assessing which combinations of grassland management practices are most effective for restoration, as well as which are most attractive for implementation by the farmers," says Joseph. The most important feature of any land restoration scheme is that it must be desirable for local farmers. If it is expensive, time-consuming or reduces the productivity of their land in the short-term, farmers will have no incentive to participate.

The team has also investigated different methods of livestock management, surveying how land degradation is affected by different cattle numbers, grazing regimes, availability of feeds, and interactions with current restoration attempts. "By integrating this information with farmers' needs and wants, we can design bespoke land management recommendations that best fit their aspirations," says Mariana.

A BOTTOM-UP APPROACH

'Top-down' approaches, which involve governments or scientists telling farmers what to do, are often unsuccessful. Enforcing regulations is expensive, logistically challenging and ignores the needs of the individuals whose livelihoods are affected. These approaches often neglect to consider the variability in different areas, attempting to give the same solution for all regions when in fact a more tailored approach is needed. Designing a tailored approach requires involvement from those who best understand the land – the farmers themselves.

Therefore, Project ReDEAL advocates a 'bottom-up' approach instead. "We want our initiatives to be taken over and run by local farmers and local institutions," says Rachael Middleton, the research administrator for the project. "The science-based solutions we develop need to be cost-effective for farmers and must consider their livelihoods." The farmers know their land better than anyone, so are best placed for implementing the most effective solutions. "Farmers need to have the power to make decisions and design solutions for the challenges they encounter on their land," explains Rachael. "This is vital for socio-economic development in the region."

The ultimate aim of ReDEAL is for the land restoration methods developed during the project to be carried forward by local farmers. The team is hosting workshops and training events to teach farmers, agricultural students and land management agencies throughout Kenya how to implement these land management solutions. When the project ends, these outreach and engagement measures will ensure the legacy of the project lives on.

PROFESSOR MARIANA RUFINO

Professor of Agricultural Systems, Lancaster University, UK

FIELD OF RESEARCH

Agricultural Sciences

DR JOSEPH HITIMANA

Dean of Agricultural Sciences and Natural Resources, University of Kabianga, Kenya

FIELDS OF RESEARCH

Agricultural Sciences, Forestry

RESEARCH PROJECT

Investigating methods for promoting land restoration and using a bottom-up approach to promote these methods among rural communities in Kenya

FUNDER

UK Research and Innovation's Biotechnology and Biological Sciences Research Council (BBSRC) as part of the Global Challenges Research Fund

ABOUT AGRICULTURAL SCIENCE

Agricultural science encompasses a wide range of disciplines, and the ReDEAL project highlights how this interdisciplinarity is essential for tackling the issue of land degradation. Agricultural scientists may also address other environmental problems caused by agriculture, such as depletion of water supplies, overuse of fertilisers and pesticides, and loss of biodiversity due to agricultural intensification.

WHAT DIFFERENT SKILLSETS ARE NEEDED TO ADDRESS LAND DEGRADATION?

"Land degradation results from multiple interacting factors, which means there is a need to include expertise from different disciplines," says Rachael. "It's not just a biological issue, as degradation and restoration both impact the human communities that use the land. The ReDEAL project addressed this by building a diverse team of ecologists, agronomists, soil scientists, anthropologists, social scientists, environmental scientists and geographers."

WHY SHOULD LAND MANAGEMENT BE COMMUNITY-BASED?

"Communities are the owners of the land and rely on it for their livelihoods and income generation," says Joseph. "However, communities often lack the resources or exposure to new methods needed to develop more sustainable ways of land management. Scientists can help empower rural communities to develop effective resource management skills. Blending traditional knowledge in resource management results in sustainable development and provides communities with a greater sense of ownership and social pride. The effectiveness of this process gives me hope for the future."

HOW CAN LAND RESTORATION BENEFIT FUTURE GENERATIONS?

"ReDEAL is addressing a complex and pressing problem by building a solution for the future that incorporates ecological, social and economic concerns," says Mariana. "I am convinced we need to create 'green jobs' to engage young people in reconnecting with the land that feeds us, while helping society build resilience to environmental changes. This would also help address the serious issue of youth unemployment in Africa."

EXPLORE A CAREER IN AGRICULTURAL SCIENCE

- Mariana recommends seeking summer placements with land management organisations such as Natural England (**www.naturalengland.gov.uk**), or with farmers or farming organisations such as the National Farmers' Union (**www.nfuonline.com**). There is an increasing awareness in such organisations to improve sustainability and resilience.
- Lancaster University runs many outreach initiatives, including summer schools and STEM days for school students (**www.lancaster.ac.uk/sci-tech/about-us/outreach**). The Lancaster Environment Centre provides support to schools and teachers (**www.lancaster.ac.uk/lec/about-us/engagement**).
- Prospects gives an overview of possible career paths in agricultural sciences and provides links to potential work experience opportunities in the UK and abroad: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/agriculture**

MARIANA AND JOSEPH'S TOP TIPS

01 Be brave, try new things and don't listen to that inner voice that doubts your abilities.

02 To live a rewarding life, we need to find out what matters to us, which involves encountering a variety of experiences.

03 Whatever path you aspire to follow, pursue it with passion and honesty.

04 The power of positive thinking is real. Think positively, nurture creativity and live in harmony with yourself.

PATHWAY FROM SCHOOL TO AGRICULTURAL SCIENCE

- At school, study biology, chemistry and geography for a foundation in agricultural science. Humanities subjects will help you understand the social aspects of agricultural activities, while maths will be useful for data analysis.
- Some universities provide degrees in agricultural sciences, but degrees in ecology, plant or soil science, geography or environmental science could also lead to a career in agriculture or land restoration.

HOW DID MARIANA BECOME AN AGRICULTURAL SCIENTIST?

I grew up on a farm in Argentina and spent lots of time outdoors. As a young child, I had an insatiable thirst for knowledge – I wanted to know everything! I have always been fascinated by science, then, as a teenager, I did a geography project about the rivers of Africa. I became fascinated by that mysterious continent and wanted to explore it.

I knew I wanted to go to university as I was passionate about learning. After completing a degree in agronomy in Argentina, I worked as a research assistant for a couple of years. I wanted to see more of the world and was lucky enough to secure a master's degree in the Netherlands, where I met a professor who helped me establish my first research project in Africa.

I have now spent almost 20 years conducting research in this beautiful continent. I have visited many countries and lived in Kenya for six years. My hope is that environmental problems in Sub-Saharan Africa do not increase.

Our relationship with nature has changed since I was a child. This is especially obvious in high-income countries where many of us have adopted urban lifestyles and lost our connection to the natural world. People no longer know where food comes from.

I have always embraced opportunities and challenges that have come my way, which has helped me build experience as a researcher. It is important to keep your eyes open to opportunities, to try new things and to ask others for help. I have always been amazed to see how many people are willing to help when I ask.

HOW DID JOSEPH BECOME AN AGRICULTURAL AND FORESTRY SCIENTIST?

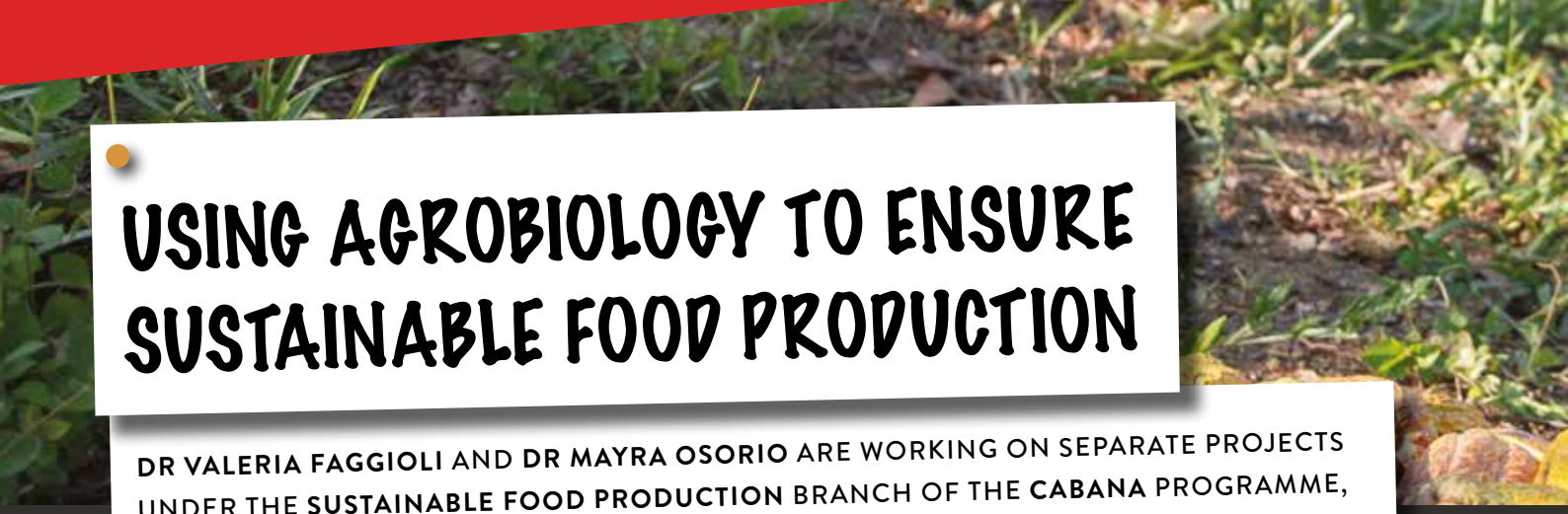
I was an attentive student when I was younger. I enjoyed listening to stories and playing during my free time. Mathematics was my favourite subject, but I was curious to learn about others, too. I wanted to pursue applied sciences or to be a medical doctor.

I have always endeavoured to pursue my studies and work with passion. I enjoyed my university education, and when I was granted a lecturing position, I embraced the opportunity to teach students and work in harmony with other academics. I am now the Dean of the School of Agricultural Sciences and Natural Resources, a role which has a lot of responsibility. I focus on achieving clear goals, using my own energy and skills but also looking for support from others where needed.

As a scientist, I am motivated by a sense of responsibility to humanity. I want to use my work and my abilities to make a positive impact, no matter how small it may be. I value self-motivation and am guided by the philosophies of positive thinking and teamwork.

I take great pride in training graduates to become competent and confident scientists who positively contribute to the welfare of our environment and people. I am also proud of my published research, which has engaged the international community and promoted a sense of shared values and aspirations beyond geographical boundaries.

In the future, I hope to build the research and training capacity in my university through international partnerships. I wish to reveal the coexistence between the natural environment, its resources and communities, which will enable the real harmony between people and nature to prevail.



USING AGROBIOLOGY TO ENSURE SUSTAINABLE FOOD PRODUCTION

DR VALERIA FAGGIOLI AND **DR MAYRA OSORIO** ARE WORKING ON SEPARATE PROJECTS UNDER THE **SUSTAINABLE FOOD PRODUCTION** BRANCH OF THE **CABANA** PROGRAMME, WHICH AIMS TO ACCELERATE THE IMPLEMENTATION OF DATA-DRIVEN BIOLOGY TO OVERCOME A RANGE OF ENVIRONMENTAL CHALLENGES IN LATIN AMERICA

TALK LIKE AN AGROBIOLOGIST

AGROECOSYSTEM – a functioning unit of agricultural activity

ANTHROPOGENIC – of, relating to, or resulting from the influence of human beings on nature. For example, anthropogenic pollutants

BIOINFORMATICS – a subdiscipline of biology and computer science concerned with the acquisition, storage, analysis and dissemination of biological data

CARBON SEQUESTRATION – the process of capturing and storing atmospheric carbon dioxide

ENERGY METABOLISM – all the chemical processes that go inside an organism to generate energy

GENOTYPE – an organism's complete set of genetic material

METAGENOMICS – the study of a collection of genetic material (genomes) from a mixed community of organisms

MGNIFY – a free resource for the analysis and comparison of metagenomic data

PHENOTYPE – the observable physical properties of an organism

PHOTOSYNTHESIS – the process by which plants turn sunlight into chemical energy

PHYSIOLOGICAL – relating to the functions and mechanisms of a living organism

SOIL MICROBIOME – the dynamic community of microorganisms associated with plants and soil

STOMATA – pores found in the leaves, stem and organs of a plant

STOMATAL CONDUCTANCE – a measure of a plant's stomata opening and closing (and hence, water loss)

TILLAGE – the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning

TRANSPIRATION – loss of water vapour through the stomata

TRANSCRIPTOMICS – the study of the complete set of RNA transcripts produced by the genome – under specific circumstances or in a specific cell – using high-throughput methods such as RNA sequencing (RNAseq)

Whether through the direct effect of human activity, such as deforestation and mass crop production, or the indirect impacts caused by climate change, such as droughts and floods, the natural world is under a huge amount of pressure unlike ever before. To ensure our planet continues to provide for us, researchers the world over are investigating ways to make the way we live more sustainable. How we get our food is a huge part of this.

With this in mind, CABANA (Capacity Building for Bioinformatics in Latin America) is an exciting initiative strengthening the field of bioinformatics in Latin America. The programme is an international consortium of organisations – one in the UK and nine in Latin America – and targets three specific challenges: communicable disease, protection of biodiversity and sustainable food production.

Dr Valeria Faggioli, of the National Institute of Agriculture Technologies in Argentina, and Dr Mayra Osorio, of the Pontificia Universidad Javeriana in Colombia, have worked on research projects under CABANA's sustainable food branch.

SUSTAINABLE SOILS

Valeria is investigating the impact of long-term anthropogenic practices, such as intensive farming, on soil bacterial and fungal communities. Human activities that may be considered necessary for society – from planting certain plant species to constructing buildings – impact soil microbiomes and can affect the condition of the soil. They also have potentially devastating effects on food production, now and in the future.

Valeria is also investigating the long-term impact of human activities on soil microbiomes, with a view to demonstrating the need to change local and national practices to ensure sustainable food supplies. By studying soil samples, she hopes to show how human alteration of soil microbiomes can be sustainable if the modification is done thoughtfully and strategically, following procedures that consider the importance of ecosystem conservation.

A UNIQUE STUDY

The soil samples Valeria has studied were taken from the oldest experiment of soybean monoculture in the world. "The experiment was initiated in 1975 and includes a sustainable technique for cropping soybean, which includes the no-tillage method. This is now widely used in Argentina and other countries, but was novel at the beginning of the experiment,"

she explains. “Planting without ploughing is crucial to preserve soil and accumulate organic matter contributing to reduced carbon dioxide emission to the atmosphere. The microbiome inhabiting such conditions represents a valuable resource to improve carbon sequestration in agricultural soils.”

METHODS

Supported by CABANA, Valeria spent several months in Rob Finn’s lab at the EMBL-European Bioinformatics Institute. There, she used a bioinformatics tool that classifies fungi and bacteria from DNA sequencing reads. She also used MGnify, a bioinformatics service run by the institute, which allowed for a complete analysis of the data and a precise identification of microorganisms in her unique set of soil samples. The main advantage of MGnify is that it allows researchers like Valeria to publish their own data in a way that can be used by other scientists and to visualise and analyse their data alongside similar datasets from investigations around the globe.

THE IMPACTS

Valeria’s research has generated information about the composition of microbial communities under different cropping practices in a specific location over a long period. It showed that no-tillage systems supported a more diverse soil microbiome and, ultimately, higher crop yields. “As soybean cultivation is spreading around the world because of its nutritional (mainly protein) value, the consequences on soil microbiomes can be extrapolated to other agroecosystems,” she says. “For instance, in South Africa, the crop has been recently adopted by farmers and we can share information about the consequences in terms of soil biological properties.”

THE NEXT STEPS

As Valeria’s research has shown, it is possible to identify thousands of species in a single gram of soil, so the next step is to establish the functional role of the identified species. So far, her findings have been presented in virtual seminars – nationally and internationally – for the scientific community and the farmers who will utilise the findings in the future.

SUSTAINABLE PLANTS

Mayra’s research aimed to characterise and compare the responses of two varieties of the Cacao plant to water deficit. How do the genetic differences between these Cacao varieties affect their reactions to drought? Can this information be used to develop more drought-resistant varieties of Cacao?

Cacao cultivation is suffering from changes in rainfall because of global warming. The availability of water has reduced and there have been significant losses in yield, and the situation is expected to worsen.

INVESTIGATIONS

A typical day in the field sees Mayra getting up before dawn to collect physiological data, like hydric potential, which is indicative of the water status of a plant. “The rest of the day involves the observation of the plants and collecting data related to photosynthesis, stomatal conductance, and transpiration, through which it is possible to analyse the effect of drought on plant fitness,” explains Mayra. “For all these data measurements, I use special equipment, some of which is very heavy, and with little or no lighting. I register data in my field experiment notebook or directly on the computer.”

METHODS

Mayra also uses RNA sequencing (RNAseq) to find out which genes were expressed in samples from her Cacao plants. These patterns of gene expression can indicate which biological pathways are affected by the plant’s response to water shortage. The team Mayra works with uses statistical methods to help answer the biological question being addressed. “I expected that the Cacao genotypes would respond differentially to severe water deficit stress,” she says. “There were several approaches. For example, for the physiological data, we used an analysis of variance (ANOVA), followed by a mean comparison. In the case of RNAseq data analysis, the amount of data is so big and noisy that several analytical steps are needed, connected sequentially into a complex

DR VALERIA FAGGIOLI

The National Institute of Agriculture Technologies, Argentina

FIELD OF RESEARCH

Microbiology

RESEARCH PROJECT

Investigating the impact of long-term anthropogenic practices on soil bacterial and fungal communities

DR MAYRA OSORIO

Plant and Crop Biology Lab, Department of Biology, Pontificia Universidad Javeriana, Bogotá, Colombia

FIELD OF RESEARCH

Biology

RESEARCH PROJECT

Characterising and comparing the phenotypic response to water deficit stress of two Cacao genotypes with contrasting physiological behaviour

FUNDERS

Vice-presidency for Research of the Pontificia Universidad Javeriana; Valeria and Mayra’s CABANA secondments were funded by UKRI-BBSRC [grant no. BB/P027849/1] and European Molecular Biology Laboratory

bioinformatic pipeline. This involves data filtering and transformation, statistical testing and graphical representations of analysed data, using several software tools and databases developed by computer scientists or bioinformaticians." Mayra conducted this part of her study at the EMBL-EBI, spending several months in the Gene Expression Team led by Dr Irene Papatheodorou, with the support of CABANA.

THE FINDINGS

The Cacao clones evaluated showed different levels of tolerance to drought; to a certain degree, they were all able to recover from a severe drought after rehydration. However, Mayra did find differences between the genotypes. "The most tolerant seemed to respond more to the specific type of stress imposed while maintaining a certain level of photosynthetic rate. The less tolerant clone response was seemingly broader, involving important changes in energy metabolism and photosynthesis," she explains.

THE IMPACTS

Mayra's research provides new insight into the genes involved in the tolerance of Cacao plants to stress caused by drought, which, until now, has been unclear. "Our results are relevant for seedling establishment in the field. For example, the high susceptibility to dehydration of young trees is something growers need to be aware of," she says. "Differences found in efficient tolerance mechanisms and identification of the genes involved open new avenues for research aimed at understanding this response in more depth, as well as for genetic improvement of this trait."

Growing Cacao varieties that are more tolerant to climate conditions influenced by global warming is becoming more necessary. As Mayra explains, "Cacao cultivation provides a livelihood for smallholder farmers and their families. It is part of their everyday diet and an important source of antioxidants." Importantly, Cacao also provides farmers with a viable alternative to growing coca for the drugs trade.

Agro research like Mayra and Valeria's is helping to keep the environment healthy, food production sustainable and people's lives secure.

ABOUT BIOLOGY

Biology is a pathway to microbiology, agrobiology, agronomy, bioinformatics, molecular biology and plant physiology.

Global warming and the resultant climate change are adversely affecting all corners of life, including food production. The global population is increasing at a rapid rate – more food will need to be produced to feed more people. Determining which practices are harmful to food production will help identify beneficial practices and secure a sustainable future – and biologists will continue to play a significant role in this.

"Latin America is a crucial grain producer in the world and the success of crop seasons can determine the provision of food worldwide," explains Valeria. "To achieve this, the next generation of microbiologists must strengthen collaborative networks with scientists to generate brand new information and with farmers/decision makers to have a real impact in agriculture."

EXPLORE A CAREER IN BIOLOGY

- Valeria advises identifying the subjects you like most, creating a Twitter account, and following researchers, labs and societies relating to the topic – this will help update you on any open positions.
- Prospects has a page dedicated to biology and all the things that you can do with a degree in the subject, including links to useful organisations: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/biology**
- Explore the work of The European Bioinformatics Institute (EMBL-EBI): **www.ebi.ac.uk**
- According to the ERI Economic Research Institute, the average salary in a year for a biologist in Argentina is ARS 900,000 (**www.erieri.com/salary/job/molecular-biologist/argentina**) and in Colombia it is COP 36,000,000 (**www.erieri.com/salary/job/biologist/colombia**).
- In the UK, the average salary of a biologist can range from £15,000 to £70,000 depending on the level of experience and the particular role you are performing: **nationalcareers.service.gov.uk/job-profiles/biologist**

PATHWAY FROM SCHOOL TO BIOLOGY

Mayra and Valeria are keen to emphasise that the subjects you should study depend on your specific interests as biology is a broad field. However, there are some that are of particular importance, such as genomics and molecular biology, computational biology/bioinformatics (including programming skills), experimental design, biochemistry and (nano)biotechnology.

Mayra also stresses the importance of communication. "A high English language proficiency is critical for non-native speakers, as many of the above opportunities are available abroad, and this is a key competency to write proposals, publish papers or apply to any international call," she says. "I have faced these issues myself at different moments and it is important to see them as personal challenges that must be overcome if you are to succeed."

MEET MAYRA

MAYRA'S TOP TIP

Persevere and always finish what you started, no matter how difficult it seems to be!

When I was studying biotechnology engineering, I realised that I could find answers to contribute to food security. I started working with in vitro tissue culture of important tropical food crops, with the aim of obtaining low cost and high quality clonally propagated seedlings. Improving seedling quality and diversity, and making them more affordable for farmers, is one way to improve field production and food security. Since then, I have worked on tropical food crops and begun to incorporate molecular biology, physiology and bioinformatic approaches to address different aspects related to crop biology.

I have always been interested in the genetic improvement of food crops. I started with plant tissue culture and in vitro regeneration of Cacao, which are important steps for genetic improvement. As Cacao is improved by conventional breeding and hybrid generation, providing basic knowledge – as well as developing phenotyping methodologies related to the improved trait – becomes necessary.

Persistence and patience are fundamental to success. You also need to be curious and love what you are doing, because obstacles are always just around the corner in research. Being creative and confident enables you to look for novel solutions to challenges.

I feel very proud of our results on Cacao drought response using physiological and transcriptomic approaches, with the challenge of integrating them to obtain new knowledge. This allowed me to reach the important and personal milestone of obtaining my PhD.

MEET VALERIA

VALERIA'S TOP TIP

Select your mentor carefully! Ask before accepting a position – remember that science is a constant challenge, and you will need support and guidance.

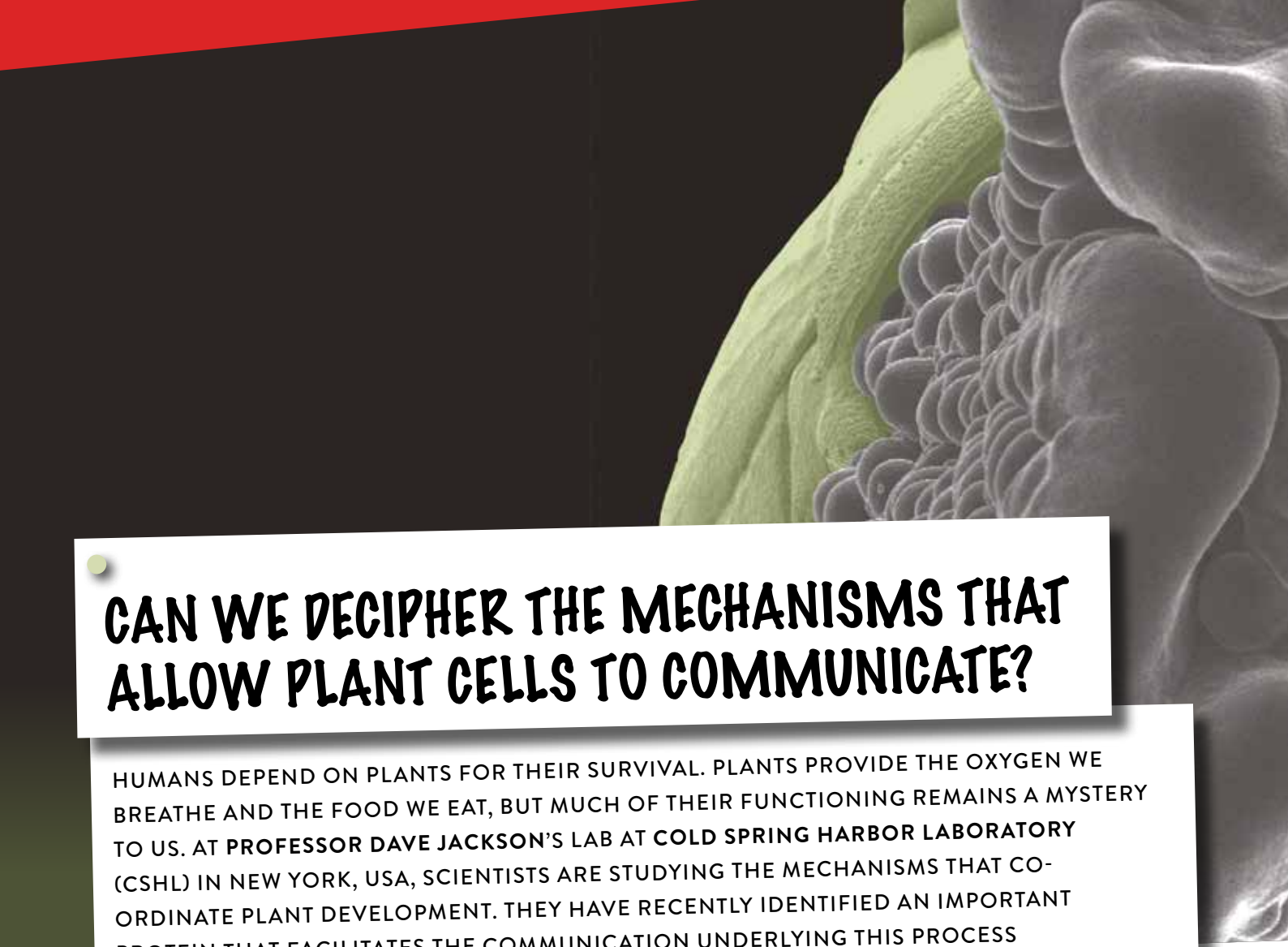
Curiosity inspired me to be a scientist. I grew up in a dairy farm, without other kids or social media. My best friends were my imagination and a couple of books. I remember one book that belonged to my father when he was a primary school student. It was really cool because it included experiments to perform at home. My favourite ones were those involving soil and biology. During the early stages in my professional career, amazing mentors inspired me to embrace science.

At the beginning of my career, I investigated soil biology in agroecosystems and worked in recognised European research institutes. This allowed me to be more prepared to apply and succeed in calls for funding to cover this research.

Motivation and passion about science are the great pillars of my professional life. I am constantly learning new things to apply in my career, not just science topics but also communication and leadership. Soft skills are crucial to embrace a joyful scientific career in this highly competitive world.

To overcome obstacles, persevere and focus on the positives. During this research, there were times when we felt overwhelmed by difficulties, but something inside us gave us the courage to continue and reach our goal.

My proudest career achievement is being an advisor to four doctoral students who are investigating soil microbiology in agriculture. I have mentored 23 undergraduate students over the past 10 years (three of whom are currently doing their graduate thesis). It is a pleasure for me to guide young researchers and motivate them to pursue a career in science.



CAN WE DECIPHER THE MECHANISMS THAT ALLOW PLANT CELLS TO COMMUNICATE?

HUMANS DEPEND ON PLANTS FOR THEIR SURVIVAL. PLANTS PROVIDE THE OXYGEN WE BREATHE AND THE FOOD WE EAT, BUT MUCH OF THEIR FUNCTIONING REMAINS A MYSTERY TO US. AT **PROFESSOR DAVE JACKSON**'S LAB AT **COLD SPRING HARBOR LABORATORY** (CSHL) IN NEW YORK, USA, SCIENTISTS ARE STUDYING THE MECHANISMS THAT CO-ORDINATE PLANT DEVELOPMENT. THEY HAVE RECENTLY IDENTIFIED AN IMPORTANT PROTEIN THAT FACILITATES THE COMMUNICATION UNDERLYING THIS PROCESS

TALK LIKE A PLANT BIOLOGIST

PLASMODESMATA – tiny channels that connect adjacent plant cells to each other

CHAPERONE – a molecule that helps large molecules un-fold so that they can move through plasmodesmata

STEM CELLS – undifferentiated cells that have the ability to develop into all types of plant cells. They are crucial to the plant's growth and development

mRNA – a type of nucleic acid that transmits the information from DNA into making proteins

RNA BINDING PROTEIN – proteins that bind to RNA molecules and help them, among other things, to move around and between cells

KNOTTED1 – a gene found in plants that gives stem cells their special functions and is vital for a plant's growth and development

Communication between cells is a vital process for all multi-cellular organisms, and plants are no exception. In plants, this communication is particularly important during the development stage, when stem cells differentiate into all of the cells that an adult plant needs. Communication allows each cell to know which kind of cell it needs to become. Even when the plant is fully grown, its cells still need to be able to 'talk' to each other. They share information to co-ordinate the plant's responses to changes in light and temperature, and to protect the plant from pathogens and disease.

One common form of cell-cell communication involves signal molecules, known as ligands, being released from a cell and binding to a receptor molecule on a different cell. Once the ligand has bound to the receptor, it changes shape and sets off a chain reaction in the receiver cell. This allows the receiver cell to react accordingly to the signal delivered by the ligand.

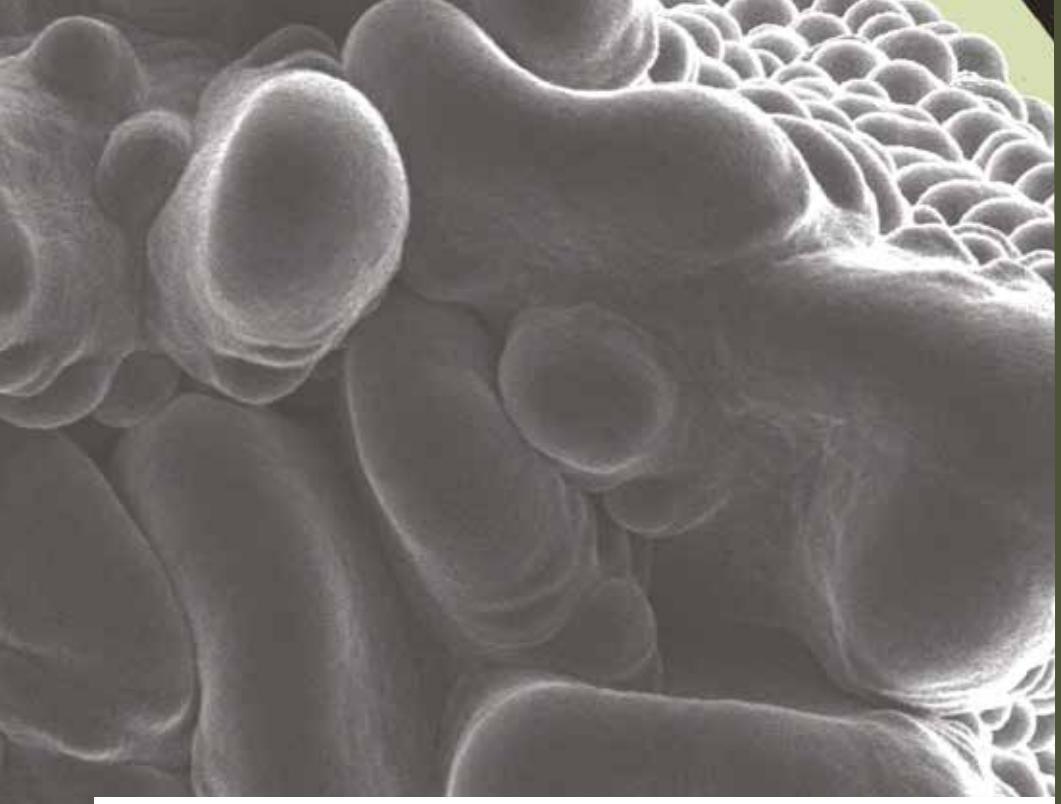
Beyond this indirect form of communication, plants also use proteins and RNA molecules to send signals directly to a receiver cell. This form of signalling is faster and more efficient as the signal molecules pass directly between cells using tiny pores called plasmodesmata.

Professor Dave Jackson, based at Cold Spring Harbor Laboratory in New York, has recently discovered how a particularly important RNA signal molecule passes through these pores.

HOW DO SIGNALS PASS THROUGH PLASMODESMATA?

The plasmodesmata are so small that only tiny molecules like water or nutrients can pass through them easily. The size of the plasmodesmata can change throughout the plant's life and this affects which molecules are able to pass through them. This dynamism is crucial to co-ordinating the plant's development and can also help the plant protect itself from disease. If a cell is infected by a pathogen, the plasmodesmata can shrink, keeping the pathogen locked in and stopping it from spreading around the plant.

Large molecules, like proteins and RNA, need special help to guide them through the membrane. "Proteins are strings of amino acids, but in order to function, they need to be folded properly, like turning a ball of wool into a sweater," explains Dave. This folding process increases their size and prevents them from moving through the plasmodesmata. Special chaperone molecules help these larger molecules



PROFESSOR DAVE JACKSON

Cold Spring Harbor Laboratory, USA

FIELD OF RESEARCH

Plant Biology

RESEARCH PROJECT

Investigating how important signals move between plant cells to aid with development and growth

FUNDERS

US National Science Foundation (NSF), US Department of Agriculture

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to unfold and squeeze through the pores so that they can take their signals to other cells.

WHAT IS THE KNOTTED1 GENE?

Dave has been studying a gene called KNOTTED1 (KN1), which keeps plant stem cells in their undifferentiated, embryonic state, and is therefore crucial to the plant's growth and development. To do its job, the KN1 gene needs to send signals between cells, which it does via an RNA signal molecule. Dave and his team have managed to identify a protein that helps to escort the KN1 RNA molecule through the plasmodesmata so that it can move between cells.

HOW DID THEY STUDY THE KNOTTED1 RNA MOLECULE?

Dave and his team used a genetics technique known as 'screening' to search for genes that are involved in the transport of the KNOTTED1 RNA signal molecule. They identified a gene that encodes an RNA binding protein, which they suspected to be the molecule they were looking for.

To take a closer look, Dave's team used a technique called MS2 tagging. This technique makes use of a viral protein that binds to a specific RNA sequence. The team added this RNA sequence to the KNOTTED1 RNA molecules and expressed them in the plants being studied. The team then attached a fluorescent marker to the viral protein and introduced these into the plants as well, so that when they attached to the specific RNA sequences, each KNOTTED1 RNA molecule gained a fluorescent tag that the scientists could use to track their movements.

"Next, using a fancy microscope called a super-resolution confocal, we could watch the KNOTTED1 RNA moving around in the cell, and even saw it moving to the plasmodesmata," says Dave. "That was a real breakthrough moment!" The team then used another technique called immunoprecipitation to identify that the RNA binding protein was attaching to the KNOTTED1 RNA signal molecule, confirming their suspicions.

WHY ARE RNA BINDING PROTEINS IMPORTANT?

RNA binding proteins control which RNA molecules move through the plasmodesmata. This means that they control which cells receive signals from the RNA molecules, which has a significant effect on the plant's development. If the movement of RNA signal molecules was not regulated, the development of the plant's cells would become confused and disordered, leading to a break-down of the whole system. "It would be like chopping up your favourite house plant in a blender, then hoping it would grow afterwards," explains Dave.

HOW DO RNA BINDING PROTEINS WORK?

How RNA binding proteins bind to specific RNA molecules is not yet fully understood. Dave hypothesises that RNA molecules may have a specific code that allows the binding protein to attach to them. Alternatively, RNA molecules may have chemical modifications that help the binding proteins identify which molecules to attach to.

"We have some ideas... but it's a little too early to discuss them," says Dave. This is what makes his research so exciting. He and his team are conducting what is known as fundamental research. They are not aiming for any specific applications; their goal is simply to understand how things work. "This kind of research is really important, and you never know where it could lead," says Dave. "For example, the discovery of CRISPR genome editing started with researchers trying to figure out why yogurt cultures went bad!"

WHAT IS NEXT?

Having identified the RNA binding protein that enables cell-to-cell transport of the KNOTTED1 RNA molecule, Dave's next aim is to find out how the binding protein actually attaches to the KNOTTED1 RNA, and whether it binds to any other RNAs.

It is this continuing quest of discovery that motivates Dave and makes his work as a plant biologist so rewarding. We rely on plants for many of our basic needs including food, shelter and oxygen. Many plants, such as trees and grasses, are also great at capturing carbon and keeping it out of the atmosphere. As the global population continues to increase and the effects of the climate crisis start to impact farming, fundamental research in plant biology may provide the world with novel solutions to these pressing issues.

ABOUT PLANT BIOLOGY

Plant biology helps us understand the processes and mechanisms that underly some of the most important organisms on earth. Plants form the base of almost all food chains and without them, life as we know it would not exist. Understanding the details of how they work may help us discover new ways of solving some of our biggest problems such as climate change and hunger.

Scientists have been studying plants for a long time, but new technologies and disciplines have allowed scientists like Dave to dive deeper into their complexities.

WHAT DISCIPLINES DO PLANT BIOLOGISTS MAKE USE OF?

"Stem cell research and developmental biology are the major disciplines that we study, and they go together. Stem cells are the starting point of development, since they can multiply and then differentiate into all the different types of plant cells," says Dave. His work also involves genetics, using mutations to understand which genes are involved in the developmental process. Combining these disciplines allows Dave and his team to understand the details of how plants work.

WHAT MAKES PLANT BIOLOGY REWARDING?

"When we make a new discovery, often it's something that no one in the world has ever found before, so it's exciting," explains Dave. "It's also fun to collaborate with scientists all around the world. We can't do every kind of experiment in my lab, but when we have an interesting question, we may be able to find someone in a different lab who has perfected that technique, and we can work together to speed up the research." Dave also spends a lot of time outdoors. "Being out in the corn field during summer and spending time with the plants is a real treat," he says.

WHAT MAKES PLANT BIOLOGY DIFFICULT?

"Many of our experiments fail, sometimes because our ideas are wrong, but often because the techniques are extremely challenging and tricky to get to work," explains Dave. Although their work is often challenging, if the experiments succeed, plant biologists could discover ground-breaking new science. These discoveries could help tackle big societal problems like climate change and sustainability.

EXPLORE A CAREER IN PLANT BIOLOGY

- The multi-disciplinary nature of plant biology means that you might find yourself working in a variety of locations. Some plant biologists, like Dave, spend a lot of time in laboratories using specialist equipment like microscopes and imaging software, whereas others are based in the field, conducting surveys and collecting data.
- The American Society for Plant Biology has lots of information and online talks and symposia that are free to attend: **aspb.org**
- In the UK, Open Plant is a great place to find information and has an 'opportunities' section that advertises online events: **www.openplant.org**
- Dave's lab runs a research programme for high school seniors in the US (**jacksonlab.labsites.cshl.edu/outreach**). Students may also consider writing to professors whose work they find interesting to see if they can shadow a scientist in their labs.
- Dave says that the starting salary of a professor in plant biology is approximately $100,000. For more information about salaries linked to the field, visit: **www.payscale.com/research/US/Job=Plant_Biologist/Salary**

PATHWAY FROM SCHOOL TO PLANT BIOLOGIST

- Nowadays, science is very multidisciplinary so students can enter plant biology from several different pathways, even computer science or engineering.
- It is important to study science subjects, but students should study what they are passionate about.
- Programming skills are needed in all areas of science, so learn them as early as you can!

DAVE'S TOP TIPS

01 Follow your dreams. No matter who you are, if you want to be a scientist, go for it!

02 Be persistent. Science is quite competitive, and you may experience many failures and rejections. But it is worth it!

03 Learn coding skills; they are pretty much universally needed in science these days.

Dave out in the field in Cold Spring Harbor, NY, with his corn plants. Photo credit: Constance Brukin

HOW DID DAVE BECOME A PLANT BIOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

As a child, I was always interested in figuring out how things work. My dad worked as an engineer fixing machines that made wallpaper, and we had a workshop at home and were always taking things to pieces.

HAVE YOU ALWAYS BEEN INTERESTED IN PLANTS?

I never thought about studying plants until I did a research project in my final year of undergraduate study at the University of Leeds. Before that, I always loved the outdoors and so I think it's a good fit.

WHAT WAS YOUR PATH TO LEADING YOUR OWN LABORATORY?

My path was fairly meandering and not exactly planned out! After my undergraduate degree, I worked in a lab in France for a couple of years before returning to the UK to study for my PhD at the John Innes Institute in Norwich. I really came to love genetics because of its logicality and elegance.

I saw a conference talk from Professor Sarah Hake who had just found one of the very first genes that control plant development: KNOTTED1. I loved her talk, so I asked her if I could work with her, and she said yes! I spent five years in her lab in California before getting the position at Cold Spring Harbor. I was nervous about starting my own group and being responsible for managing other people and raising grant funding, but it's been an incredible experience. CSHL is a very supportive and collaborative environment; people share ideas all the time.

WHAT ARE YOUR GREATEST CAREER ACHIEVEMENTS, SO FAR?

I think my greatest achievement is training people who have gone on to have their own independent research positions around the world. I am also proud of having expanded the high school research programme at CSHL – it has exposed a lot of young minds to the excitement of scientific research.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I still have a lot of scientific questions I want to solve. Making new discoveries opens up new questions and uncovers new methods. That is what is so exciting about science – it is constantly advancing, and with new tools we can address deeper questions. I also hope I will see some of our discoveries applied in agriculture, for example, to improve crop yields and sustainability.

WHAT DO YOU ENJOY DOING WHEN NOT WORKING?

I enjoy spending time with family, travelling and listening to live music, especially jazz. I also volunteer with a citizen science group called Genspace, in Brooklyn, New York, USA. It is a diverse group of people, from high school students to retirees, and mostly non-scientists, so we always have interesting discussions. Traditionally, science has been seen as a career for ageing white men like myself, but things are changing rapidly and people are beginning to really value diversity; everyone who is interested in science should be able to get involved.

Dave standing next to a giant corn plant in his field in New York. This was not a planned experiment. Instead, the seed came from a research institute in Mexico, and plants tailor their growth according to the environment. In New York, the days are much longer, and this confuses the plant and makes it grow taller. Photo credit: Constance Brukin

GROWING A COMMUNITY: BUILDING THE PLANT CELL ATLAS

PLANTS ARE INTEGRAL TO SOCIETY, BUT THERE ARE STILL BIG KNOWLEDGE GAPS ABOUT HOW THEY WORK AT THE MOLECULAR AND CELLULAR LEVELS. TO ADDRESS THIS, **DR. SEUNG YON (SUE) RHEE** AND **DR. SELENA RICE** FROM THE **CARNEGIE INSTITUTION FOR SCIENCE** IN STANFORD, CALIFORNIA, USA, ARE HELPING TO BUILD THE PLANT CELL ATLAS, A COMPREHENSIVE COMPILATION OF EVERYTHING WE KNOW ABOUT PLANT CELLS AND THE MOLECULES WITHIN

TALK LIKE A PLANT SCIENTIST

GENE EXPRESSION – the process by which the 'instructions' within genes are converted into the creation of proteins and RNA molecules

MERISTEM – a region of plant tissue consisting of actively dividing unspecialised cells to form new tissue

MODEL ORGANISM – an intensively-studied species used as a reference for drawing conclusions about the wider group of organisms to which it belongs

MOLECULAR PATHWAY – a series of interactions among molecules in a cell, which leads to a particular outcome

PROTEIN – complex, diverse molecules made up of amino acids, found within cells and which are the building blocks and molecular machineries for many cellular processes

SINGLE-CELL MULTI-OMICS – a catch-all term for powerful scientific techniques that measure multiple types of molecules within a cell simultaneously

Plants supply most of our food, underpin our ecosystems, supply many of our medicines, store vast amounts of carbon from photosynthesis, and are a powerful source of renewable energy. They are very important! However, despite major advances in our understanding of plants thanks to new technologies and collaborative efforts, there are still many unanswered questions about how exactly they grow, respond to environmental cues, and reproduce at the molecular and cellular levels. Answering these unknowns is essential to ensuring that we can address some of the biggest challenges that society faces, such as food and energy insecurity, climate change, and environmental degradation.

"A comprehensive understanding of plant cell structure and function at a molecular level is essential to understanding how plants fulfill the services we rely on," says Dr. Sue Rhee. She and Dr. Selena Rice work at the Carnegie Institution for Science in Stanford, California, and have helped bring together over 800 experts to create the Plant Cell Atlas – a community resource that will describe everything we know about plant cell types, the molecules they contain, and how these molecules and cells interact.

WHY WE NEED THE ATLAS

These days, scientists tend to be specialists. This means that research teams tend to focus on discovering more about specific, often quite niche, topics. While this is fantastic for building depth of knowledge, there is a danger of developing isolated 'pockets' of understanding without any wider appreciation for how they fit together.

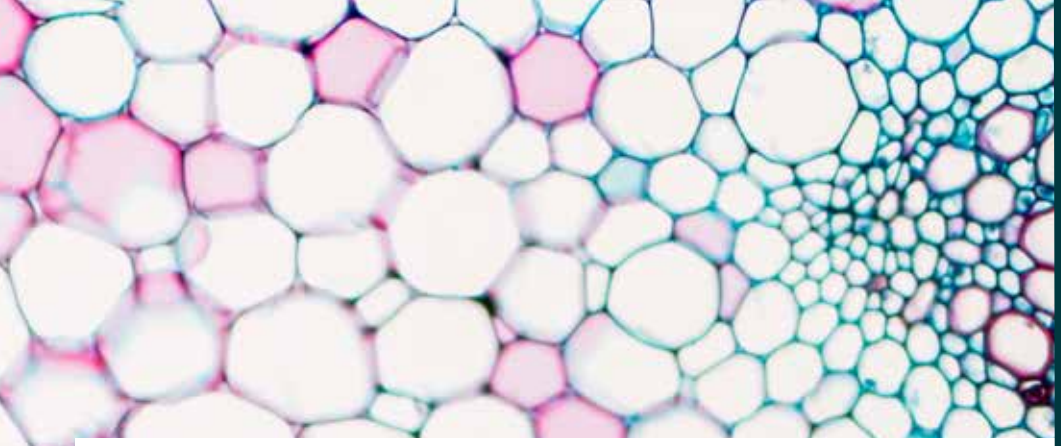
The Plant Cell Atlas hopes to fix this for plant sciences, by drawing these 'pockets' together into one place and developing methods for integrating them so that scientists can make connections between different areas and get a better grasp of the bigger picture. "We need both new data and better frameworks to answer unanswered questions about plant sciences and link these data types together," says Sue. "This need is becoming increasingly pressing, as disasters associated with rapid climate change and other factors will increase societal demand for plant-based solutions from scientists, breeders, growers, engineers, and entrepreneurs."

The Atlas will work to develop universal techniques and standardise methods, to ensure that different datasets can be integrated and compared. Networking and training opportunities will help strengthen collaboration, not only on scientific research itself but also exploring funding opportunities and developing useful shared tools and methods. "The development of innovative tools is enabling us to make unprecedented discoveries within plant science," says Sue. "These tools and approaches cover systems biology, synthetic biology, biosensors, data science, artificial intelligence, gene editing, precision breeding, the microbiome, and more."

BUILDING THE ATLAS

"There's still a lot we don't know about plants," says Selena. "Even for the most-studied plant in the world, model organism *Arabidopsis thaliana*, we don't know and can't even predict the molecular function of around 20% of its genes. This percentage is much higher for other plants, including important crops such as soybean and rice." At a larger scale, there is still a lot we do not know about plant cell types, especially when comparing different species that might not be structured in the same way.

Addressing these unknowns will require a wide array of scientific techniques, which can be broadly categorised as 'single-cell multi-omics'.



This term refers to any technology that measures multiple types of molecules within a cell. In addition to helping to define the overall function of the cell and differences between cell types within an organism, this also sheds light on molecular pathways that give the cell its identity and role. "Single-cell multi-omics technologies will be necessary to get a deeper understanding of plant cell processes across all layers of molecular regulation," says Selena. The 'omics' suffix refers to any technique that results in rich, large-scale datasets, including proteomics, transcriptomics, and metabolomics.

QUESTIONS TO ADDRESS

To ensure the Atlas develops in a useful direction, the team has identified specific areas to focus on. The first of these is post-embryonic development – understanding the mechanisms that make a plant develop from a simple seed to an adult organism. Unlike animals, where most development happens during embryo formation, plants do most of their development after the seed geminates. "We want to characterize the functions of every cell within a plant embryo, to help decipher the 'rules' underlying the earliest stages of plant tissue formation," says Selena.

The team is especially interested in the meristem, which is relevant for every stage of a plant's life. These regions of unspecialised cells are found in areas such as the tips of roots and shoots. "Plant meristems are remarkable multicellular machines," says Sue. "They are continually producing new cells that must be given a 'fate' and then guided through phases of maturation." Meristems are one of the ways that animals and plants differ. While animals typically develop according to a set 'blueprint' – for humans, this means two arms, two legs, a head at one end containing eyes and ears, and so on – plants are more flexible. Plants develop more modularly, as the meristems will react to their surroundings to stimulate the development of a branch, a leaf, or a root, to name a few. Uncovering how meristems coordinate this development at the molecular level is a key research question.

This also relates to crucial questions about how plants respond to the environment. Reactions to pathogens is a key area of interest because disease outbreaks can be catastrophic for crops. "There are questions about how the signals that plant cells emit when attacked are communicated to neighbouring cells and propagated to remote regions of a plant," says Sue. "Is there a simple 'switch' system, or is there something more complex going on?" Understanding these systems could help scientists develop more disease-resistant crop varieties, potentially ensuring better food security for millions of people.

THE IMPORTANCE OF LOCATION

The team believes that the location of proteins is a relatively untapped source of information about their role within plant cells. In recent decades, scientists have unlocked the relationship between the molecular structure and function of proteins; now, it is believed that location is the next knowledge goldmine. "The location of a protein can dramatically affect its function," says Sue. "For instance, the differing environments of a cell nucleus, cytoplasm, or cell membrane may stimulate a protein to behave differently."

Deciphering this relationship could help introduce advances in genetic technology, given that proteins are created by the expression of genes. "There is evidence that the location and timing of gene expression in rice impacts grain size and yield," says Sue. "Other studies have found relationships between the location of gene expression and the sequestration of extra carbon within plants' roots." These findings have clear benefits for crop production and carbon sequestration, which are essential for dealing with a changing climate. "Currently, these sorts of location-to-function datasets are incomplete and have no central repository," says Sue. "This limits the rapid development of improved crops." The Atlas aims to directly address this issue.

BUILDING A COMMUNITY

"The Plant Cell Atlas community consists of over 800 scientists and stakeholders, who attend our events and contribute to discourse," says Selena. "We have a core group of 60 scientists who guide the development of the Atlas, drawing on their diverse range of expertise." The community has benefited from the connectivity granted by social media platforms and from existing academic relationships that have allowed the message to spread. The COVID-19 pandemic has seen the rapid development of digital communication potential, which has meant that the Atlas team has been able to attract more scientists to participate.

DR. SEUNG YON (SUE) RHEE

Senior Staff Scientist

DR. SELENA RICE

Scientific Coordinator and Biocurator

Carnegie Institution for Science, Stanford, California, USA

FIELD OF RESEARCH

Plant Sciences

RESEARCH PROJECT

Building the Plant Cell Atlas, a comprehensive repository of knowledge and data on plant cells, molecules, and pathways

FUNDERS

US National Science Foundation (NSF), Carnegie Institution for Science

Recently, the Plant Cell Atlas received a Research Coordination Network grant from the US National Science Foundation, which has allowed the community to host workshops and a landmark symposium, as well as expand outreach efforts for early-career researchers and the public. "Our next steps involve hosting more virtual scientific workshops, a new Gordon Research Conference on single-cell approaches in plant biology, and career panels, and expanding our Art and Science exhibit to feature artists and scientists from historically excluded groups," says Selena.

EXPLORE A CAREER IN PLANT SCIENCES

• Careers in plant sciences are diverse. In addition to academia, plant scientists are sought by agricultural organizations, the food industry, pharmaceutical developers, government labs, and environmental management institutions.

• Check the National Science Foundation's Research Experience for Undergraduates (REU) page for internship opportunities: **www.nsf.gov/crssprgm/reu/reu_search.jsp**

• Selena recommends the American Society of Plant Biologists (**www.aspb.org/about**) and the Botanical Society of America (**www.botany.org**) as useful organizations for building networks, investigating areas of interest, and accessing work experience and internship opportunities. They require membership fees but have discounts for students.

• The Plant Cell Atlas website has lots of useful information (**www.plantcellatlas.org**) and anyone can join its community by requesting to be included in its email list (**www.plantcellatlas.org/contact.html**).

PATHWAY FROM SCHOOL TO PLANT SCIENCES

At school, biology, chemistry and mathematics will help lay the groundwork for a career in plant sciences.

Selena explains that she has never taken a formal course in plant sciences, and there are many related routes into the field. Sue lists several relevant university subjects, including plant biology, cell biology, ecology, evolutionary biology, bioengineering, biochemistry, genetics, computer science, statistics, applied mathematics, chemistry, and physics.

Selena highlights the growing role of bioinformatics and data science as datasets expand, meaning that skills in managing data are becoming increasingly desirable.

MEET SUE

I got excited about science when my family moved to the US from South Korea, and I did experiments with fruit flies and dissected guinea pigs in a high school biology class. My interest was solidified when I attended a summer school on protein engineering at Columbia University during high school and through independent research in plant physiology and biochemistry in college.

I conceived the Plant Cell Atlas (PCA) initiative and formulated the early concepts with my colleagues Dr. David Ehrhardt and Dr. Ken Birnbaum, which became the seed for a global grassroots movement and community. I am currently the principal investigator of the National Science Foundation's Research Collaboration Network grant to further develop and support this community. I serve on the Steering Committee of the PCA initiative, along with five amazing colleagues, Dr. Marisa Otegui, Dr. Julia Bailey-Serres, Dr. David Ehrhardt, Dr. Nicholas Provart, and Dr. Ken Birnbaum.

My career path has been driven by five major sources: curiosity, serendipity, annoyance, technology, and lab members. The PCA came about largely because of the sequencing revolution revealing all the genes harboured in plant genomes and my annoyance at the slow pace of figuring out what these genes do! I felt that a global initiative like the PCA could help accelerate gene function discovery and our efforts to understand how plants are made, how they work, and how we can engineer plants for improving the conditions of people and our planet.

Most of my working day is spent on meeting with people in my lab and collaborators outside of our lab, writing (papers, grants, recommendation letters, and emails) and reading (articles, proposals, manuscripts, and job applications). On occasion, I do some research by helping people in the lab with data curation and data analysis and, on rare occasions, experiments!

The best thing about being a plant scientist is the community; plant scientists are generally highly motivated, smart, nice people and it's a pleasure to be part of that community. The biggest challenge is the limited funding.

I am very proud that 150+ people have trained in my lab, so far. I am also proud of the papers we have published, and the databases and resources we have created to support the research community.

In the future, I would like to contribute to making a world where plant-based bioeconomy is reversing the climate crisis, where the sixth mass extinction is mitigated, and people and the planet are healthier and more resilient because of advances in fundamental plant science being linked directly to solving many societal problems.

SUE'S TOP TIP

Reach out to people – such as scientists, university faculty, journalists, CEOs of start-ups, etc. – to connect, learn, and discuss your goals and interests. I enjoy getting emails from students who are genuinely interested in exploring ideas.

MEET SELENA

As a youngster, I loved learning about science and nature, everything from volcanoes to stars, to plants and animals. I also spent a lot of time studying martial arts, gaining my black belt in kung fu while at high school. Ancient history and cultures also fascinate me, which led me to spend a semester in Egypt during college to study ancient Egyptian art and history.

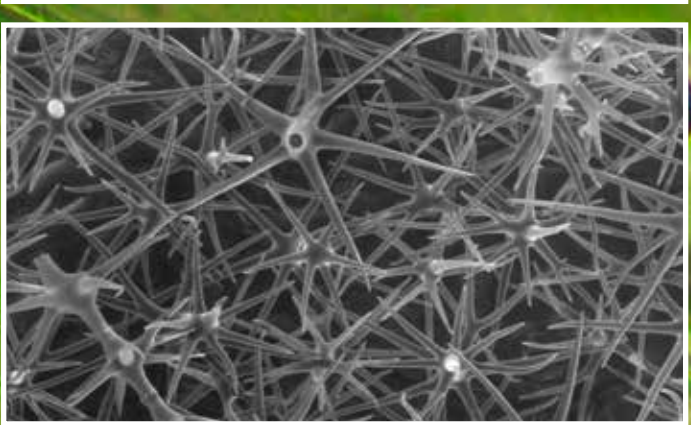
Neither of my parents were scientists but both had a love for science, which they passed on to me. I was always surrounded by books and toys about science, so developed a love and curiosity of the natural world from a young age.

I work as the Scientific Coordinator for the Plant Cell Atlas, so I handle most of the behind-the-scenes work that goes into building a new community. I spend most of my days communicating with scientists, and organizing the project's logistics. This can mean anything from developing formal documents, to coordinating our exhibits at partnering universities.

I've had what most would consider a non-traditional career path for academia. After earning my PhD in biology, I became a lab manager as I found that I enjoyed the administrative aspects of running a lab more fulfilling than undertaking the research itself. I found my current position when I was looking to spend less time in the lab and grow my administrative skills, while still being connected to science.

Plant science is a vast field, with so much to learn and so many applications. Plants play a central and vital role in our society, providing everything from food to materials to energy to healthcare. Keeping up with the quantity of relevant research is both fascinating and extremely challenging.

I was very proud to develop the Plant Cell Atlas Art and Science Exhibit. We received lots of great feedback and interest, and it's wonderful to shine a light on these remarkable but often-overlooked scientists. I am excited to expand the exhibit to include other incredible scientists, showcasing their work to help inspire people to become scientists themselves.



Tidestromia oblongifolia (Arizona Honeysweet) is a heat tolerant plant native to Death Valley. We want to understand how this plant thrives under the summer heat of Death Valley and translate the thermotolerance traits into crops to allow them to be resilient against climate change. T. oblongifolia growing in its natural environment (top left), flowers (top right), leaf hairs (bottom left), and young plants in a growth chamber with an instrument measuring photosynthetic performance (bottom right). (Photo credit: Dr. Karine Prado)

"WE NEED TO RADICALLY REFORM THE NATIONAL CURRICULUM, BUT THAT'S NOT GOING TO HAPPEN OVERNIGHT."

ACCORDING TO RECENT RESEARCH, 84% OF YOUNG PEOPLE ALL OVER THE WORLD ARE WORRIED ABOUT THE CLIMATE CRISIS. SO WHY IS CLIMATE EDUCATION LEFT SOLELY TO GEOGRAPHY AND SCIENCE TEACHERS? FORMER ENGLISH TEACHER AND FOUNDER OF THOUGHTBOX EDUCATION, **RACHEL MUSSON**, EXPLAINS WHY SHE IS WORKING WITH ORGANISATIONS LIKE TEACH THE FUTURE TO BRING CLIMATE EDUCATION INTO ALL SUBJECTS IN THE UK'S NATIONAL CURRICULUM

ABOUT RACHEL MUSSON

Formerly a secondary school teacher, **Rachel** set up ThoughtBox Education in 2015. She is also an international speaker and thought leader in regenerative education and well-being in schools. She works with the Climate Psychology Alliance, Teach the Future and other organisations to form a united front on climate education and "show children that there are adults out there doing things to bring this education into schools".

WHAT IS YOUR EXPERIENCE OF CLIMATE EDUCATION IN THE UK?

At the moment, students receive 13 hours of explicit climate education across the entire primary and secondary sphere. It's taught in geography and science but lots of students aren't taking geography at GCSE level, which means many are missing out. Crucially, we need to recognise that it's not the geography or science teacher's job to teach students about climate change. We should all be responsible because climate change impacts all of us.

A lot of the young people we work with find it incredibly confusing as to why they're not learning anything about the climate crisis. Yet teachers of all subjects don't have the headspace to bring it in. This is one of the biggest issues with climate education as it's currently taught – it's piecemeal and disconnected. What we need is an education for sustainability, happening right across the school context.

AS A FORMER SECONDARY SCHOOL ENGLISH TEACHER, HOW DID YOU BRING CLIMATE EDUCATION INTO YOUR LESSONS?

Outside the classroom, I set up an eco-group which enabled young people to start recycling schemes, community projects, meat free Mondays, swap shops and energy saving strategies.

In the classroom, I was fortunate that English lessons provided a discussion framework. You're reading books and poems whilst discussing big human issues and ideas with students. English lessons can be an opportunity to talk about thoughts, feelings and questions around things that are happening in the text to explore how these thoughts, feelings and questions relate to the wider world. Learning to feel connected to ourselves, others and the wider world is a crucial part of this sort of learning.

Even though I was an English teacher, I was also involved in cross-cultural learning projects, connecting with people living in different, more sustainable cultures.

DID STUDENTS COME TO YOU TO TALK ABOUT CLIMATE CHANGE?

One of the reasons we started an environmental network in my last school was because I had several students who were aghast that nothing was being done. Through the eco-group, we set up eco-audits and all the measures I mentioned previously, which were a way for students to feel that they had something purposeful to do and were making a change.

According to recent research*, which asked 10,000 young people across 10 countries how they feel about climate change, 75% think the future is frightening, 84% are incredibly worried about the climate crisis, and 45% say it is already affecting their daily lives. These children aren't necessarily living in the Maldives or in other countries on the frontline, but they're aware of the climate crisis and they don't know what to do.
***papers.ssrn.com/sol3/papers.cfm?abstract_id=3918955**

IS IT UP TO TEACHERS TO BRING CLIMATE EDUCATION INTO THEIR CLASSROOMS?

Teachers encounter so many challenges. There is a hugely dense curriculum in every subject that must be taught. So many teachers feel the pressure of having to get through so much content. It feels as if there is little time or space for reflection, never mind discussing something that's happening outside of the learning space.

It shouldn't be up to teachers to find ways to bring climate education into the classroom but, unfortunately, that's where we are at this point.

WHAT DO DECISION-MAKERS NEED TO DO TO EFFECT CHANGE?

We need to radically reform the national curriculum, but that's not going to happen overnight. It's a huge beast. What we need in the interim is integration – connecting climate education with the curriculum all the way through the learning process.

We need to embed the knowledge, skills and practices for thriving futures right across the curriculum.

Most importantly, climate education isn't just about teaching information. It needs to be supported with strategies for growing emotional resilience. I work with the Climate Psychology Alliance who deal with climate anxiety and recognise the psychological reasons for not simply teaching children hugely horrifying facts about climate collapse.

There are two approaches that need to happen: meeting where we are now by connecting to initiatives such as the Department for Education's (DfE's) new climate and sustainability framework, whilst recognising that, in the future, we really need to explore a new model for education. What we need is an education for sustainability (not just sustainability education).

ARE TEACHERS STARTING TO ADVANCE WITH CLIMATE EDUCATION THEMSELVES?

Some teachers are, yes. At ThoughtBox, we've had 3,500-4,000 teachers coming to us asking for climate education resources. One of the biggest challenges, however, is teacher confidence. Climate change raises a lot of issues, some of which may not seem directly related, like colonialism and social justice. Therefore, there are many different avenues to explore. A lot of teachers don't know where to start and many are anxious about discussing potentially political issues in the classroom.

One of the things we've been talking about with the DfE is the need for teacher training. We run teacher training at ThoughtBox and also recommend an amazing organisation – Aimhi – that also works with teachers in this space. It begins by recognising that these issues will affect us all – emotionally as well as physically – and we can support our resilience and awareness through action and empowerment. This is what our CPD training is really focused on at ThoughtBox.

WHY DID YOU LEAVE TEACHING?

One of the reasons I left was a big dissatisfaction with an education system that is not helping young people prepare for the world they're actually going to be living in. A lot of teachers are in a similarly desperate space – they don't want to leave but don't know how to continue.

HOW DID YOU BECOME INVOLVED WITH TEACH THE FUTURE?

I've been working in this space for seven years now, but I connected with Teach the Future in 2019, when it was quite a small network. In 2021, I helped with a Teach the Teacher campaign, which was put together by students. It's a one-hour training session that supports teachers in knowing how to talk about climate change with children.

WHAT ARE THE BENEFITS OF JOINING TEACH THE FUTURE'S TEACHERS NETWORK?

Joining the Teacher Network is a way of staying in the system but being part of a movement that's working inside out. It's a support network for teachers who don't necessarily want to leave but don't know where to start with climate education work.

IS THERE ANYTHING TEACHERS CAN DO TO START INTEGRATING CLIMATE CHANGE INTO THEIR LESSONS NOW?

The three things we talk about at ThoughtBox are: be brave, be safe and be connected.

Being brave is about having the conversations. Simply asking 'Do any of you know anything about climate change?' is a good start, even in the final five minutes of a lesson. It's about showing students that you are also aware of climate change. You don't need to know the answers as a teacher, simply welcome the conversations.

Being safe is about recognising that when you start to have these conversations, it will trigger different emotions in children. Some may not have thought about it; some may cry every night because they're totally overwhelmed, and then there will be others experiencing different emotions on the spectrum. Create a safe and supportive space for this.

Being connected is about being part of a network, and knowing about other networks that support children with their questions and places to become active and empowered. It is also about helping children connect the dots on how their actions can impact wider system change.

WHAT MESSAGE WOULD YOU LIKE TO SEND TEACHERS WHO ARE READING THIS ARTICLE?

It's time to talk. You don't need to be an expert, you don't need to know the answers, you don't even need to know very much about it yourself. Just start the conversation. I think that's where this work needs to begin. Don't be afraid because we're all in this together. It affects all of us.

Rachel is an international speaker and thought leader in regenerative education and well-being.

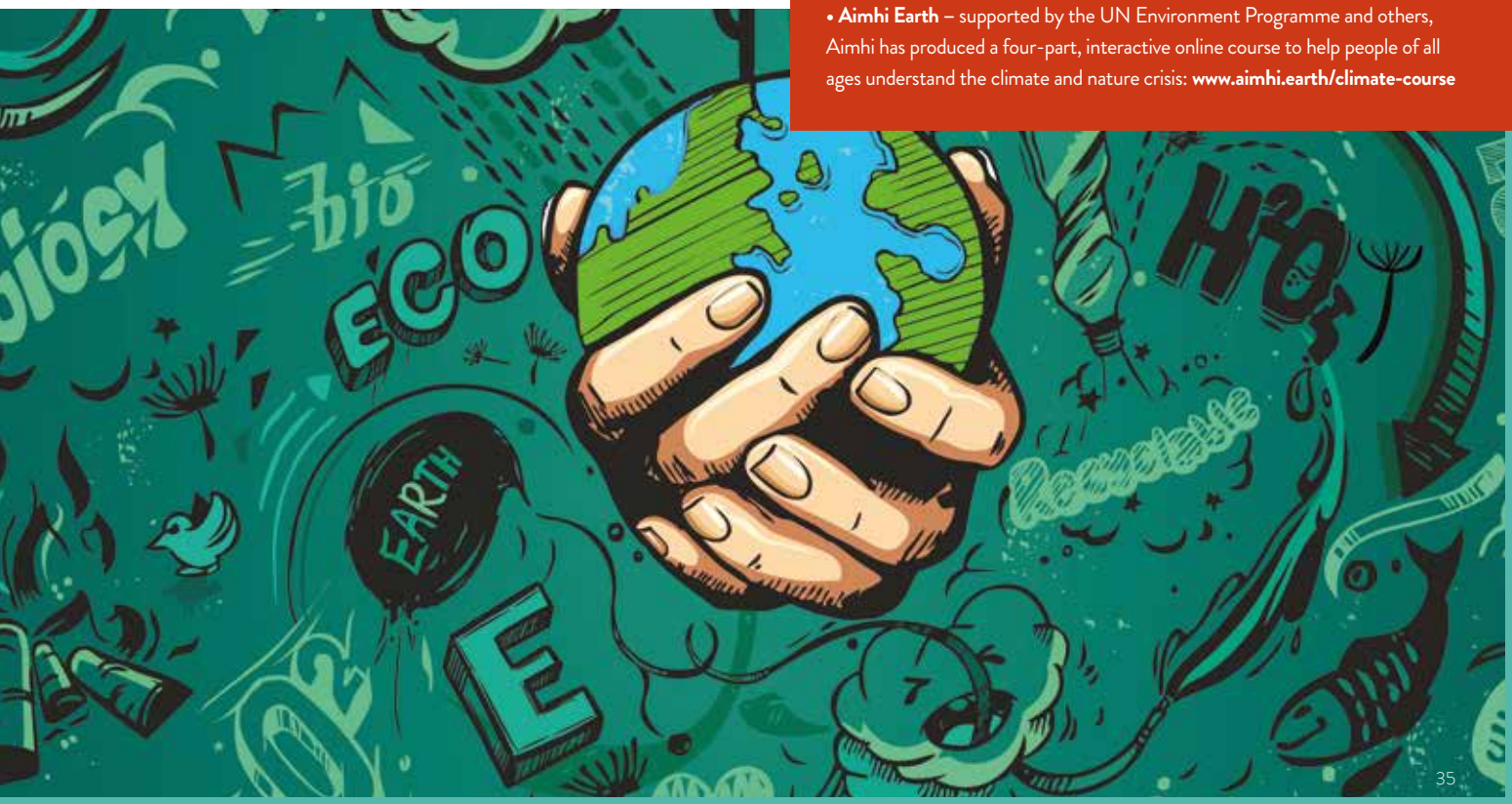
RACHEL'S SUGGESTIONS *FOR CLIMATE RESOURCES*

• **Teach the Future's Teachers Network** – a place for teachers across the UK to share resources and have chats with other teachers interested in climate education: **www.teachthefuture.uk/action/teachers-network**

• **ThoughtBox** offers a whole school approach to education for sustainability, including CPD, curriculum and leadership support. As a starter, the team has created a free toolkit for teachers to help young people start to make sense of the climate crisis: **www.thoughtboxeducation.com/climatecurriculum** (4,000 schools in 74 countries have already downloaded this resource).

• **ThoughtBox's short training video** is also a good place to start for educators wondering how to respond to eco-anxiety and support young people in schools: **www.youtube.com/watch?v=GQxyMIksrtc**

• **Aimhi Earth** – supported by the UN Environment Programme and others, Aimhi has produced a four-part, interactive online course to help people of all ages understand the climate and nature crisis: **www.aimhi.earth/climate-course**



HOW CAN WE BUILD QUANTUM ELECTRONICS FROM ATOMS AND MOLECULES?

DR JAN MOL IS AN EXPERT IN QUANTUM AND NANOELECTRONICS AT THE **QUEEN MARY UNIVERSITY OF LONDON**, IN THE UK. HE IS TRYING TO UNDERSTAND HOW ELECTRICITY FLOWS THROUGH INDIVIDUAL ATOMS AND MOLECULES, WITH THE AIM OF ONE DAY USING THEM AS ELECTRONIC COMPONENTS

TALK LIKE A QUANTUM TECHNOLOGIST

ELECTRONIC COMPONENT – the basic building blocks of electronic circuits which control the flow of electrons. For example, resistors, diodes and transistors

NANOMETRE – a unit of length equivalent to one billionth of a metre

QUANTUM PHYSICS – a fundamental theory in physics that describes how things behave at the scale of atoms and subatomic particles

SUPERPOSITION – a principle in quantum physics that a system can be in two different states at the same time. For example, both on and off or both 1 and 0

ENTANGLEMENT – where a property of one particle is linked with that of another regardless of the distance between them

DNA – short for deoxyribonucleic acid. It is a molecule that contains the genetic code in a living thing. Can also be made in a laboratory and used to store information

Understanding the flow of electricity through individual atoms and molecules is key to building the smallest possible electronic components. These components could then be used to create tiny biosensors that could monitor your health in real-time, from inside your body, or super-fast quantum computers that can model complex systems like the Earth's climate and financial markets. To give you an idea of the scale of these molecular components, think about this the next time you drink a glass of water: the glass contains ten million times more water molecules than there are grains of sand on all of Earth's beaches and deserts combined. We normally experience the collective properties of all these water molecules as things like temperature and pressure. However, at the molecular and atomic scale, the classical physics we experience breaks down, and the weird world of quantum physics takes over. Even Albert Einstein, one of the key founders of quantum physics, described it as 'spooky'!

Dr Jan Mol, of the Queen Mary University of London, has developed various methods to manipulate and hold individual atoms and molecules in place, to perform experiments on them using electricity. He is investigating some of these quantum properties that will allow the development of new forms of technology at the smallest scale possible. The first challenge is handling and manipulating something so small you cannot even see it using regular light.

HOW DO JAN AND HIS TEAM MOVE AN INDIVIDUAL ATOM OR MOLECULE?

Trying to move individual atoms and molecules around is a challenge because they are so incredibly small and the tools used to move them are much larger! Jan says the process is like trying to pick up and move a single grain of rice using a digger. As if that was not enough of a challenge, Jan and his team want each molecule-sized device to work in exactly the same way, which is akin to picking up hundreds and thousands of grains of rice in exactly the same way every single time.

Various methods are used to build tiny structures that can hold individual atoms and molecules. Using the controlled breakdown of a material, so that the break is only a few nanometres wide, is one method. This is the same process as the breaking of a tungsten filament in an old lightbulb. Another way to do it is to take a very high-powered electron 'microscope' that can see individual atoms and use a beam of electrons or a very sharp needle to move the atoms and molecules around. Finally, there are chemical reactions that can create small metal spheres a few nanometres apart that can be used to hold molecules. Despite the challenges, there have been successful demonstrations of electronic devices that connect to an individual atom or molecule.

DR JAN MOL

UKRI Future Leaders Fellow, Materials Research Institute Academic Fellow, Reader in Quantum & Nanoelectronics
Queen Mary University of London, UK

FIELD OF RESEARCH

Quantum and Nanoelectronics

RESEARCH PROJECT

Developing ways to use individual atoms and molecules as electronic components that can be used for highly efficient data storage, quantum computing and generating electricity form waste heat

FUNDER

UK Research and Innovation

This work is/was supported by the UKRI Future Leaders Fellowship, under award number MR/S032541/1, with in-kind support from the Royal Academy of Engineering.

WHAT DO JAN'S EXPERIMENTS LOOK LIKE?

Now that the molecule has been carefully trapped in the structure, it is time to study its electronic properties. This is done in the same way as testing electrical components with a multi-meter. A voltage is applied at two points, called terminals, on the structure. An electric current begins to flow from one terminal, called the source electrode, to the other, called the drain electrode. Next, the current needs to flow through the molecule being tested, while a third electrode regulates the number of electrons that pass through the molecule. As the molecule is so small, only a few electrons can pass through it per second, and special instruments are required to measure the electrical current. Some of the experiments must be done at a very low temperature close to absolute zero (-273 degrees Celsius).

WHERE COULD THIS RESEARCH LEAD?

There are a huge number of potential applications in chemistry, physics, electronics, medical equipment and artificial intelligence. Jan highlights three that could have a big impact on society in the future: quantum computing, data storage and energy harvesting.

Quantum computers harness the strange properties of quantum physics that occur at the atomic scale. These strange properties are lost as things get bigger, so you do not see them at the scale we live at where objects are made up of trillions of atoms. Jan says, "A trillion sounds like a lot, but actually it isn't. At our scale, we're looking at trillion trillions (10^24)." If you can control these quantum properties in a computer, you can perform certain tasks exponentially faster than a regular computer which is limited by the laws of classical physics. A regular computer uses bits to store information, and these can be either a 1 or a 0, whereas a quantum computer uses qubits, which can represent both a 1 and a 0 simultaneously. This means that eight bits in a regular computer can represent any number between 0 and 255, whereas eight qubits could represent all the numbers from 0 to 255 simultaneously. This is where the exponential difference in speed comes from.

The inspiration for data storage comes from nature, specifically DNA. A single molecule of your DNA contains about a gigabyte of information which stores all your genetic information. Jan and his team are trying to store data and read it using molecules in the same way your body does. Using DNA to store data would be incredibly efficient compared to current methods which are bulky, inefficient and use lots of energy, most of which ends up as waste heat.

In fact, most human activity generates a lot of waste heat. Around 70% of all the energy we consume globally is lost as waste heat, so there is huge potential if you can find a use for it. To feel this waste heat in action, just put your hand under your laptop or phone. Harvesting waste heat energy and turning it into electricity by using nanostructured materials could increase the efficiency of our energy consumption, which in turn has big implications in the fight against climate change, as well as savings on energy bills. Some of the waste heat coming off the back of your phone might one day be used to charge the battery.

WHAT ARE THE SUCCESSES SO FAR?

Jan has managed to study a single phosphorous atom, which is a potential key building block of quantum computers. He used a special microscope to investigate the quantum properties of the atom. He has also studied a molecule called fullerene (which looks a bit like a football made of 60 carbon atoms) which has the potential to convert heat into electricity.

Finally, Jan has worked on a method to scan and read DNA molecules by passing them through a very small hole called a nanopore, just a few nanometres across and only slightly bigger than the molecule itself. This is done in a salt solution which is full of ions which flow across the nanopore when a voltage is applied. As the DNA molecule moves through the nanopore, it blocks and changes this flow of ions, which can be measured and provides a way to read the DNA molecule.

WHAT'S NEXT?

The future work in molecular electronics will focus on improving the reliability of the connections to the individual atoms and molecules. From there, these technologies are going to require lots more creative scientists like Jan to develop new and exciting ways to build molecular electronics that will improve our lives in the future.

ABOUT QUANTUM TECHNOLOGY

Quantum mechanics began as a theory over 100 years ago and is used in everyday technologies. Lasers and fluorescent lights both rely on something called spontaneous emission, which is a direct physical manifestation of the Heisenberg uncertainty principle. This is one of the most famous principles in quantum physics which, in simple terms, means that knowing the location of a particle prevents you from knowing its speed and direction.

Another common piece of technology that uses quantum physics is a transistor. Jan explains, "Transistors that are in your laptop or smartphone rely on quantum mechanics because they are made of semiconductors – crystalline material where there is an energy gap between the electrons that bind the atoms in the crystal and electrons that can move around freely." Quantum physics is a huge and complicated subject, but there are many popular science books that explain the concepts in simple terms if you want to learn more.

WHAT WILL THE NEXT GENERATION OF QUANTUM TECHNOLOGISTS WORK ON?

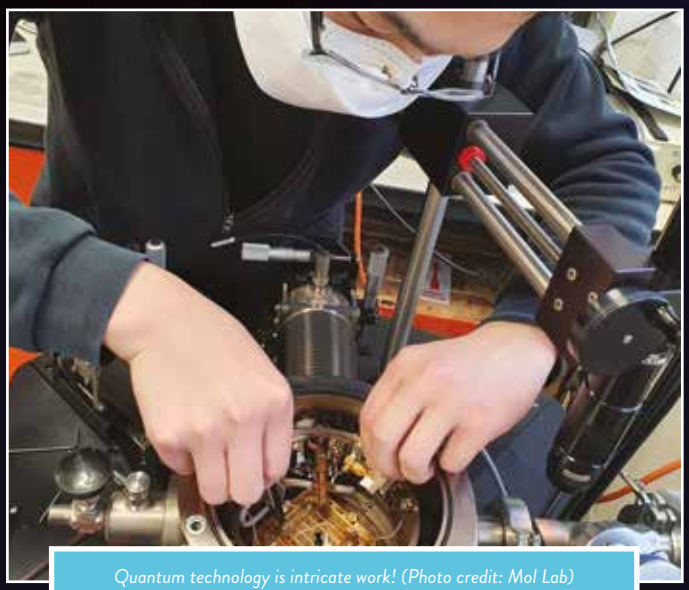
In recent years, scientists have taken advantage of other strange quirks of quantum mechanics such as superposition, where quantum systems can exist in several states at the same time, and entanglement, where two particles are linked even when they are miles apart. Entanglement is what Einstein called, "spooky action at a distance". The challenge is transferring these principles into real technology in the lab – future quantum technologists will develop super precise engineering at atomic and molecular scales to develop quantum computers and other technologies. These computers will also require an entirely new type of programming that makes use of superposition and entanglement, so future quantum technologists will need to be creative. Are you up to the challenge?

EXPLORE A CAREER IN QUANTUM TECHNOLOGY

- Jan recommends exploring some online resources to see what is involved, including talks from Michelle Simmons at the University of New South Wales (**www.youtube.com/watch?v=FnPp73F5cnE**) and the Oxford Nanopore Technologies website which has videos on DNA sequencing using nanopores (**nanoporetech.com/resource-centre/nanopore-sequencing-101**).

- There are also lots of video resources on quantum technology on the International Artificial Intelligence and Quantum Technology (AIQT) Foundation website (**www.inaiqt.com/news-2/**).

- Average annual salaries for a research scientist in academia (after completing a PhD) in the UK are between £25,000 and £35,000, which rises with new responsibilities. University professors and principal investigators can earn more than £50,000 per year.



Quantum technology is intricate work! (Photo credit: Mol Lab)

PATHWAY FROM SCHOOL TO QUANTUM TECHNOLOGY

- Jan recommends studying maths, physics and chemistry at school, college and university.

- You will also need to complete postgraduate studies, such as for a master's and PhD, in a relevant topic.

- More general guidance on becoming a physicist can be found on the government's careers website: **nationalcareers.service.gov.uk/job-profiles/physicist**

JAN'S TOP TIPS

01 This stuff is not easy to get your head around, so only do it if you really enjoy it.

02 Be curious!

HOW DID JAN BECOME A QUANTUM TECHNOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I have always been interested in figuring out how stuff works. Back in the 90s, computers weren't that shiny or smart, but it was a lot of fun taking them apart and reassembling them again (or breaking them and getting them to work again).

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I don't think there was a specific moment at which I decided to become a scientist, I just naturally progressed in that direction. There are of course lots of interesting characters in physics, people like Richard Feynman, but I think I only found out about them when I was already a physicist myself.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Curiosity.

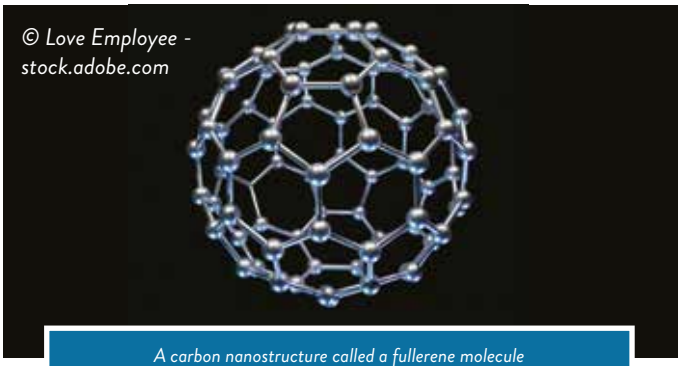
HOW DO YOU OVERCOME OBSTACLES/SWITCH OFF FROM YOUR WORK?

I enjoy long distance running. Running a marathon is an all-consuming activity and allows no time to worry about anything else.

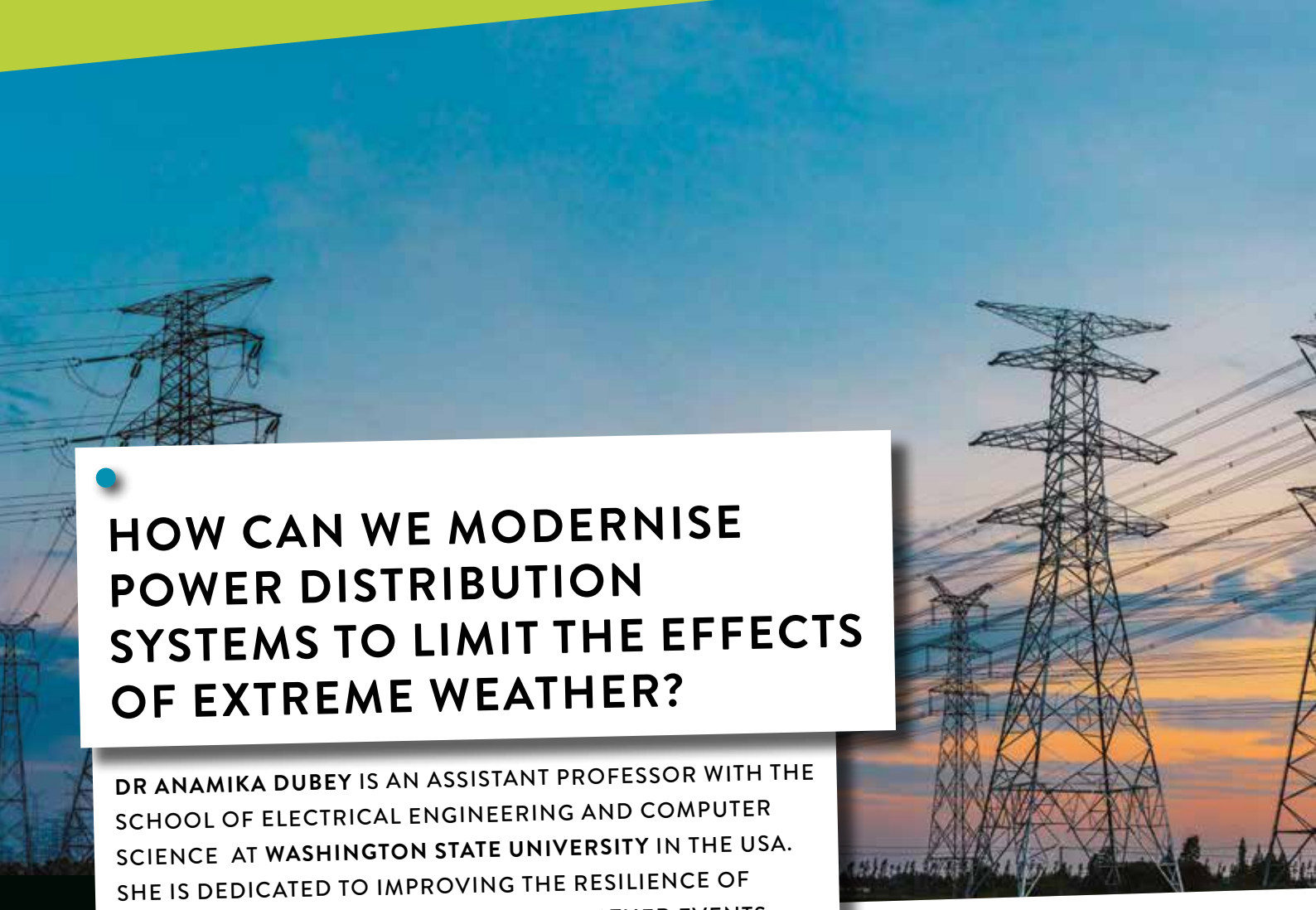
WHAT ARE YOUR PROUDEST ACHIEVEMENTS SO FAR?

Teaching our two-year-old daughter arithmetic – it's a work in progress!

Careful observations taking place in Jan's lab (Photo credit: Mol Lab)



A carbon nanostructure called a fullerene molecule



HOW CAN WE MODERNISE POWER DISTRIBUTION SYSTEMS TO LIMIT THE EFFECTS OF EXTREME WEATHER?

DR ANAMIKA DUBEY IS AN ASSISTANT PROFESSOR WITH THE SCHOOL OF ELECTRICAL ENGINEERING AND COMPUTER SCIENCE AT **WASHINGTON STATE UNIVERSITY** IN THE USA. SHE IS DEDICATED TO IMPROVING THE RESILIENCE OF ELECTRIC POWER GRIDS TO EXTREME WEATHER EVENTS

TALK LIKE AN ELECTRICAL ENGINEER

BLACKOUT – a total loss of electrical power

BROWNOUT – a drop in voltage of electrical power

ELECTRIC GRID or POWER GRID – an interconnected network that delivers electrical power from producers (e.g., power stations) to consumers (e.g., individuals using electricity in their homes)

HIGH-IMPACT LOW-PROBABILITY (HILP) EVENT – an extreme event that does not occur very often

POWER OUTAGE – a loss of electrical power

STOCHASTIC MODELLING – a model that estimates the probability distribution of outcomes under different conditions by using random sampling of variables

We rely on electricity for almost all aspects of our modern lives. "The electric power grid is one of the nation's most critical infrastructures," explains Dr Anamika Dubey, an electrical engineer at Washington State University. "Virtually every system in modern society, from healthcare to transportation, water to communications, depends on electricity." So, when this power infrastructure fails, it has serious consequences.

A loss in power for an extended period severely affects human well-being, the economy and even national security. During Hurricane Ida, in August-September 2021, about 1.2 million customers in northeastern USA were left without power.

EXTREME WEATHER EVENTS AND POWER OUTAGES

Hurricanes, severe storms and other extreme weather events have the potential to damage power grid infrastructure, such as power lines and poles, disrupting electricity supply to customers. The accompanying floods often prevent a rapid recovery of services, resulting in extended power outages. "In the aftermath of Hurricane Ida, it took almost 15 days to restore the electric power supply," says Anamika.

"Approximately 78% of power outages from 1992 to 2012 in the USA can be attributed to extreme weather events," Anamika adds. "These took a toll of $18-33 billion per year on the US economy, while affecting around 178 million metered customers." As both the global demand for energy and the frequency of extreme weather events increase, the number of power outages, their economic costs and their human impacts will continue to grow.

Power stations and related infrastructure may be damaged by storms, preventing electricity from being supplied to customers. A disruption to power supply can also be caused by a lack of supply or excessive demand, both of which might take place during extreme weather events such as during unusually cold winters or hot summers. There might simply not be enough electricity generation, powerplants that have not been designed to withstand the weather conditions may be forced to shut, or excess demand can lead to overloading of the grid, resulting in power failure. Sometimes, power supply must be shut off for public safety, for example to reduce the risk of wildfires. "Wildfires ignited by the ageing and stressed power grid are costing billions of dollars annually," says Anamika. "Power shut-offs to avoid these wildfires

DR ANAMIKA DUBEY

Washington State University, Pullman, USA

FIELDS OF RESEARCH

Electrical Engineering, Electric Power Systems

RESEARCH PROJECT

Improving resilience of power distribution systems against extreme weather events

FUNDERS

US National Science Foundation (NSF), Department of Energy, Pacific Northwest National Laboratories

cause extended outages during the wildfire season and will only worsen due to rising global temperatures."

HILP EVENTS

Although the electric power grid is designed to overcome known and credible threats of disruption, it is not resilient to rarer, more extreme disruptions, known as high-impact low-probability (HILP) events. HILP events happen infrequently but have the potential to cause unprecedented disruption of the power supply. These events include hurricanes, wildfires and winter storms. As the occurrence of these events becomes more frequent due to climate change, there is a pressing need to characterise and quantify their impacts on power grid infrastructure. "Rare events such as extreme weather continue to surprise us, so we must investigate new ways of managing their impacts on the grid and customers," explains Anamika.

QUANTIFYING THE RISK OF HILP EVENTS

Anamika assesses the risk of power loss due to extreme weather events using computational models. "Our risk modelling framework uses event intensity models (such as profiles of regional wind speed) and component level fragility curves (the probability of grid components failing depending on event intensity)," she explains. "As expected, these probabilities increase sharply with the increase in weather intensity."

As there is a stochastic element to weather intensity and its impact, Anamika uses 'Monte-Carlo simulations', which randomly sample data to produce more realistic models. These mathematical models allow her to evaluate the probabilistic impacts of weather events on the power grid infrastructure.

INCREASING GRID RESILIENCE

To reduce the extent of power outages, the resources needed to repair power infrastructure can be stockpiled to ensure they are easily available when the grid becomes damaged. Electrical engineers like Anamika are also working to reduce the risk of outages in the first place, by increasing the resilience of the grid.

Advances in smart grid technology are helping to ensure that power distribution networks are more resilient to HILP events. By creating 'microgrids' and using many different power generation sources, including local sources, smart grids can be made more resilient to outages. One solution to improve resilience in the grid is the formation of 'intentional islands', where the large-scale electric grid is separated into smaller units. During power outages, these islands can maintain the required voltage and frequency within a contained area, enabling a continuous power supply to vital services such as hospitals.

However, several technical challenges must be overcome to ensure reliable operation of these grid islands in the aftermath of extreme weather events. "Our approach entails distributed optimisation and control solutions to ensure feasible island formation and stable island operations for continuous supply to critical loads," explains Anamika.

Traditionally, decision making in power distribution systems is made centrally, but this leaves the system vulnerable to single-point failure, cyber-attacks, communication failures and computational challenges. Therefore, Anamika is developing a distributed decision-making paradigm where multiple agents solve smaller sub-problems and jointly coordinate their individual decisions to achieve network-level objectives. "This approach is robust to failures, allows autonomous control of power distribution, and has comparatively low computing cost compared to large centralised systems," Anamika says.

"Traditional planning and operational solutions for resilience are limited, due to inadequate characterisation of HILP events and overly simplified models," Anamika explains. Resilient power networks must use risk modelling frameworks to simulate the trajectories of extreme events and quantify their impacts through time. By using data-driven, simulation-based frameworks and improved sampling techniques, Anamika can effectively model the time-varying impacts of HILP events on power grids. The next step will be to develop more comprehensive climate-impact models for power grid devices, as well as systems and scalable solutions for climate-adaptation of the large-scale regional and national electric power grid.

As climate change increases the frequency and intensity of extreme weather events and the world has an ever-increasing demand for electricity, electrical engineers such as Anamika are vital for ensuring that electrical grids are resilient so that we have uninterrupted access to power supplies.

ABOUT ELECTRICAL ENGINEERING

Electrical engineers study the applications of mathematics and physics in all electrical, electronic or computer-based devices and systems. They apply fundamental principles of electromagnetism, electronics and electricity to design and operate many valuable systems, such as power networks, telecommunications and satellite communications.

As Anamika investigates the impacts of extreme weather events on power systems, she requires an interdisciplinary set of skills and knowledge. She needs an understanding of meteorology, climate modelling and data science, alongside her knowledge of electric power infrastructure systems. "Most research related to the power grid is done on computer-generated models, so an expertise in computer programming is a must," Anamika adds. "Moreover, as we are working with large-scale complex systems, expertise in large-scale computing, mathematical optimisation techniques and data-driven analytics are all crucial."

WHAT IS REWARDING ABOUT WORKING AS AN ELECTRICAL ENGINEER?

"The impacts of electrical engineers are visible in every aspect of our modern lives, from access to electric power, modern medicine and the internet, to shuttling us to the farthest reaches of the universe," says Anamika. Research in electrical engineering aims to improve our day-to-day lives. "I find my job deeply satisfying, knowing that I am contributing to making this world a better place every day," Anamika says.

WHAT CHALLENGES WILL FACE THE NEXT GENERATION OF ELECTRICAL ENGINEERS?

The demand for electricity worldwide will continue to increase in the coming decades, however, it is essential that this increasing demand is met by energy that is produced without negative impacts on our precious planet. Future electrical engineers will design innovative ways to increase our use of renewable energy, including improving storage technologies and integrating them into the grid. They will also modernise the grid itself, improving its efficiency through use of digital technologies. This means they will have to manage associated cybersecurity challenges. With so much technological innovation required to ensure the world has access to electricity, Anamika says, "The future for electrical engineers in the area of power and energy is very exciting!"

EXPLORE A CAREER IN ELECTRICAL ENGINEERING

• Anamika recommends joining the Institution of Electrical and Electronics Engineers (**www.ieee.org**), one of the largest societies of electrical and electronics engineers. The IEEE Learning Network provides courses in areas such as power and energy, telecommunications, emerging technologies, and computing, allowing you to explore the wide range of topics studied by electrical engineers.

• The Institute of Engineering and Technology (**www.theiet.org**) also provides information and opportunities related to electrical engineering.

• Electrical Careers (**www.electricalcareers.co.uk**) has a wealth of information on careers, qualifications and apprenticeships in the electricity industry.

• According to Glassdoor, the estimated salary for an entry-level research electrical engineer in the USA is around $99,000: **www.glassdoor.com/Salaries/electrical-engineer-research-salary-SRCH_KO0,28.htm**

ANAMIKA'S TOP TIP

Follow your passion and find the time to act on what you think is important. Most of the hours of your life will be spent working. Why not work on something that you truly enjoy?

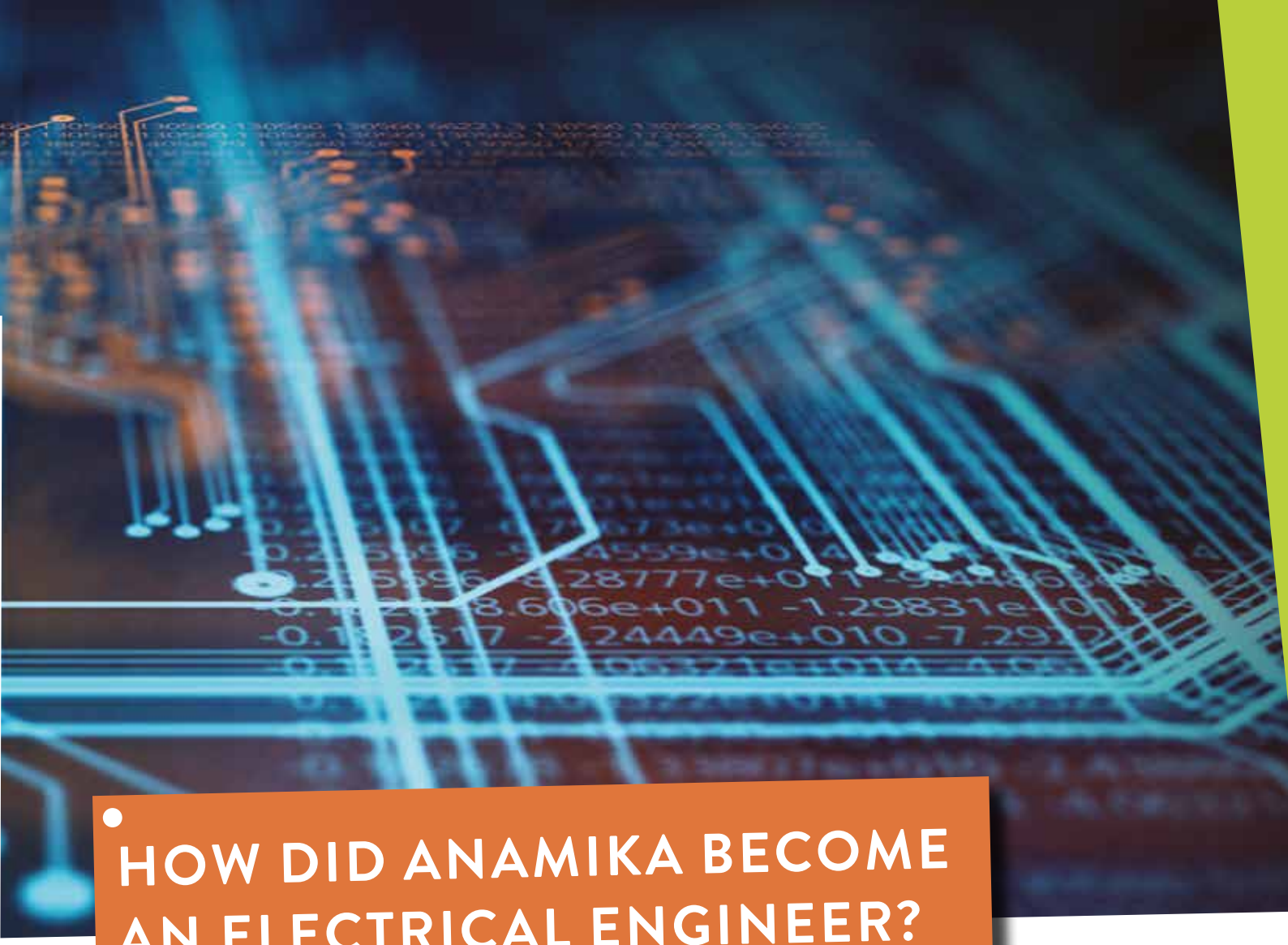
PATHWAY FROM SCHOOL TO ELECTRICAL ENGINEERING

• At school, Anamika recommends developing strong analytical skills by studying maths and science, especially physics. She also recommends taking courses related to computer programming to understand the basic principles of code development.

• Many universities offer degrees in electrical engineering. Anamika suggests taking courses in advanced maths and physics, electromagnetics, electric circuits, electronics, and signals and systems.

• As you progress through an electrical engineering degree, you can specialise in the specific fields that interest you, such as electric power, microelectronics, communication systems, etc.

• Electrical engineers who work in industry rather than academia often pursue apprenticeships or vocational qualifications.



HOW DID ANAMIKA BECOME AN ELECTRICAL ENGINEER?

I spent my childhood in a small town in central India, where my family greatly valued education and encouraged me to pursue excellence. From an early age, I was fascinated by all types of machines, I had a knack for maths and science, and was curious to learn more about the world. Luckily, my family nurtured my curiosity, and a supportive environment motivated me to pursue a bachelor's degree in engineering from one of the premier institutions in India and, consequently, master's and doctorate degrees in the USA. Throughout my journey, my grandfather ('Nana') has been a great source of support.

My interest in engineering was a by-product of my father working as an engineer, and the fact I always enjoyed and achieved in maths and physics at school. My maths and physics teachers guided me through the process of getting into the top engineering college in India.

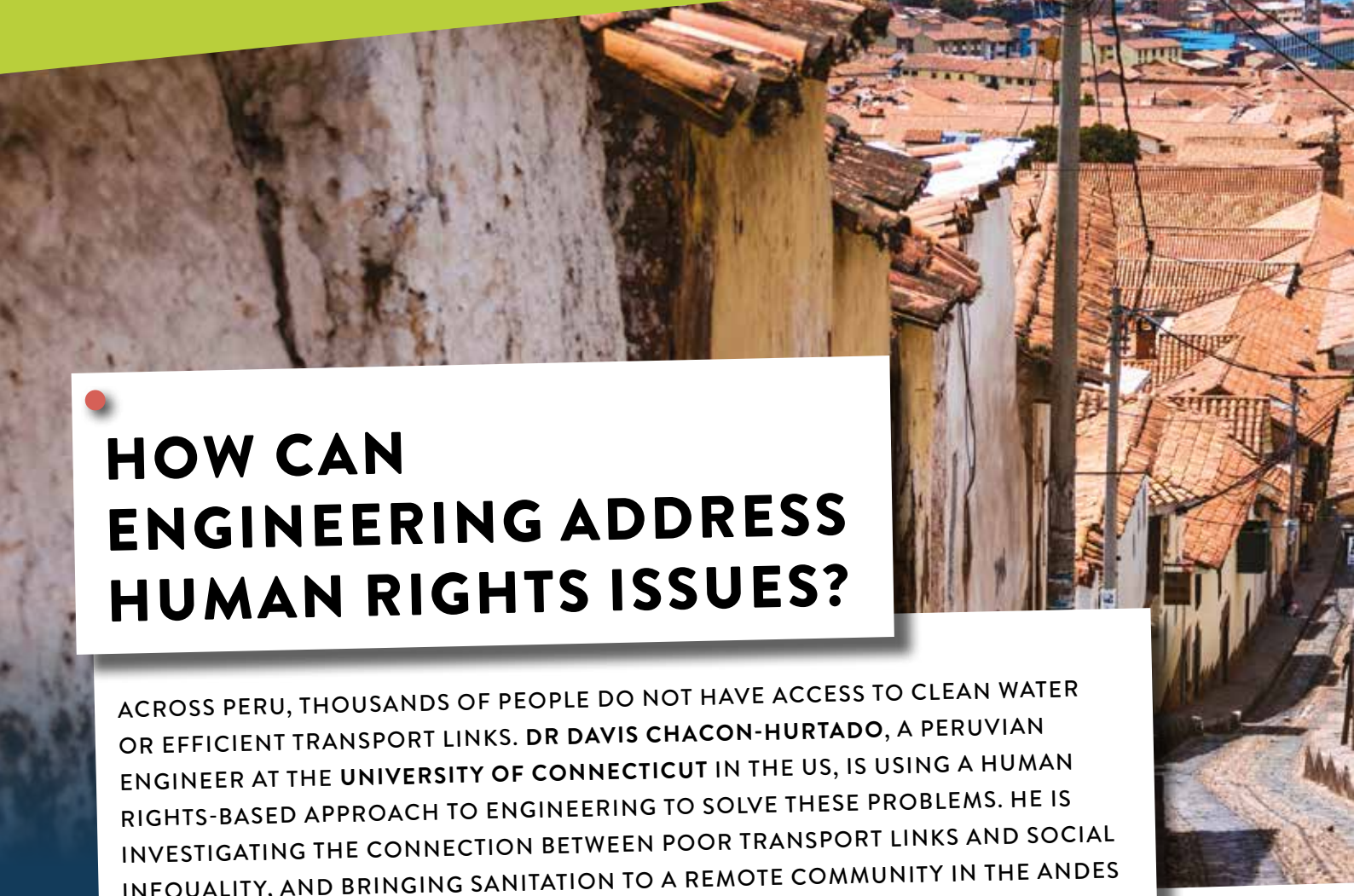
My mother, who is a doctor, has been the greatest source of strength and inspiration. She constantly inspired and motivated me not to be defeated by circumstances and to choose my own path in life.

I grew up in an era when a major part of rural India did not have access to regular electricity supply, and urban India experienced frequent blackouts and brownouts. Having experienced this problem first-hand, I decided to work on improving the electric power grid infrastructure. This led to further interest in renewable energy resources and their value towards a sustainable energy future, and motivated me to pursue a university professorship in electric power systems.

As a student, I undertook internships with the Defence Research Development Organization of the Government of India, and with the Mitsubishi Electric Research Laboratories in the USA. My internships provided an opportunity to learn about how theoretical principles are applied in the real world. In school, we learn mostly about theory and principles of engineering with less focus on real-world applications. All my internships provided me with valuable experience and helped me to develop a deeper appreciation for the field by seeing its direct application to the real world. I think internships during college are crucial for the development of a well-rounded engineer.

Our electricity infrastructure is a technological marvel. We may take it for granted, but it needs our collective attention if we are to continue to reap the benefits of electric power while not damaging our environment beyond the point of no return. Thus, we need to pay attention to where our power is coming from. While energy conservation at an individual level is great, we need to make our politicians understand the need for clean power and push for progressive policies that will lead to a more sustainable energy future.

When not working, I love to hike and spend time with my husband. I am lucky to have a partner who values my career aspirations and continuously supports, encourages and inspires me. I also enjoy catching up on regional, national and international politics on several issues related to energy, sustainability and technology.



HOW CAN ENGINEERING ADDRESS HUMAN RIGHTS ISSUES?

ACROSS PERU, THOUSANDS OF PEOPLE DO NOT HAVE ACCESS TO CLEAN WATER OR EFFICIENT TRANSPORT LINKS. **DR DAVIS CHACON-HURTADO**, A PERUVIAN ENGINEER AT THE **UNIVERSITY OF CONNECTICUT** IN THE US, IS USING A HUMAN RIGHTS-BASED APPROACH TO ENGINEERING TO SOLVE THESE PROBLEMS. HE IS INVESTIGATING THE CONNECTION BETWEEN POOR TRANSPORT LINKS AND SOCIAL INEQUALITY, AND BRINGING SANITATION TO A REMOTE COMMUNITY IN THE ANDES

TALK LIKE A HUMANITARIAN ENGINEER

INFRASTRUCTURE – the structures needed for a society to operate e.g., roads, buildings, electricity supplies and water systems

SANITATION – the process of keeping people and places clean, which requires clean water, latrines and sewage systems

PERIPHERALISATION – being forced to live on the periphery, or outskirts, of a city

LATRINE – a very simple toilet facility

BIO-DIGESTER – a tank system that biologically digests organic material, including human sewage

CHAPTER – a local group that is part of a larger organisation

Access to water and sanitation are fundamental human rights. The ability to travel to reach educational or employment opportunities is essential for ensuring social equality. Yet around the world, hundreds of thousands of people are denied these basic rights.

Dr Davis Chacon-Hurtado, an engineer at the University of Connecticut, hopes to address these issues in his home country of Peru. By combining engineering and human rights disciplines, he is researching the links between access to transport and the inequalities facing Peruvians today. His projects and collaborations, as part of the Engineering for Human Rights Initiative (EHRI), aim to reduce these inequalities by investigating the benefits of better transportation systems to influence policy changes in Peru as well as in Connecticut, USA. Davis is also working in collaboration with Engineers Without Borders to improve sanitation by providing latrines in rural communities.

HOW DOES PUBLIC TRANSPORT AFFECT INEQUALITY?

We might not always be aware of it, but efficient transport structures and services are vital for social inclusion. Most people need to travel to school or to work, or to go to the shops or the doctors. For those without private cars, or who are unable to walk, this means relying on public transport systems. Lack of transport creates a key barrier for many people to access opportunities and services, resulting in social exclusion and inequality. Davis highlights that transport-related social exclusion is usually greater in rural areas as opportunities and services are more spread out, so it is more expensive and time-consuming to travel around.

HOW IS SOCIAL DEPRIVATION LINKED TO TRANSPORTATION IN CUSCO, PERU?

Rapid urbanisation has been occurring in Latin America in recent decades. However, as cities have expanded, their infrastructure and services have not developed at the same pace. Davis grew up in Cusco, a city that lies high in the Peruvian Andes. He is leading a research project that uses a human rights-based approach to understand how transportation services in Cusco affect residents' access to education, employment and health opportunities.

"The first step was to develop a multi-dimensional metric of transport disadvantage and equity from a spatial perspective," explains Davis. This involved gathering data about transport services and availability of health and education opportunities for each district in Cusco. "The second step was to compare those measures with a multi-dimensional index of social deprivation." This required data about social factors in each district, such as the population age structure, level of employment and literacy rate.

Davis has been working with Ashley Benítez Ou, a geography PhD student at the

DR DAVIS CHACON-HURTADO

Department of Civil and Environmental Engineering, Human Rights Institute, University of Connecticut, USA

FIELDS OF RESEARCH

Engineering for Human Rights, Transportation Engineering

RESEARCH PROJECT

Investigating the correlation between access to transportation and sanitation infrastructure and social equality in Peru

FUNDER

University of Connecticut's Office of the Vice President for Research

University of Connecticut, and their research has revealed significant differences in access to opportunities between different districts in Cusco. Educational, employment and health opportunities are concentrated in the centre of Cusco, whereas fewer opportunities are available on the outskirts of the city. Correspondingly, levels of social deprivation are lower in the city centre and higher in surrounding districts.

"There are marked spatial differences in access to opportunities," says Davis. "This pattern might be related to the cost of land, where low-income groups are segregated to the outskirts of the city." This process is known as peripheralisation. In these districts, there are fewer local opportunities, and travelling to reach opportunities in the city centre is more expensive and time-consuming.

Davis hopes his research findings in Cusco can influence transport policies in Peru and beyond. New policies should monitor and address the issues of peripheralisation and unequal development in rapidly urbanising regions in Latin America, to ensure that all urban residents have access to essential services.

WHAT INFRASTRUCTURE PROBLEMS EXIST IN RURAL PERU?

While Peruvian cities have been rapidly growing and developing since the 1990s, rural communities commonly remain isolated, underdeveloped and lacking the infrastructure found in cities. This is a particular issue in the mountainous regions of Peru, where challenging geography makes it hard to build infrastructure and where policymakers have not focused much attention.

In response to this rural deprivation and inequality, Davis collaborated with the Engineers Without Borders (EWB) chapter at the University of Connecticut and Ecosistemas Andinos, a local NGO, for the Peru Sanitation Initiative. Working with EWB and Ecosistemas Andinos, Davis and his students set out to use their engineering skills to provide clean water and sanitation to the highland community of Thastayoc.

The main aim of this student-led, community-driven project was to improve sanitation in Thastayoc by providing clean water and constructing latrines and bio-digesters for the community. The team closely collaborated with community members to ensure the engineering solutions they provided were directed by the needs of the community. Another key component of the project involved educating children in the community about water sanitation and hygiene practices, such as hand washing.

Community members said they were most concerned about the risk of contamination of their water sources, so Davis' engineering team designed three potential water treatment systems. The community selected the option most appropriate for their needs and gave input as the final design was planned and constructed. "The final version consisted of a bathroom with shower features and a bio-digester septic tank, sludge-pit and leaching trenches to remediate waste," says Davis.

WHAT WERE THE CHALLENGES AND JOYS OF THE PROJECT?

"Thastayoc is located 14,000 feet above sea level," says Davis. "So, the first challenge was to adapt to the altitude, which makes performing manual labour very challenging for those who are not accustomed to it." The mountainous terrain provided additional challenges. The lack of phone signal hampered the coordination of logistics and provision of materials from the nearest town, while the lack of road access to the community centre meant all tools and materials had to be carried to Thastayoc from the nearest road.

Language barriers were also a challenge as communication was translated from English to Spanish to Quechua, an Indigenous language spoken throughout the Andes. As good communication was vital for the project's community-based approach, team members who spoke English and Spanish and community leaders who spoke Spanish and Quechua were essential. "Engineers are sometimes seen as problem-solvers and communities as the passive receivers of solutions," says Davis. "We wanted to overcome this limitation by always working with the community leaders to ensure robust, two-way communication and community engagement."

The students who participated in the Peru Sanitation Initiative had an incredible learning experience, both in terms of practical engineering application and cultural exchange. One student commented that he did not have a full sense of the role of engineering in society before the trip but was now excited by the potential of his engineering profession as he saw how it could be used to change lives. Students learnt that the community should always be at the heart of any engineering project and had the opportunity to share their engineering skills with the people of Thastayoc, working together to help reduce inequality.

Davis' projects in Cusco and Thastayoc highlight the important role that engineers play in ensuring communities around the world have access to essential services and infrastructure.

ABOUT ENGINEERING FOR HUMAN RIGHTS

Engineers identify problems and seek to design and make solutions to those problems. "Engineering applies science and mathematics to adapt and transform matter and energy for the benefit of people," says Davis.

There are many fields of engineering, including civil, mechanical, electrical and chemical, all of which benefit from a human rights-based approach to ensure the solutions and systems developed by engineers are used to improve the world. Civil engineering, Davis' field, involves designing, building and testing all kinds of infrastructure, from buildings to bridges, transport links to water systems.

HOW CAN ENGINEERING PROMOTE SOCIAL JUSTICE?

Davis uses his skills and knowledge as an engineer to address human rights issues, particularly focusing on access to resources such as sanitation and transport for the most vulnerable in society. He says this collaboration between engineering and human rights is the most exciting part of his job.

Davis and his team focus on using a human rights-based approach to engineering. This means the work they do must always promote public welfare. "This approach enhances the ability of engineers to enact socially and environmentally responsive technological solutions that advance human dignity," he explains.

WHAT IS THE ENGINEERING FOR HUMAN RIGHTS INITIATIVE (EHRI)?

This exciting initiative is a collaboration between the School of Engineering and the Human Rights Institute at the University of Connecticut. By combining disciplines, the initiative hopes to address the biggest challenges facing the world today. "Interdisciplinary collaborations are essential to the work of the EHRI," says Davis. The variety of skills and expertise within the EHRI allows the team to apply engineering solutions to address a broad range of human rights challenges, from food and water security to education, sustainability, and cybersecurity. Davis works alongside his colleagues, Dr Shareen Hertel and Dr Michael Rubin, in the EHRI.

If you were an engineer, how would you use your skills and knowledge to promote human rights?

EXPLORE A CAREER IN ENGINEERING FOR HUMAN RIGHTS

- Learn about the Engineering for Human Rights Initiative at the University of Connecticut, including the projects conducted by the EHRI and educational pathways offered at the university: **www.engineeringforhumanrights.initiative.uconn.edu**
- If you want to use your engineering skills to improve the lives of others, Davis recommends volunteering with Engineers Without Borders when you begin your studies, which will provide you with impactful, hands-on experience: **www.ewb-usa.org**
- Engineering for Change has helpful career resources for people looking to start their career in engineering for human rights: **www.engineeringforchange.org/what-we-do/professional-development**

DAVIS' TOP TIPS

01 Search for topics that inspire you and get involved in those

02 Read the scientific literature around those topics, attend conferences, and do not be discouraged if it all looks overwhelming

03 Develop the ability to listen to other people and value their opinions

04 Search for mentors who can guide you in your interests, and be a mentor to others whenever you can

PATHWAY FROM SCHOOL TO ENGINEERING

- Engineering combines maths and science to solve real-world problems, so studying maths, physics, chemistry and computing at school will all be useful when applying for an engineering degree at university.
- Different fields of engineering (e.g., civil, mechanical, electrical) will have different university degree programmes, all of which will have different entry requirements. Research the fields of engineering that interest you to find out what subjects you should study at school.
- A human rights perspective can be applied to every field of engineering. Study social science subjects at school to learn about the human side of engineering challenges.
- Davis recommends that engineering students take university classes focused on human rights and sustainability.
- The School of Engineering at the University of Connecticut has recently launched a Multidisciplinary Engineering Degree, which explores the collaborative approach between research disciplines and includes courses in engineering for human rights.

HOW DID DAVIS BECOME AN ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I have always been interested in how things work, and once I came to understand them, I enjoyed sharing what I learned with my family and friends. I tend to look at things from a historical perspective as I've always been fascinated by history. I often spend hours at my local library going through history books.

HOW DID GROWING UP IN CUSCO INFLUENCE YOUR DECISION TO USE ENGINEERING TO ADDRESS INEQUALITY IN PERU?

I think it came from two primary sources. My trips to rural areas in the highlands of Cusco helped me understand the link between social exclusion and poverty. I was also interested in policymaking for economic development, where economic inequality is a critical topic. I used to ask myself: what can I do to help as an engineer?

WHEN AND WHY DID YOU BECOME INTERESTED IN THE HUMAN RIGHTS APPLICATIONS OF ENGINEERING?

During my master's studies at the University of Puerto Rico and PhD at Purdue University in the US, I became interested in the social dimensions of engineering. My work in Puerto Rico was based on community engagement. I became fascinated by research at the intersection of social sciences and transportation engineering.

HOW DID YOU COME TO ENGAGE WITH THE ENGINEERING FOR HUMAN RIGHTS INITIATIVE?

As my colleagues have said, it seemed this position at the Human Rights Institute was created specifically for me and my interests! I applied for the position with great excitement and curiosity to learn more about the work of the initiative at the intersection of human rights and other disciplines.

Working alongside colleagues specialising in a broad range of topics helped me feel comfortable working in interdisciplinary areas. My experiences of studying and working in different schools, from the highlands of Peru, to the Caribbean, to the US Midwest, and of working with a diverse group of colleagues, also helped me see things from different perspectives.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR, AND WHAT ARE YOUR AMBITIONS FOR FUTURE?

My proudest achievement is to be able to inspire my students to believe that engineering can make our world more equitable and sustainable. Some of my students are starting new jobs where I am sure the material learned through classes or research will help guide their work.

In the future, I hope my colleagues and I can spread the ideas of the Engineering for Human Rights Initiative to other schools and create a network of scholars and students working on the most pressing human rights issues in the USA and around the world.

WHAT DO YOU ENJOY OUTSIDE OF WORK?

I used to visit my grandparents in a rural area of Cusco, and that's where I got my enjoyment for hiking. I also enjoy cooking Peruvian cuisine and visiting museums and historical landmarks.

Davis at the National Convention of the Society of Hispanic Professional Engineers in Cleveland, USA.

THE MISSING MILLIONS: BRIDGING DIGITAL DIVIDES

SCIENCE AND TECHNOLOGY SUFFER FROM UNDERREPRESENTATION OF MANY SOCIAL GROUPS, WHICH AFFECTS THE QUALITY AND SOCIETAL IMPACT OF NEW ADVANCEMENTS. THIS IS ESPECIALLY TRUE IN DATA AND COMPUTATION, WHERE THE LACK OF ACCESS AND PARTICIPATION FOR MANY MEANS THAT THEIR VIEWS, VALUES AND SKILLS ARE NOT ACCOUNTED FOR IN NEW DEVELOPMENTS

Alan Blatecky has been leading a pioneering project from the National Science Foundation entitled "The Missing Millions: Democratizing Computation and Data to Bridge Digital Divides and Increase Access to Science for Underrepresented Communities." From his position at RTI International in North Carolina in the U.S., he worked with other researchers and countless practitioners to build a strong case for the democratisation of computational resources.

The report focuses on the many millions of people who are currently excluded from the world of research. "The 'missing millions' are those students, faculty and citizens who are not involved or engaged in STEM activities because they don't have access to the digital resources or technologies required," says Alan. "This means they are severely limited in their ability to fully participate in the economic and research engines driving society."

Given that these people are underrepresented, their knowledge and perspectives are also marginalised within science and technological advancement. "There are countless research questions of importance to these missing millions that are not being pursued because of the lack of support," explains Alan. Ensuring underrepresented people have the opportunity to participate in, drive and lead research, specifically through computational and data means, is the focus of the Missing Millions report.

ACCESS AND ABILITY

Providing access to resources is often identified as a straightforward solution, but access alone will not solve this issue. Digital technologies require some level of expertise to be able to use them; any forward-thinking programme needs to facilitate training, as well as supply resources. "Although having access is fundamental, without having a corresponding ability to use and deploy computation and data resources, providing access is a hollow goal," says Alan. People need the ability to use statistical software, data visualisation tools, data curation and storage infrastructure, data quality assurance and artificial intelligence. They also require equitable funding for training, hiring qualified personnel and maintaining infrastructure.

Despite the assumption that science is objective, scientific and technological progress is inevitably shaped by the demographics of the researchers behind it. "We know there is the risk of bias and adverse societal impacts of data, so the people who are at risk need to be part of the solution," says Alan. "Without having the ability to use computation and data resources, the digital divide remains and, worse, will continue to expand."

THE RESEARCH PROCESS

The Missing Millions project involves engaging with a diverse range of people. "The people we talked to range from cyberinfrastructure experts to computer and data researchers and practitioners, to leaders of underrepresented institutions, as well as organisations focused on broadening data access," says Alan. "Broad communication was essential in this research as the changes required go far beyond just making targeted investments with technology."

Beyond discussions, the project also helped set the groundwork for building the networks needed to bring the discussed improvements to fruition. "Changes need to provide opportunities for people to familiarise themselves with data and computer

The opinions, findings, conclusions, and recommendations expressed are those of the co-authors and do not necessarily reflect the views of the National Science Foundation. Award number NSF OAC 2127459.

We acknowledge the traditional owners of the lands where Washington, Maryland and Virginia now stand – the Pamunkey, Chickahominy, Upper Mattaponi, Rappahannock, Monacan and Nansemond. We pay respect to their Elders past, present and emerging.

TOP TIPS FOR YOU AND YOUR STUDENTS

01 Find things that you're passionate about and people who are also passionate about them.

02 Focus on local social or science issues that are important to your community.

03 Work with others to accomplish together what you can't do alone.

04 Consider what your role is in contributing to your communities in the future. What is your responsibility today to prepare for tomorrow?

ALAN BLATECKY

RTI International, Research Triangle Park, North Carolina, USA

FIELD OF RESEARCH

Cyberinfrastructure (for Research and Education)

RESEARCH PROJECT

'The Missing Millions: Democratizing Computation and Data to Bridge Digital Divides and Increase Access to Science for Underrepresented Communities'

FUNDER

US National Science Foundation (NSF)

resources, so they can build experience and expertise," says Alan. "This can only be accomplished by broad educational, social and community efforts."

ENTERING THE FIELD

Established entry-level work and training opportunities are often emphasised as gateways into research careers but often fail to meet their intended purpose. "Many internships and apprenticeships are given to those students already 'qualified,' who have already made it into the research community, while others continue to remain outsiders," says Alan. "To address this, these programmes must have a component that enables those with non-traditional backgrounds to participate."

Alan's team engaged closely with educators from establishments such as Historically Black Colleges and Universities (HBCUs), Tribal Colleges and Universities (TCUs), and other Minority-Serving Institutions (MSIs) to understand how these barriers could be overcome. The team found that approaching local issues through research provided a gateway to build communities of students that could tackle issues that matter to them, while simultaneously building research skills.

THE IMPORTANCE OF COMMUNITY

The project concluded that engaging the missing millions was best achieved at the grassroots level, by supporting communities to come together to address research issues that affect them. "A sense of community in research has always been important," says Alan. "However, to become a member of the research community, you often need to have certain resources or backgrounds. Those individuals who don't have the 'correct' experience or sufficient financial capacity are often left out." Local communities that focus on local issues can help build the skills needed to access the broader research community.

"One of the most effective ways to nurture research communities at the ground level is to enable small groups of students to address and explore issues in their own neighbourhoods," says Alan. "By addressing local issues that matter to them and their local communities, students can begin to create their own research communities. They also gain a sense of belonging and receive validation from their peers and community." Ultimately, these efforts can feed into broader scientific projects, helping to enrich findings through the inclusion of diversity and new perspectives.

MODERN CHALLENGES

The global issues facing the modern world – climate change, pandemics and conflicts – affect the marginalised in society more severely. To ensure that science and technology address these impacts and meet the needs of the people affected, it is essential that the voices of the missing millions are included. "It isn't just about having large numbers of people engaged but also ensuring that large numbers of people from diverse backgrounds, experiences and perspectives are asking questions and exploring solutions," says Alan. "The complexity of research demands it."

Reiterating the vital combination of resources, training and engagement that meaningful research requires, Alan explains, "We use the expression 'access + ability = capability.' Nurturing this capability to cross the digital divide is essential to allow the missing millions to participate fully in the economic prosperity and opportunities of modern society."

MEET THE TEAM

LAUREN MICHAEL

RESEARCH COMPUTING FACILITATION LEAD, CENTER FOR HIGH THROUGHPUT COMPUTING (CHTC), UNIVERSITY OF WISCONSIN-MADISON, USA

Lauren's role involves engaging with researchers to advise on the most impactful computing approaches, services and relevant learning pathways.

As well as addressing disparities within its domain, computing also has an important role to play in democratising science across all research domains and underrepresented groups by making research data and methodologies accessible to new communities of researchers. Repeatedly, we see research emphasising the importance of diversity and representation to the quality of the nation's science and engineering endeavours.

We specifically looked for individuals who could provide insights around multiple angles addressed by the study and also asked them for recommendations from their networks. This included people experienced in expanding diversity and representation at different levels and people bringing research, data and computation to wider audiences.

Educators showed us the need to incorporate computational training at earlier stages. However, they lack access to standardisable datasets, tools and methodologies that they can incorporate into classrooms easily. Additionally, there is a lot of research demonstrating that engagement is best driven by societally relevant research problems and datasets rather than methodologies and tools.

I was led to this role by my passion for communication and teaching, for computation and for impacting and learning about a wide range of research topics. The greatest rewards continue to be the achievements and gratitude of the thousands of researchers who I have been fortunate to work with, where I have seen significant gains in the diversity of research and researchers using large-scale computing over the last decade.

I think the most successful community-building efforts engage members to 'own' their organisational work by building in processes that achieve ongoing, regular community input and by creating opportunities for members to share the work.

Communication is the most important skill for Research Computing Facilitation and probably for any form of facilitation. You do not have to know all the answers, but you do have to really understand the client's questions, navigate the plethora of people and information sources that have the answers and then translate these for the client's specific context and background.

A diverse and representative research community will ensure that the STEM community is appropriately prioritising research that representatively addresses societal issues, including other social disparities.

PROFESSOR JOEL E. CUTCHER GERSHENFELD

THE HELLER SCHOOL FOR SOCIAL POLICY AND MANAGEMENT, BRANDEIS UNIVERSITY, BOSTON, MASSACHUSETTS, USA

Joel's career spans social impact enterprises, large-scale systems change, cyberinfrastructure and many other areas.

Long-standing disparities in society have become more visible with the rise of social protest and the COVID-19 pandemic. The Missing Millions project's mission to democratise data and computation is an essential and positive response to these inequalities.

We conducted online interviews with small groups of participants covering the following topics:

- Visions of success: what the next 10 years could look like if efforts to democratise research computing were successful.
- Enabling technologies: how new or emerging technologies, or novel research applications, could facilitate this democratisation.
- Communities of practice: how to encourage diverse and inclusive innovation driven by communities.
- Institutional and societal barriers: entrenched issues, potential risks and avenues for overcoming these barriers.

Discussions were lively and enthusiastic, with many participants offering to take the conversations further.

From speaking to educators, we found that there is great innovation at the "edge" of computation. For instance, electronic lab notebooks are helping make science more accessible. The potential for communities to control their own data is a powerful idea.

Much more data could be open access than they are at present. Fields and disciplines with more openly available data will progress faster. Considerable work is needed to reduce the disincentives to make data available and provide accessible computing infrastructure.

Inclusive and representative research communities need strong leadership, effective collaboration and appreciation of diverse voices. They also need improved infrastructure and funding and further support in removing barriers to progress.

My career has seen several "eureka" moments that I take pride in. I have helped develop what has become the Ford-UAW Production System and pioneer new strategies for labor-management negotiations. In recent years, I have helped document the rise of the third digital fabrication revolution and how it relates to broad societal challenges.

The Missing Millions project aims to inspire a collaborative mindset, which leads to diverse, inclusive and equitable institutions in the 21st century. It is essential that we learn to accomplish together what we can't do separately.

CHRIS CALDWELL

PRESIDENT OF THE COLLEGE OF MENOMINEE NATION (CMN), KESHENA, WISCONSIN, USA

Chris has held positions as Tribal Resources Director/Compliance and Enforcement Officer for the Menominee Indian Tribe, forest products technician with the USDA Forest Service's Forest Products Laboratory in Madison and Director of Sustainable Development Institute.

Through my work with our Sustainable Development Institute (SDI) at the College (CMN), I understand how a lack of control over the research process can negatively impact Tribal communities. Being able to control the research process means prioritising topics of inquiry relevant to the community, employing culturally appropriate approaches to addressing the topic and having access to resources and expertise to carry out the work. Tribal research institutions often have limited access to the funding, resources and infrastructure required to carry out the necessary research – the Missing Millions report helps to address this.

I was asked to participate in a focus group of Tribal Colleges and Universities (TCUs) presidents and leaders. This came at the same time the SDI and the University of Wisconsin-Madison were discussing ways to increase capacity for storing, managing and protecting data derived from research projects at CMN SDI.

I'm a PhD candidate in Environment and Resources, looking at how environmental issues impact human and environmental relationships. This is important to me as a researcher and educator for my Tribe.

The Menominee theoretical model of sustainability was developed by Menominee Tribal leaders and is used to develop a research agenda, processes and projects. SDI is the steward of this model of sustainability on behalf of the community.

As College President, it is my job to communicate with students, Tribal communities and the general public. Past Tribal leaders have been forward-looking, thinking about future generations and what decision-making today means for that future. I see my role continuing this.

Our focus as a Tribal college is how we can help our Tribal communities. We understand our students need to be prepared to engage the broader world – student researcher and research leadership opportunities are important and can be achieved by providing more resources and funding to institutions like TCUs.

Reaching the missing millions will see Indigenous peoples having more control over research. The data generated in their communities is important for sovereignty, self-determination and revitalising Indigenous approaches to inquiry. Accepting and valuing other ways of knowing beyond dominant Western-based research paradigms is important to this story as well. This is a grounding point from which STEM can advance beyond its current state.

DR. DEBORAH F. DENT

CHIEF INFORMATION OFFICER AT JACKSON STATE UNIVERSITY, JACKSON, MISSISSIPPI, USA

Deborah oversees the management of the university's cybersecurity and network and communications infrastructure. She is a founding member of the Minority Serving – Cyberinfrastructure Consortium (MS-CC), working to advance cyberinfrastructure capabilities on historically underserved campuses.

I was drawn to the Millions project's goals because I support the desire to expand, diversify and support the development of new communities of researchers. How else can we truly begin to address pressing research, social and global issues today and in the future? I'm a co-author of the report and participated in meetings, focus groups and webinars.

At the Minority Serving - Cyberinfrastructure Consortium, we envision a transformational partnership to promote advanced cyberinfrastructure capabilities on historically underserved campuses with data, research computing, teaching, curriculum development and implementation, collaboration and capacity-building connections among institutions. We're committed to learning and adjusting our operational model to ensure that we continue to lift all participating institutions by advancing cyberinfrastructure for research and education across diverse fields, disciplines and communities.

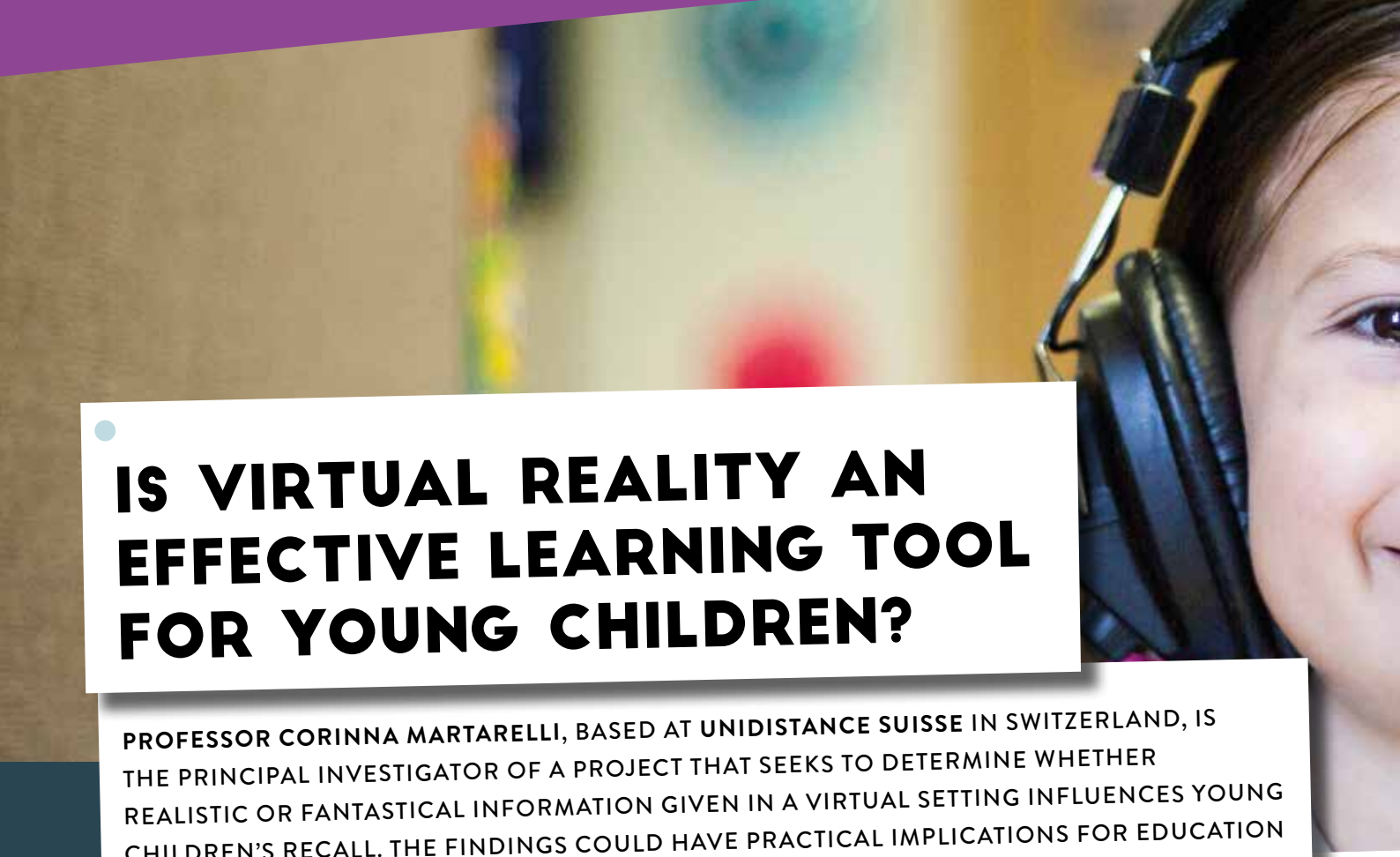
We have the data and empirical evidence that show what the immediate cyberinfrastructure needs for Historically Black Colleges and Universities (HBCUs), Hispanic-Serving Institutions (HSIs), Tribal Colleges and Universities (TCUs), and other Minority-Serving Institutions (MSIs) are and what barriers are preventing campuses from achieving them. A common need is the actual infrastructure – the hardware and connectivity – without which you can't enable data, computing services and resources essential to supporting advanced science, engineering and mathematics.

There has been an increase in pandemic-related government funding, allowing campuses to improve their basic cybersecurity equipment and services. Recently, the MS-CC, in collaboration with Internet2 and American Indian Higher Education Consortium, received funding to provide cyberinfrastructure resources, support and training for HBCUs and TCUs.

To nurture inclusive research communities, we must understand the barriers limiting access to research data and computing, and that's what the Missing Millions report addresses. We must be intentional in making incremental changes while addressing the broader, systemic changes in the science and engineering enterprise.

Mentorship works! Creating mentorship opportunities for students, such as afterschool programmes and summer camps, can have profound impacts on increasing STEM participation. This is especially needed for students living in rural areas.

I believe inclusive and representative teams across STEM fields will bring different life experiences and add valuable perspectives to research. A more diverse research community will see our societies flourish as we begin to tackle some of the world's most pressing research problems.



IS VIRTUAL REALITY AN EFFECTIVE LEARNING TOOL FOR YOUNG CHILDREN?

PROFESSOR CORINNA MARTARELLI, BASED AT **UNIDISTANCE SUISSE** IN SWITZERLAND, IS THE PRINCIPAL INVESTIGATOR OF A PROJECT THAT SEEKS TO DETERMINE WHETHER REALISTIC OR FANTASTICAL INFORMATION GIVEN IN A VIRTUAL SETTING INFLUENCES YOUNG CHILDREN'S RECALL. THE FINDINGS COULD HAVE PRACTICAL IMPLICATIONS FOR EDUCATION

GLOSSARY

VIRTUAL REALITY (VR) – a computer-generated environment with scenes and objects that appear to be real, making the user feel they are immersed in the computer-generated surroundings

RECALL – the cognitive process of retrieving information from the past

AVATAR – a VR character. For example, representing a player in a computer game. In this research, the avatar is LinLin, a VR character presenting information to the children

THEORY OF MIND – the ability to understand somebody's mental processes

WESCHSLER INTELLIGENCE SCALE – a measurement that provides an estimate of global intellectual ability

RECEPTIVE LANGUAGE – the ability to understand spoken or written language

COGNITIVE – related to the mental processes of perceiving, knowing and understanding

COGNITIVE LOAD – the amount of information our working memory has to hold at any one time

PROTAGONIST – the main character or one of the leading characters in a story

From magical books to out-of-this-world superheroes, it is easy to link childhood to a love of fantasy. We often regard fantasy as more engaging for children than realism and so, intuitively, often teach young children concepts and ideas through fantastical stories and contexts. But is this intuition right? How beneficial is fantasy within an educational context? Do realistic settings and storylines make recalling information easier for young children?

With improvements in technology, it has become possible to use virtual reality (VR) to create fantasy worlds that appear incredibly real. By putting on a headset, you can be transported to worlds where anything can happen. Armed with this technology, Professor Corinna Martarelli, based at UniDistance Suisse, has embarked on a project that is interested in understanding how children differentiate between reality and fantasy and how they learn from fictional and realistic sources.

WHAT FORMS DOES THE RESEARCH TAKE?

Corinna is the principal investigator of the project and works alongside PhD student Lucas Dall'Olio and VR designer Olivier Amrein. Together, they want to ascertain whether the realistic versus fantastical information presented in a virtual setting influences young children's recall. To achieve this, the team is studying short-term and long-term recall by manipulating different settings (realistic and fantastical) and media types (3D virtual settings and 2D tablets). "168 children, aged five and six, were given the same presentation with either a realistic or fantastical avatar in virtual reality or on a tablet," says Corinna. "To identify the effect the setting and media type had on the children's ability to recall information, a series of recall tasks were carried out."

WHAT TASKS WERE CHILDREN GIVEN IN THE STUDY?

The tasks were divided into recall tasks and theory of mind tasks. The recall tasks were broken down into questions that ascertained the children's comprehension about the material, recognition tasks about visual stimuli seen in the virtual environment and a transfer task that assessed whether the learned material can be applied to a novel situation in the real world.

The children were also given four theory of mind tasks. "In these tasks, children are told four stories, including materials such as puppets

PROFESSOR CORINNA MARTARELLI

Faculty of Psychology, UniDistance Suisse, Switzerland

FIELD OF RESEARCH

Psychology

RESEARCH PROJECT

Investigating the educational impact of realistic versus fantastical information when presented on a tablet or through virtual reality

FUNDER

Swiss National Science Foundation (SNSF), under award number 100019 185477

and boxes. In one story, originally developed by Wimmer and Perner in 1983, Maxi and his mother (two puppets) are the protagonists," explains Corinna. "The story goes like this: The mother puts some chocolate in a blue box. Maxi leaves the room. The mother moves the chocolate from the blue box to the green box. Then Maxi comes back, and he wants some chocolate." At this point, the experimenter asks the child three questions: "Where will Maxi look for the chocolate?", "Where is the chocolate?" and "Do you remember where the mother put the chocolate at the beginning?"

The idea behind these questions is that children who have a 'theory of mind' (and are able to make a distinction between their own knowledge and the knowledge of others), will answer that Maxi will look for the chocolate in the blue box. Previous research has shown that this ability is linked to the ability to distinguish between reality and fantasy.

WERE ANY OTHER TESTS INCLUDED IN THE PROJECT?

Yes – children's receptive language abilities were also assessed using one subset of the Wechsler Intelligence Scale. In psychological research, researchers often assess variables that might be related to the main research questions. In Corinna's experiments, an avatar called LinLin explains information about China which requires receptive language abilities to understand. These abilities might play a role in recall, so by testing them, the team can include these values in its statistical models and take language abilities into account when conducting analyses.

WHAT ARE THE ANTICIPATED OUTPUTS FROM THE PROJECT?

The more knowledge that can be gathered about how young children learn and recall information, the better the ability to develop effective learning tools. "Fictional material is often used in education settings, and it is possible that VR might be used more frequently in the future, but it is unclear how such material affects learning and memory in young children," says Corinna. "Before implementing virtual reality tools in schools, we need solid evidence that these tools are as good as or better than more traditional methods."

WHAT WERE THE FINDINGS FROM THE PROJECT?

After controlling for theory of mind and language abilities, the children's recall performance was better when presented by a realistic (rather than a fantastical) avatar, especially in the long-term (one week after the presentation). This result may be explained by the importance of prior knowledge. "Contrary to our expectations, children's recall performance was reduced in the virtual reality condition when compared to the tablet condition," explains Corinna. "The findings have theoretical as well as practical relevance. For example, relating to the use of fantasy in educational contexts."

WHAT ARE THE NEXT STEPS FOR CORINNA'S RESEARCH?

Given that the results were not what the team expected, the next steps are centred on improving understanding about the counterintuitive findings. "We are planning follow-up studies to better understand the underlying mechanisms. Why did young children in the tablet group, in this specific situation, with this specific learning material, outperform children in the virtual reality group?" says Corinna. "Some suggest that virtual reality implies the processing of large amounts of cognitive information that is not linked with the learning objective, so we want to reduce cognitive load by testing a version with fewer details to help children focus on the learning material."

It is possible that the novelty of VR affects the outcome – many children are familiar with tablets but are unaccustomed to VR headsets – so Corinna and the team want to understand the extent to which the novelty of the situation affects the results. Understanding the effects and impacts of VR on a young child's ability to learn and recall information could impact future educational materials and methods.

ABOUT PSYCHOLOGY

Psychology is the scientific study of the human mind and how it dictates and influences our behaviour. Psychologists are involved in many different aspects of the field, including communication, memory, thought and emotion. As Corinna's research shows, psychology is a multifaceted field that can include many different (though related) sub-fields of study.

WHAT DOES CORINNA ENJOY ABOUT THE CHALLENGES INVOLVED IN PSYCHOLOGY?

One of the main appeals of Corinna's field of study is the underlying process of science – that each result her work obtains opens up new questions and directions for future study. "I really love the discrepancy between expected results and real results that happens from time to time," explains Corinna. "These differences can make us humble as researchers and remind us that science is a constant process."

WHAT ARE CORINNA'S PROUDEST CAREER ACHIEVEMENTS, SO FAR?

Corinna highlights seeing the happiness of her team as hugely significant, especially when she has led it in the completion and publication of a study. "Seeing students and team members discover the process of science is always rewarding," says Corinna. "I enjoy seeing the creative aspects when my team comes up with an idea, but also the more methodological parts, where the team designs an effective experiment or conducts statistical analyses."

WHAT RESEARCH OPPORTUNITIES WILL BE OPEN TO THE NEXT GENERATION OF PSYCHOLOGISTS?

In the future, academic research will become more interdisciplinary, where educators, psychologists, teachers, computer scientists and designers will collaborate. "I see this as a positive for future psychologists," says Corinna. "Outside academia, psychologists are employed in several fields, such as clinics, hospitals, schools, government, private companies, etc. I think that psychologists will be very much needed in several domains in the future."

EXPLORE A CAREER IN PSYCHOLOGY

• The British Psychological Society is a brilliant resource that is dedicated to promoting excellence in psychology: **www.bps.org.uk**

• Verywellmind provides a wealth of student resources: **www.verywellmind.com/student-resources-overview-4581768**

• The American Psychological Association has lots of useful career information: **www.apa.org/education-career**

• If you are interested in academic psychology, Corinna recommends doing an internship in a research lab to get an insight into the field. If, like her, you are based in Switzerland, find more information here: **www.psychologiestudierende.ch/how-do-i-get-an-internship-in-psychology** If you are in the US, visit: **www.psychology.org/resources/how-to-find-an-internship** In the UK, read more about internships here: **www.thepsychologist.bps.org.uk/volume-22/edition-10/benefits-internships**

• According to the National Careers Service, the average salary for a psychologist in the UK is between £24,000 to £60,000 depending on the level of experience – although studying psychology can lead to many different jobs with differing salaries: **www.nationalcareers.service.gov.uk/job-profiles/psychologist**

• Payscale has the average salary for a psychologist in Switzerland as 87.000 Fr: **www.payscale.com/research/CH/Job=Psychologist/Salary**

LUCAS' TOP TIP

Work on research questions that you are passionate about. Research is not always easy and it takes perseverance, but being passionate will increase your motivation.

OLIVIER'S TOP TIPS

01 Do not be afraid to start learning on your own.

02 Follow your instincts, be curious and never be afraid to go outside your comfort zone.

PATHWAY FROM SCHOOL TO PSYCHOLOGY

"There are a lot of methods and statistics in the study of psychology that are often underestimated, so mathematics and science will help," explains Corinna. "Creative and critical thinking are also important, so consider that throughout your studies."

Visit Prospects to find out more about routes into psychology: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/psychology**

MEET THE TEAM

LUCAS DALL'OLIO
PhD student

WHAT IS YOUR ROLE IN THIS RESEARCH?
I am the main investigator of this research. As such, I am involved in almost every step of the study, from its design, recruitment of participants, testing, analysis and valorisation of the results.

HOW HAS YOUR CAREER PATH LED TO THIS CURRENT PROJECT?
I have always had a great interest in new technologies and their daily use. My professional experience has allowed me to work with children and I realised that it was an area I enjoyed even more when applied in the field of psychology and learning.

WHAT WERE YOUR INTERESTS AS YOU WERE GROWING UP?
I always liked to solve problems, whether it was through games, brain teasers or other puzzles. I find many of these interesting elements within the world of psychology research.

WHO OR WHAT INSPIRED YOU TO BECOME A PSYCHOLOGIST?
When I arrived at university, I had chosen to study psychology without really being sure that I was going to make it my profession. However, when I took my first courses, that focused on the world of research, and read my first articles, I was immediately attracted to this way of working and thinking.

WHAT DO YOU FIND REWARDING AND CHALLENGING ABOUT PSYCHOLOGY?
What I like about research in psychology is that you have to constantly question yourself and find new and innovative ways to observe what you want to observe and measure what you want to measure. We are still far from having all the keys to understanding how our brains work and participating in the development of this field of knowledge is exciting.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A PSYCHOLOGIST?
I think my main qualities are perseverance, critical thinking and attention to detail. I also believe I have good communication and empathy skills, which are essential.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?
As a young researcher, I like to think that my proudest career achievement is ahead of me! Still, I was very proud to finish collecting the data from my first study and present the first results to the faculty of psychology. Preparing a study and collecting data is one thing, but being able to showcase research through meetings or conferences is the pinnacle of our work and brings a lot of satisfaction.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?
I would like to publish our first study in a scientific journal and complete my PhD. I then hope to continue to participate in the development of knowledge on the use of new technologies in learning.

OLIVIER AMREIN
VR Designer

WHAT IS YOUR ROLE IN THIS RESEARCH?
I am responsible for creating the virtual reality (VR) experience. This includes designing the two versions of the LinLin character (realistic and fantastical), as well as the environment and 3D objects presented by LinLin. I also animate the movements and lip synching based on the recorded audio in French and German.

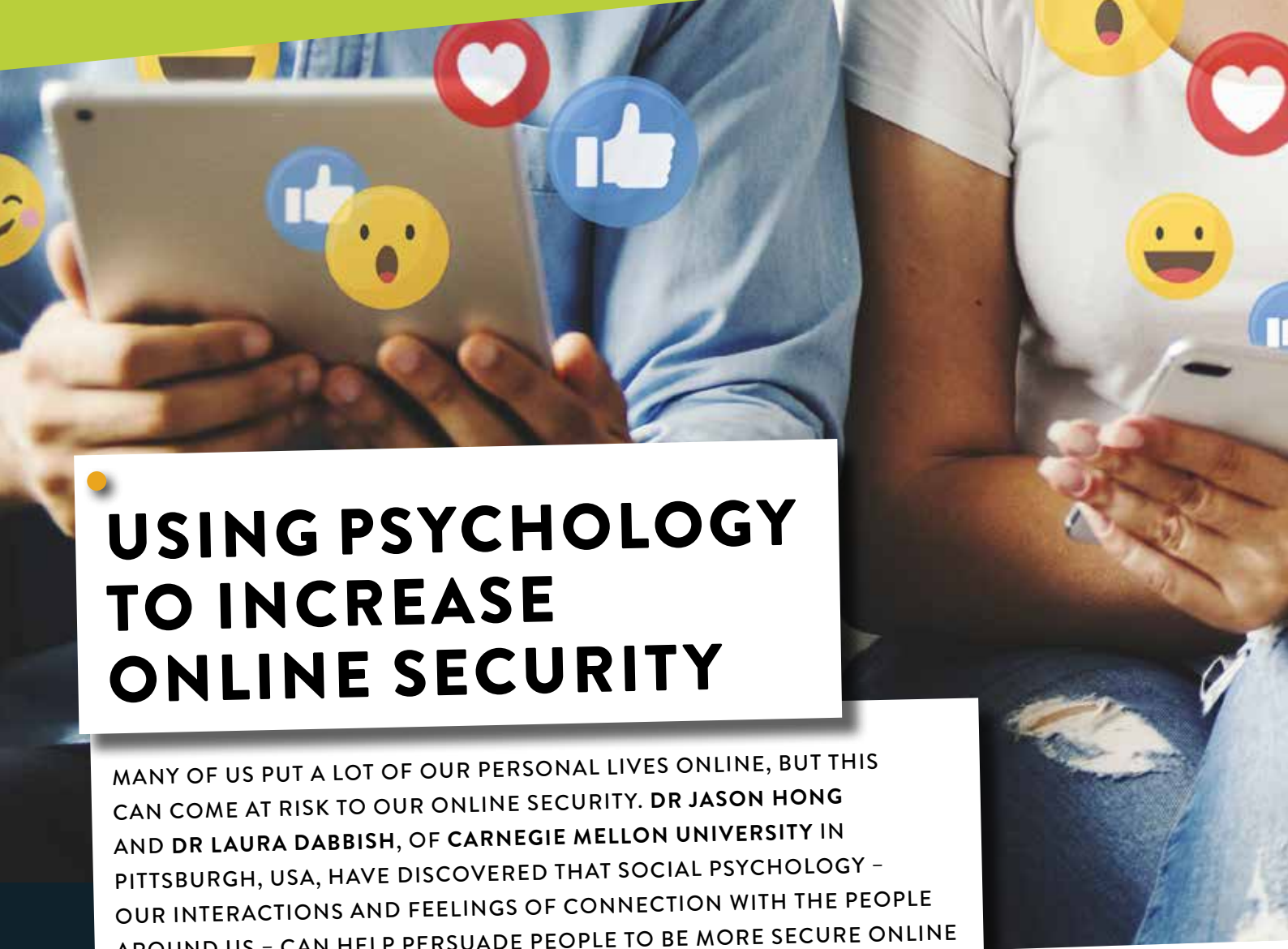
HOW HAS YOUR CAREER PATH LED YOU TO THIS RESEARCH?
I did not follow a traditional school/university path – I began at the dawn of the internet as a self-taught person. I was always interested in science and consider myself at the frontier between artistic/creative and technical/scientific.

WHAT CHALLENGES DOES THIS RESEARCH POSE FOR YOU AS A VR DESIGNER?
In projects for commercial clients, I usually follow a creative brief and I interpret it as I see fit. Here, the challenge was to create a more controlled story, because in this kind of research, we do not want random factors to influence our results.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A VR DESIGNER?
A capacity to hold deadlines, and being able to prototype environments or experiences rapidly, which gives a quick overview of whether a creative direction is working or not. If it is not working, I start again!

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?
Every career step or project is different from the previous one, so, for me, it's important to know that I am always learning and improving. Teaching and sharing are important, so seeing people who I have coached or helped making great art or conducting projects is a proud achievement for me.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?
I would like to continue working on research projects where I can bring my skills as both a technician and a designer. We are only at the dawn of what virtual reality and extended realities can do. There is still so much to explore.



USING PSYCHOLOGY TO INCREASE ONLINE SECURITY

MANY OF US PUT A LOT OF OUR PERSONAL LIVES ONLINE, BUT THIS CAN COME AT RISK TO OUR ONLINE SECURITY. **DR JASON HONG** AND **DR LAURA DABBISH**, OF **CARNEGIE MELLON UNIVERSITY** IN PITTSBURGH, USA, HAVE DISCOVERED THAT SOCIAL PSYCHOLOGY – OUR INTERACTIONS AND FEELINGS OF CONNECTION WITH THE PEOPLE AROUND US – CAN HELP PERSUADE PEOPLE TO BE MORE SECURE ONLINE

GLOSSARY

CYBERSECURITY – protection against criminal or malicious use of electronic data

PHISHING – a form of cyber scamming using a fraudulent message to trick someone into revealing personal information

SOCIAL NORMS – 'typical' behaviours of a particular social group, which can be used as reference points for members of the group to guide their individual behaviour

SOCIAL PROOF – a psychological phenomenon where people tend to copy the actions of others because of a desire to fit in with the group or because they assume others know something they do not

SOCIAL PSYCHOLOGY – the branch of psychology that covers the origins and influences of social interactions

Cybersecurity has come a long way in recent decades, but threats to our digital resources – such as viruses, scams and identity frauds – have also developed rapidly. Though there are lots of steps that can be taken to increase cybersecurity, many people choose not to take them. Understanding why this is, and how to change this behaviour, is essential for helping people avoid online dangers.

Dr Jason Hong and Dr Laura Dabbish are both experts in cybersecurity at Carnegie Mellon University in Pittsburgh. Rather than focusing on just providing ways to increase cybersecurity, they aim to find lessons from how people interact with the digital world and with each other. "Our research into the human factors of cybersecurity focuses on people as social actors whose security behaviours are influenced by their relationships, communities and life situations," says Jason.

WHY SOCIAL PSYCHOLOGY IS IMPORTANT

For many years, there has been a preconception among computer scientists that if security tools exist, people will use them. Jason recounts his 'lightbulb moment' when he realised the real picture is more complex. "I overheard a conversation where one person mentioned a mutual friend who had slipped on some ice and broken their laptop," he says. "The other person said they were going to back up their own data immediately, and they did!" This was a clear example of where social influence led to a behaviour change in the digital space.

Laura explains more about why social psychology is so important. "Humans are social creatures," she says. "We look for cues on how to behave from those around us, especially those we feel close to." This applies to a huge amount of our behaviour: what we buy, how we vote and how we treat others, for example. How we manage our online security and privacy is no exception. "We look at others' social media to see what's appropriate to share, we discuss with our friends and family when we hear about data breaches to figure out how to respond," says Laura. "We share anecdotes about our own online experiences and listen to those of others."

SOCIAL PROOFS AND SOCIAL NORMS

The concept of 'social proof' is well-documented in social psychology. "If you've ever alighted from a bus or train and don't know which way to go, following everyone else is generally a pretty good strategy," says Jason.

The same concept applies in a less practical but equally important sense, through our desire to fit in through following social norms. "Social norms are mutually understood acceptable behaviours within a social group," says Laura. "They may not ever be discussed, but still drive our behaviour. For instance, cutting a queue would be a clear violation of a social norm."

Social norms can be good and bad behaviours. For instance, if you see lots of people littering or buying the latest fast fashion, you might be inclined to replicate that behaviour. "In terms of cybersecurity, if everyone in a social group is sharing lots of personal information online, there is social pressure to do the same," says Laura. "This can put people at risk of issues like identity theft or sharing photos or posts they later regret." People who take extra security precautions may violate this social norm and be labelled as paranoid or overly cautious. Jason and Laura are interested in leveraging social proof to make security precautions more accepted and adopted.

RESEARCH WITH FACEBOOK

Jason and Laura and their PhD student Sauvik Das worked with Facebook, the social media company, to investigate ways to help its users be more secure online, beginning with a large study with 50,000 people. "Facebook was about to run an awareness campaign by posting messages on people's feeds saying, 'Facebook offers extra security settings to help you protect yourself' or similar," says Jason. "We modified the messages to say things like, '108 of your friends use extra security settings'."

The Facebook study showed the importance of adapting messaging to use social proof as an effective persuasion tactic. "We found that simply showing people how many of their friends used security features drove 37% more viewers to explore the promoted security features compared to simply raising awareness through a non-social announcement," says Laura. Their research showed a clear role for social aspects within awareness campaigns, though some knowledge gaps remain to be investigated.

FROM SURVEYS TO GAMES AND BEYOND

Laura and Jason have run surveys and interviews to investigate people's attitudes to security and how they manage security and privacy in different relationships. "We found that a majority of changes to people's approaches to cybersecurity were triggered by social interactions," says Jason. "This included being warned about insecure behaviour by a friend or family, being shown an interesting new security technique by a colleague or friend, or hearing about someone's negative experience, such as being hacked." The team followed up with a larger survey that found social triggers were the most common prompts for recent adoption of new security behaviours.

Learning from their insights, Laura and Jason, along with PhD student Tianying Chen, led the development of a game called 'Hacked Time', which involves the player going back in time to help a friend correct insecure behaviour and avoid getting hacked. "We found this game was effective at increasing self-efficacy for security techniques and for increasing cybersecurity awareness," says Laura. "We are interested in learning more about how incorporating social influences into game design can motivate safer cybersecurity behaviour."

DR JASON HONG

DR LAURA DABBISH

Human Computer Interaction Institute, School of Computer Science, Carnegie Mellon University, Pittsburgh, USA

FIELD OF RESEARCH

Social Cybersecurity

RESEARCH PROJECT

Taking lessons from social psychology to encourage people to exhibit safer and more secure behaviour in digital spaces

FUNDER

US National Science Foundation (NSF)

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Jason and Laura plan on taking their research further, to use social psychology in more sophisticated ways to persuade people to be more secure online. "Google gave a presentation a few years ago that showed that less than 10% of people use two-factor authentication, a powerful security technique," says Jason. "As risks to people's security grow and evolve, we want to find out how to persuade people to better protect themselves."

ABOUT CYBERSECURITY

WHAT DO JASON AND LAURA FIND REWARDING ABOUT RESEARCH IN THEIR FIELD?

"In many areas of science, there is often a large gap between one's research and seeing a positive impact on people," says Jason. "Computer science is different, partly because we set our own rules rather than using the rules of nature, and partly because it's a younger field. It's often surprising how much influence a small team of researchers can have on industry and public policy."

"I love the interdisciplinary nature of the work," says Laura. "Our department combines insights from computer scientists, psychologists and designers, and this helps us take a much broader approach to the role of technology in people's lives. The collaboration this involves is extremely rewarding and I enjoy learning from my colleagues, while contributing my own perspective."

WHAT TYPES OF COLLABORATION DOES THEIR RESEARCH INVOLVE?

"We have assembled teams of developers, artists, designers and social scientists, which come together with a common purpose to move a research prototype towards eventually reaching the public," says Laura. "For instance, for developing 'Hacked Time' we drew on the expertise of a game design faculty, who pulled together software developers, artists and narrative designers."

WHAT ISSUES WILL FACE THE NEXT GENERATION OF CYBERSECURITY RESEARCHERS?

"The biggest problem faced by cybersecurity is that old problems aren't going away, while new problems are always developing," says Jason. "Weak passwords were a problem forty years ago and are still a problem today, for instance. Now, we have new challenges, such as security for the emerging Internet of Things – where billions of small computers sense and control parts of the physical world, including everything from traffic lights to central heating. Another example is cryptocurrency, which has some positive uses, but also has major problems in terms of theft and use of ransomware."

WHAT SKILLS ARE USEFUL FOR A CAREER IN CYBERSECURITY?

"It's useful to have a solid technical base," says Jason. "This doesn't just apply for programmers, but for anyone interacting with cyber systems. At the moment, there are many people working on the legalities or policy surrounding cybersecurity that barely understand how computers work. It's important to understand the terminology and how these systems work, the trade-offs involved, and what is possible or not. I would also encourage insight into what it means to be human, which is best achieved through an interest in the humanities and arts. Cybersecurity is, ultimately, a human problem, given it involves understanding why people may or may not adopt security measures."

WHAT SHOULD SOMEONE CONSIDERING A CAREER IN CYBERSECURITY KNOW?

"A common misconception people have about cybersecurity is that it's all technical work focused on the computer," says Jason. "In reality, it's far more varied. There are lawyers working on issues of compliance, policymakers working on nationwide goals for cybersecurity, economists investigating trade-offs of different policies, and psychologists working on how to motivate people to be more secure."

EXPLORE A CAREER IN CYBERSECURITY

- Jason and Laura's university runs a summer research experience for US undergraduates, where students contribute to cutting-edge research into human-computer interactions: **www.hcii.cmu.edu/summer-research-program**

- Cybersecurity careers are growing in the UK, too. This webpage explains more about how to get into the field, emphasising the importance of both technical and non-technical expertise: **www.prospects.ac.uk/jobs-and-work-experience/job-sectors/information-technology/cyber-security-training**

PATHWAY FROM SCHOOL TO CYBERSECURITY

- As Jason and Laura emphasise, cybersecurity involves people from a diverse array of educational backgrounds. Degrees in subjects like computer science may provide the most direct pathway, but degrees in other subjects such as psychology or law could also lead to a career in cybersecurity.

- Jason recommends technical subjects to ensure a sound understanding of computer science. This includes subjects like computer science, mathematics and physics. He also emphasises the importance of understanding human interactions with technology – this could be achieved through subjects such as psychology, history or art.

JASON AND LAURA'S TOP TIP

Experiment with possible careers through personal projects and self-directed learning. There are so many great online resources available, and don't be afraid to reach out to experts or people you admire in the field. Seek out opportunities for early research experiences if that interests you.

HOW DID JASON BECOME AN EXPERT IN CYBERSECURITY?

As a youngster, I was very lucky to have parents who let me do pretty much whatever I wanted! I was very into comic books, science and building LEGO models. I have a rather active imagination as a result.

I fell into research by accident. In my second year at college, a professor asked me if I wanted to help out with some research that summer, and, since I didn't have any other plans, I signed up. It was a really fun experience, imagining and building new things that had never been done before. I was very lucky to be admitted to the computer science PhD programme at University of California at Berkeley, where I loved thinking about big ideas and their potential. I felt that research was a way I could use my skills to make a positive difference for humanity.

I am able to connect ideas from different fields in new ways to solve problems. I've drawn on ideas from machine learning, social psychology, gaming, visual design and more. I'm also good at recovering from setbacks – though I've had many successes in my life, I've had far more failures. The important thing is to figure out how to improve and keep pushing forward.

I have two young children who help me switch off from my work. We've been building a lot of LEGO and even practising piano together. During the pandemic, I started playing video games with them too, which I think are great, but only in moderation.

I helped found Wombat Security Technologies, which used our research to protect people from phishing scams. When it was sold in 2018, we used some of the proceeds to found a scholarship and two junior faculty chairs. I've always felt it is important to give the people who come after you better opportunities than you had.

HOW DID LAURA BECOME AN EXPERT IN CYBERSECURITY?

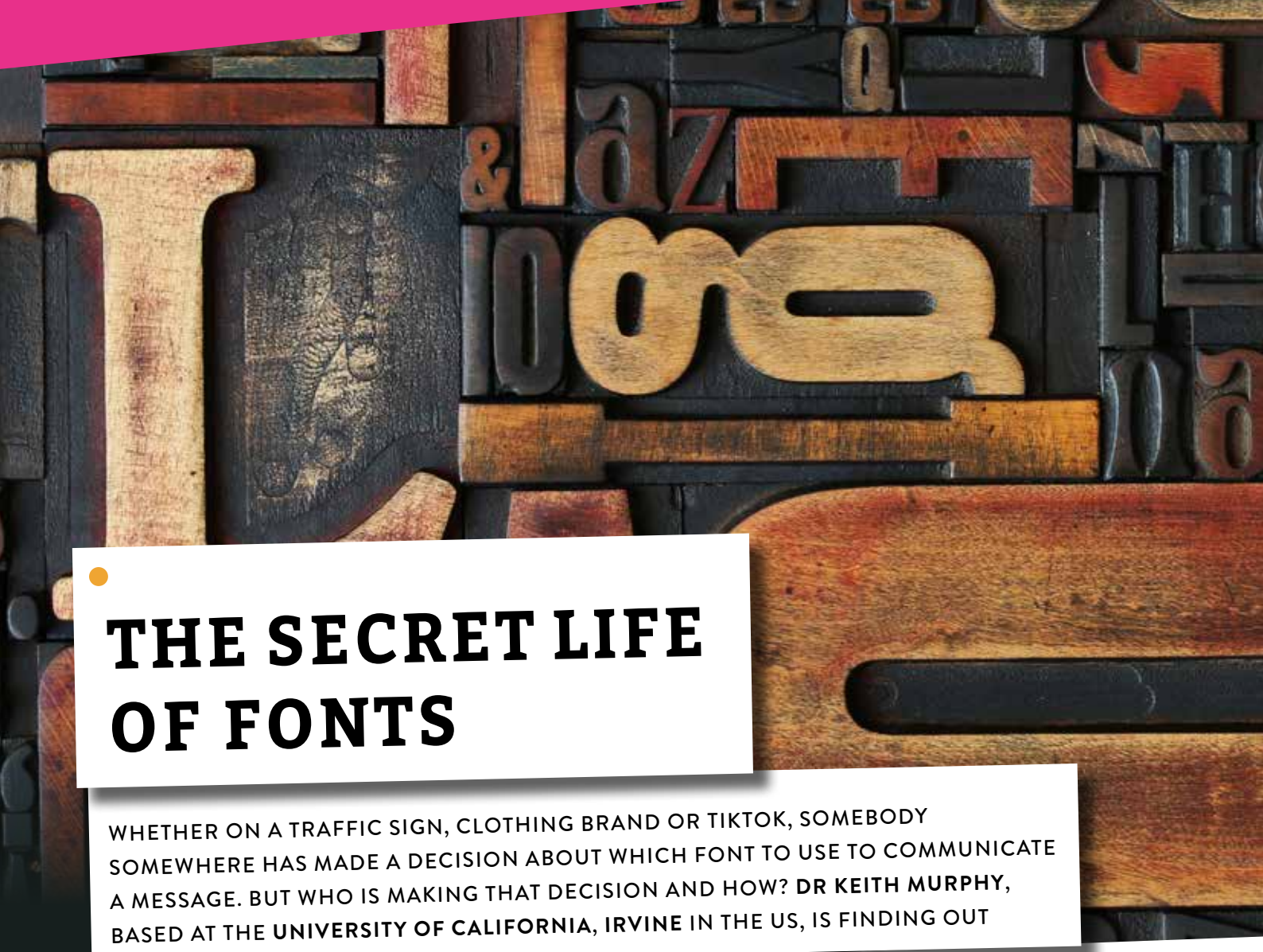
I was introduced to computers at a young age through computer games. My father was an electrical engineer and sparked my interest in computation and technology. My mother taught me to appreciate the humanities through art and music.

I attended a state-funded specialist maths and science high school, which gave me my first opportunity to participate in research. For one day a week, I got to work with researchers to find new ways to evaluate certain chemical properties of cosmetic products without having to test them on animals or people. I learned that research was something I enjoyed and that it could involve not just studying something, but also innovating and creating new tools and techniques.

I'm curious about the world, about human nature and how things work. This curiosity helps drive me to better understand the human experience with technology. Empathy is also useful – my work involves bridging disciplines, so it's important to understand the varying perspectives on the same problem.

I find daily walks restorative and a way to decompress from work. Research shows that being in nature, even for short periods of time, improves well-being. I also enjoy running in all seasons.

Mentoring is one of the most enjoyable aspects of my work, and I'm always proud to see my students go off to productive and fulfilling careers. I've mentored undergraduate students in research projects, and they've later gone on to do PhDs, move into industry, or start their own companies.



THE SECRET LIFE OF FONTS

WHETHER ON A TRAFFIC SIGN, CLOTHING BRAND OR TIKTOK, SOMEBODY SOMEWHERE HAS MADE A DECISION ABOUT WHICH FONT TO USE TO COMMUNICATE A MESSAGE. BUT WHO IS MAKING THAT DECISION AND HOW? **DR KEITH MURPHY**, BASED AT THE **UNIVERSITY OF CALIFORNIA, IRVINE** IN THE US, IS FINDING OUT

GLOSSARY

TYPE – originally, a small piece of metal containing a single raised letter or character that can be arranged to print words onto paper

TYPEFACE – a set of letters that share a common design, such as Times New Roman and Comic Sans

FONT – variations within a typeface. A font describes a set of letters that share a common design, including its size, weight, style and character set (Roman, Cyrillic or Greek). For example, Arial, **Arial Black** and Arial Narrow are all fonts of the Arial typeface. The term font also refers to the piece of software that allows text to appear and function properly on a computer or smartphone screen

Humans have been communicating with symbols and pictures for over 5,000 years. Printing, however, started to take shape during the Han Dynasty (206 BCE-220 CE). Described as one of China's Four Great Inventions, the Chinese discovered how to print on paper using blocks of wood and other materials. By the 11th century, the Chinese and Koreans were using an early form of moveable type – single, raised characters on pieces of clay that could be rearranged and used to impress ink onto paper. But it was not until the 1440s, when Johannes Gutenberg invented the Gutenberg press, that moveable type and printing became a worldwide phenomenon.

"During the Renaissance and later, lots of type foundries – shops that design and manufacture metal type – sprung up across Europe and, later, the Americas, each of which created and sold its own sets of typefaces," explains Dr Keith Murphy at the University of California, Irvine. "From early on, these foundries tried to set themselves apart from the competition by marketing their typefaces in different ways, which tended to involve a lot of over-hyped descriptions of what each typeface could communicate."

Keith is a linguistic anthropologist. Linguistic anthropologists study the nature of language and how humans use it in their everyday lives, but Keith is taking his research in an unusual direction. He is exploring the role fonts play in society and how they are used to influence the way we communicate.

WHY DO FONTS MATTER?

"Fonts give us the opportunity to do more with language, beyond simply expressing ideas and feelings," says Keith. We can play with fonts. For example, the Mocking SpongeBob meme UsEs LeTtErS LiKe ThIs tO rEpReSeNt sArCaSm. We can use fonts to deceive people. Think of websites that copy the fonts of legitimate news sites to spread disinformation. We can also use fonts to strengthen communities. Developing typefaces for Cherokee, for example, has helped preserve this endangered language in the US.

When desktop computers first entered mainstream use in the 90s, many people felt too intimidated to get onboard with the new technology. Therefore, Comic Sans was designed as a 'friendly' font with soft lines. It helped a generation of people to adapt to using text on screen. Since then, Comic Sans has arguably become the most contested font, with many accusing it of being overused and unprofessional.

In 2012, CERN used Comic Sans in a presentation announcing the discovery of the

DR KEITH MURPHY

Associate Professor of Anthropology
University of California, Irvine, USA

FIELD OF RESEARCH

Linguistic Anthropology

RESEARCH PROJECT

Researching how fonts operate as a social and cultural technology

FUNDERS

US National Science Foundation (NSF) under grant number 1851282, Wenner-Gren Foundation

Higgs boson or 'God particle', one the most significant scientific breakthroughs in recent years. Seeing the font in this academic context caused an uproar online and, that week, 'Comic Sans' trended higher than 'God particle' on Twitter. Similarly, the clothing retailer Gap became acutely aware of the power of fonts when, in 2010, it was forced to reverse its decision to change its logo font after less than a week of intense backlash on social media.

"In the USA, presidential candidates pay a lot of money to license particular fonts to use in their campaigns, preferably ones that help communicate specific messaging," says Keith. There are even examples of fonts becoming weaponised. In Nazi Germany, Adolf Hitler banned the use of almost all modern Latin fonts, insisting on old-fashioned blackletter fonts to connect his propaganda to historic German values (he later reversed the ban).

HOW IS KEITH STUDYING FONTS?

To understand fonts, we need to think about where they come from and how they get out into the world. If fonts have a social, cultural and political force, who is facilitating and managing that force, and how are they doing it? To answer these questions, Keith is using ethnography and discourse analysis. "A significant part of my research involves talking to and hanging out with people who make fonts or work with letters and writing systems in some way in their everyday lives," says Keith. Known as ethnography, the aim is to observe and work alongside graphic language experts to understand what they do, exactly, rather than relying on what they say they do or what other people say they do.

Discourse analysis looks at how humans use language, and the meaning of language in certain social contexts. "Some methods focus on printed text, some focus on spoken conversations, but they all require very close attention not only to what is said, but also how it is said, by whom, to whom or for whom, in what contexts, in what formats, and more," explains Keith.

WHAT IS KEITH'S RESEARCH REVEALING?

The ways in which typefaces take on social, cultural and political meanings has already been mentioned, but Keith's work also highlights the high level of knowledge, patience and skill needed to design typefaces. Designers have much more to consider than we realise: What do letters look like at different sizes? How spaced apart do letters need to be? How do you create fonts for non-alphabetic languages such as Chinese or Japanese? How do you ensure that all the world's languages have a digital font they can use? Some do not, which makes using computers and the internet difficult. "One way that people working in this area contribute to social justice is by contributing to 'script justice'," says Keith, "by making sure that users of even the least common writing systems have a way to type and communicate in their own language."

Indeed, on the surface, working with letters might seem frivolous, but, as Keith says, it is important that there are people who think about and maintain the underlying code and systems that allow that graphic text to work. "Graphic language experts are doing a lot of hard work to make sure we don't notice what's going on just below the surface, because if we start to notice, then things start to slow down or even stop. If we want the systems that support modern society running smoothly, we have to consider the work that the fonts are doing in that support."

ABOUT LINGUISTIC ANTHROPOLOGY

Everything you read, hear, say, or write has an impact on who you are and the way you interact with the world around you. Language is so important to our lives that it is easy to take it for granted. But when we take a moment to stop and think about language, we make way for an endless list of fascinating questions. How do children learn languages? How do adults learn languages? How do bilingual people's brains work? How do we change the way we speak to suit the social situation? How are languages lost and created around the world and across time?

BRINGING PEOPLE INTO THE PICTURE

Linguistic anthropology concerns itself with these same sorts of questions, examining how language, humans, culture and society all relate to one another. "Users of language are always the primary focus – including speakers of spoken languages, signers of sign languages, and readers of texts – and any analysis of language will always somehow bring people into the picture," Keith explains.

Linguistic anthropology originated as a branch of anthropology that sought to document endangered indigenous languages. Since then, the field has grown to encompass analysis of all the ways languages influence the social life of humans. In this way, linguistic anthropology is closely related to sociolinguistics, a subfield of linguistics which studies languages in relation to social factors. The distinguishing feature of linguistic anthropology, however, is an emphasis on using ethnography in the research process.

WHERE COULD LINGUISTIC ANTHROPOLOGY TAKE YOU?

Many linguistic anthropologists work in academia, which involves teaching and publishing research at a university. However, their knowledge and research skills are valuable in other areas, too, such as consultancy, working on historic sites, translation and diplomacy. "Linguistic anthropologists work in lots of industries," says Keith. "Including social media, industrial design, user experience, lexicography, journalism, advertising, market research and many others."

EXPLORE A CAREER IN LINGUISTIC ANTHROPOLOGY

- Keep up to date with developments in the field by reading publications and attending events. The Society for Linguistic Anthropology (**linguisticanthropology.org**) has its own publication, the *Journal of Linguistic Anthropology*, and all issues are available through AnthroSource: **anthrosource.onlinelibrary.wiley.com/journal/15481395**

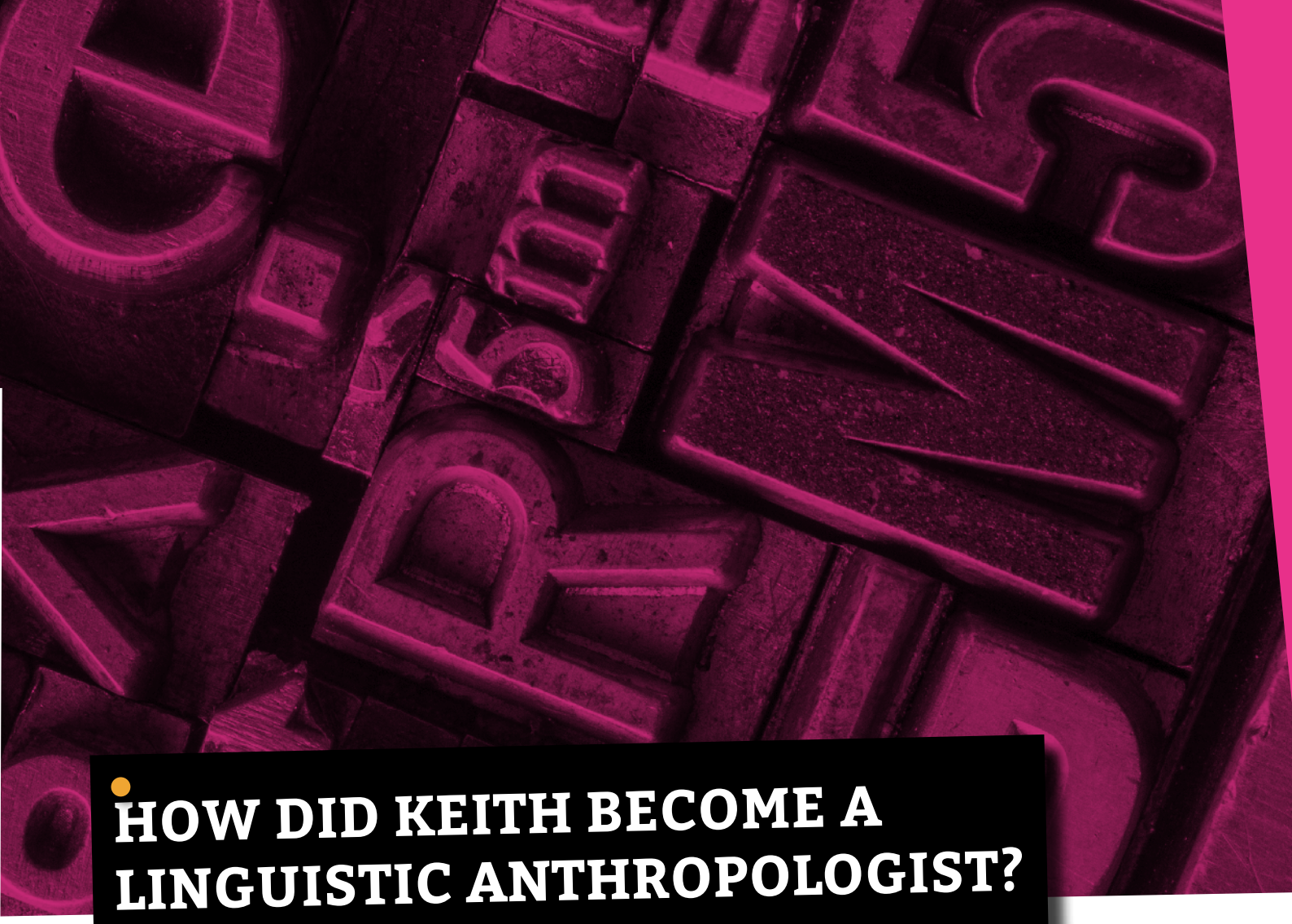
- AnthoGuide (**guide.americananthro.org**) is a great online tool, which is produced by the American Anthropological Association (**www.americananthro.org**) and lists available degrees, programmes and field schools offering training for anthropology students

- Learn.org has a webpage dedicated to linguistic anthropology, which says the average salary for all anthropologists, including linguistic anthropologists, is $50,000: **learn.org/articles/Linguistic_Anthropologist_Career_and_Salary_FAQs.html**

PATHWAY FROM SCHOOL TO LINGUISTIC ANTHROPOLOGY

Anthropology is not usually taught at school or college but taking language subjects (Latin as well as modern languages) and social science subjects (for example, psychology, sociology and geography) is a useful starting point.

Some universities offer undergraduate courses in linguistic anthropology. Alternatively, you may choose to study anthropology, narrowing down to linguistic anthropology at the master's level. If you are looking for a career in research, completing a PhD is recommended.



HOW DID KEITH BECOME A LINGUISTIC ANTHROPOLOGIST?

I watched a lot of ancient history programmes on TV when I was a kid, and at some point, I decided I wanted to be an archaeologist. As a teenager, I worked on an archaeological excavation near where I grew up and decided to pursue it in college. In the US, most bachelor's degrees in archaeology require you to take courses in anthropology, and I discovered that the linguistic anthropology courses were more interesting to me than the archaeology ones, so I began drifting in that direction.

I had a lot of mentors over the years who indirectly or directly nudged me into anthropology. One of my high school teachers really encouraged me to learn languages, even gifting me a set of "Teach Yourself Irish" cassette tapes (I never taught myself Irish). My first linguistic anthropology professor in college, Michael Silverstein, dazzled me with his brilliance and humour, and eventually became my undergraduate thesis advisor. And I applied to get a PhD at UCLA to work with Alessandro Duranti, Marjorie Goodwin, Chuck Goodwin and Elinor Ochs, all people whose work I'd read as an undergraduate and really enjoyed.

When I was accepted to the PhD programme at UCLA, I was overjoyed! I grew up in a working-class family, raised by a single mother, so there wasn't really a model for me early on for what getting a PhD was all about. But with encouragement from my family and guidance from mentors at every stage of my education, I was able to make it through and start building a career.

I very much love teaching, which is part of what comes with being a professor. But when it comes to the research side of things, I really like talking to people about what they are experts in – the stuff of their own lives – that I can learn about and learn from. I like finding connections between things in the past and things in the present, and I like writing (sort of), or at least finding ways to express complicated ideas in ways that make people think.

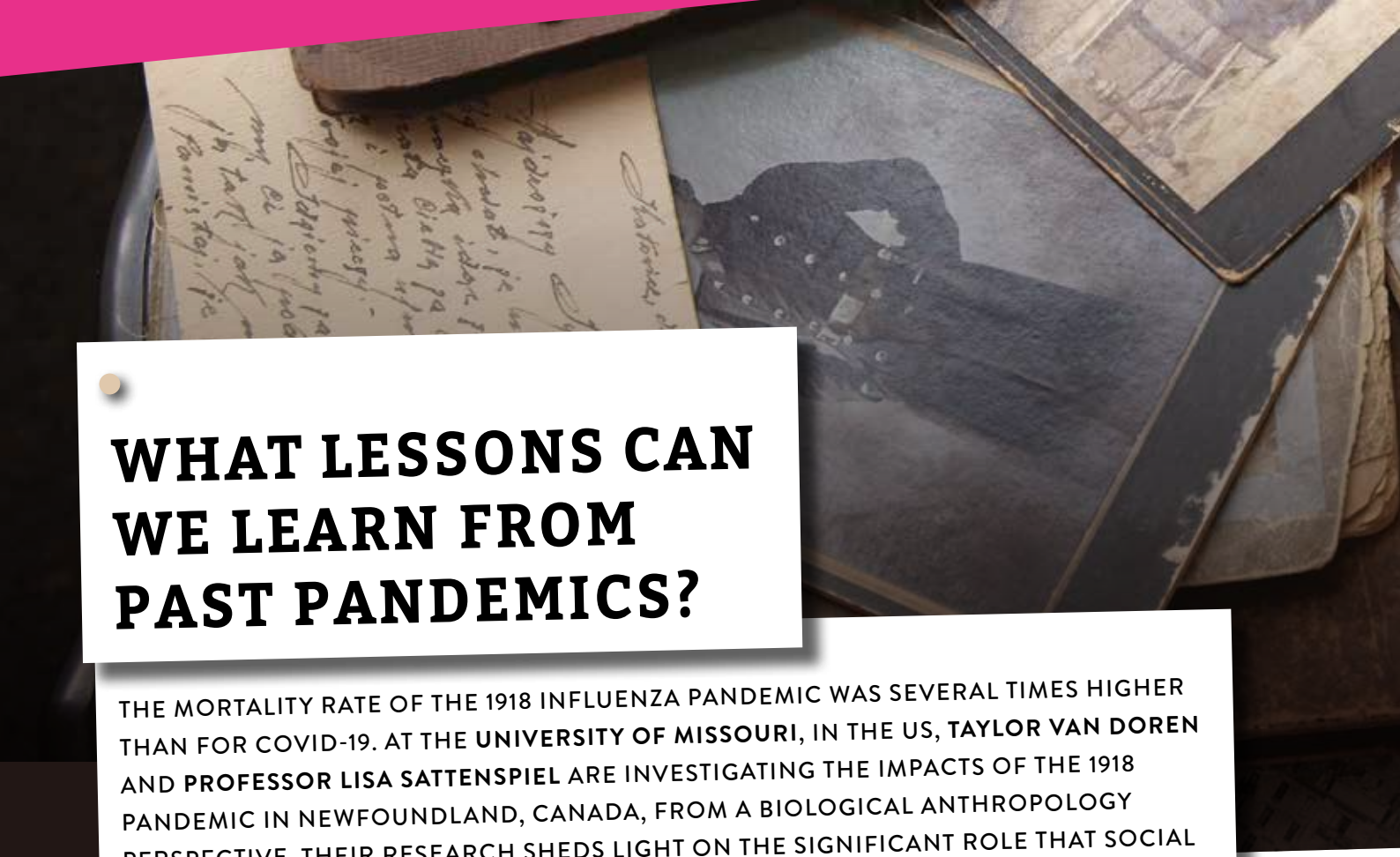
I also really like taking things that seem not so complicated – like fonts – and doing a lot of research that shows how incredibly complex they are! And important! There's so much about life that as ordinary people we take for granted. Part of what I like about my job is trying to dig deeper, to uncover why the stuff we take for granted is actually super special. My first book was about furniture designers in Sweden, so I have this interest in studying design and creativity in the context of language.

'What is your favourite font?' is the kind of question that type people bristle at, and I've come to see why. It's hard to choose, but also, it changes depending on context. I'll say that one that I've been using a lot lately is called Freight, designed by one of the first African American type designers, Joshua Darden. I also love the typeface Mrs Eaves, designed by Zuzana Licko for Emigre Fonts. But really, there are tons of others I love.

KEITH'S TOP TIPS

01 Identify what you're truly curious about and follow that as much as you can.

02 Be open-minded about discovering new interests. You may even find ways to combine your interests in creative ways.



WHAT LESSONS CAN WE LEARN FROM PAST PANDEMICS?

THE MORTALITY RATE OF THE 1918 INFLUENZA PANDEMIC WAS SEVERAL TIMES HIGHER THAN FOR COVID-19. AT THE **UNIVERSITY OF MISSOURI**, IN THE US, **TAYLOR VAN DOREN** AND **PROFESSOR LISA SATTENSPIEL** ARE INVESTIGATING THE IMPACTS OF THE 1918 PANDEMIC IN NEWFOUNDLAND, CANADA, FROM A BIOLOGICAL ANTHROPOLOGY PERSPECTIVE. THEIR RESEARCH SHEDS LIGHT ON THE SIGNIFICANT ROLE THAT SOCIAL INEQUALITIES PLAY IN DETERMINING THE OUTCOMES OF A PANDEMIC

TALK LIKE A BIOLOGICAL ANTHROPOLOGIST

INFLUENZA (FLU) – a potentially-fatal viral infection that commonly causes fever, body aches and pains, and coughing

MORTALITY RATE – a statistical measure of deaths per unit of time, scaled to the size of a population

OUTPORT – a coastal community in Newfoundland, Canada

PNEUMONIA – inflammation of tissue in the lungs, caused by bacteria, viruses or fungi

QUALITATIVE ANALYSIS – the analysis of textual data

QUANTITATIVE ANALYSIS – the analysis of numeric data

TUBERCULOSIS (TB) – a potentially fatal bacterial infection which commonly causes fever and coughing

The 1918 influenza pandemic was the deadliest pandemic in recent history. With 50 to 100 million deaths in a global population of about 1.8 billion people, the mortality rate was several times higher than for COVID-19 so far. As is typical for influenza, very young and very old individuals died at relatively high rates. However, very unexpectedly, younger adults (aged ~20-44) died at much higher rates than normal for their age. Some of the hardest hit regions were the world's remotest places, as they did not have access to medical care.

Studying the 1918 influenza pandemic enables social scientists to better understand how social inequalities contribute to different mortality outcomes. In light of the social inequalities highlighted by COVID-19, this knowledge has never been more important. The social sciences have a very important role to play in uncovering the causes and consequences of pandemics, past and present, and preparing us for pandemics of the future. "Knowledge from social sciences can be combined with knowledge from life sciences to produce a whole that is greater than the sum of its parts," says Taylor van Doren, emphasising the importance of social science research for our understanding of global pandemics.

Taylor is a PhD candidate at the University of Missouri, working under the supervision of Professor Lisa Sattenspiel. She is investigating how the 1918 influenza pandemic affected the remote island of Newfoundland in Canada, from a biological anthropology perspective.

WHAT WAS NEWFOUNDLAND LIKE IN 1918?

"Life in early 20th century Newfoundland was very difficult," says Taylor. Most people lived on the coast in small, geographically isolated fishing communities called 'outports', with the largest settlement, St John's, on the eastern tip of the island. As only a small fraction of the island was suitable for growing crops, there was not much variety of foods, especially in the winter, and this resulted in malnourishment. Very little medical care was available across the island, so it was typical for people to go for years without seeing a doctor. Sanitation was poor, so water-borne illnesses and deaths were common.

"The 1918 influenza pandemic was primarily spread around the world through the movement of soldiers returning home at the end of World War I," says Lisa. It arrived in Newfoundland in the summer of 1918, and initially caused only a mild wave of influenza on the island. The second, much more severe wave, hit in the winter of 1918, and a final wave occurred much later, in 1920.

GATHERING DATA

Taylor and Lisa use death records as their main

source of quantitative data for their research. These hold a wealth of valuable information, including the person's age at death, sex, cause of death and place of residence. Censuses provide reports of the population size and structure of each outport, and hospital records contain accounts of those who were ill with influenza but survived.

Qualitative data are also extremely important, as they provide insights about social organisation, behaviour and social inequalities that will explain interesting patterns revealed by quantitative death record analyses. Archival records include newspapers, government reports, personal and official correspondence, and journal entries. "In the fall of 1918, there were a lot of telegrams that were sent from St John's to the outports to warn of the coming influenza," says Taylor. "There were likewise telegrams seeking doctors to visit the outports for people who were very ill."

QUANTITATIVE AND QUALITATIVE ANALYSES

Once data have been extracted from these archival sources, Taylor and Lisa use a combination of quantitative and qualitative analyses, known as a 'mixed methods' approach, to address their research questions. Taylor uses various statistical modelling techniques to look for patterns within the quantitative data. For example, she calculates mortality rates for different districts to explore the geographical aspects of the pandemic and she compares mortality rates between males and females.

"Archival analyses are very different and require separate skill sets that ultimately contribute another dimension of understanding to the quantitative analyses," Taylor says. She uses qualitative analysis software to conduct 'thematic coding', allowing her to organise ideas and themes that appear throughout the archival documents in a structured and easy-to-reference way. She looks for patterns within these themes and connects them with trends observed in the quantitative data.

HOW DID SOCIAL INEQUALITIES INFLUENCE MORTALITY OUTCOMES?

The outcomes of the 1918 influenza pandemic were more severe in the outports of Newfoundland than they were in St John's. "Social inequalities are likely the primary contributors to differences in mortality rates," explains Taylor. This was not just the case in Newfoundland in 1918 but has also been observed during the COVID-19 pandemic and is a factor in many other infectious diseases in modern times.

It is important to note that influenza was not the only respiratory disease circulating in Newfoundland in 1918. Pneumonia and tuberculosis (TB) were also prevalent, and patients were commonly infected with more than one disease at the same time. All three diseases were influenced by social inequalities across the island.

Access to medical care was a key factor that contributed to the differences in mortality. The southern coast of the island was (and still is) inaccessible by land, so doctors had to travel to outports by boat, meaning they often arrived too late to treat patients. There was also a class difference in mortality. Wealthy merchants living in St John's did not need to come into contact with many people on a daily basis, so were less likely to become infected. In contrast, fishermen from the outports could not afford to lose a day fishing and so were forced to continue working even if they were ill, thereby spreading infection.

While exploring the sex-based differences in influenza mortality during the pandemic, Taylor discovered that females were consistently more likely to die from influenza on the southern coast of the island than in any other region. She also discovered that females died of TB at much higher rates than males. She attributes this to greater social cohesion among women in the community, along with their responsibility to care for each other when someone falls ill. "It's important to point out that gender-based determinants are some of the most understudied social inequalities in infectious disease research," says Taylor. "The roles of socially constructed gender identity that determine behavior have tremendous implications for social interactions and infectious disease transmission."

Taylor and Lisa's research highlights the important role that social sciences have to play in understanding pandemic determinants, impacts and consequences. Biological anthropology investigations provide key knowledge about past pandemics, which can be applied in the present to address COVID-19 and utilised to prepare for the future.

TAYLOR VAN DOREN

PhD Candidate, University of Missouri, USA

PROFESSOR LISA SATTENSPIEL

Professor of Anthropology, University of Missouri, USA

FIELD OF RESEARCH

Biological Anthropology

RESEARCH PROJECT

Investigating the impacts of social inequalities on the outcomes of the 1918 influenza pandemic in Newfoundland

FUNDERS

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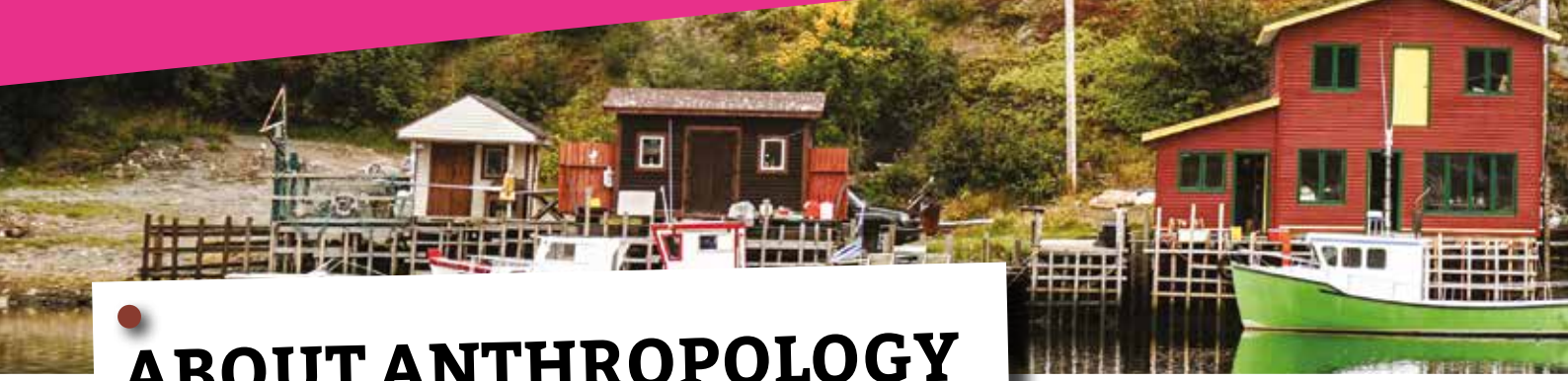


ABOUT ANTHROPOLOGY

Anthropology is the study of what makes us human. In the US, anthropology is sub-divided into biological anthropology, cultural anthropology, linguistic anthropology and archaeology. Each subfield can be applied to solve real world problems using anthropological methods and ideas.

WHY USE BIOLOGICAL ANTHROPOLOGY TO UNDERSTAND INFECTIOUS DISEASES?

"Biological anthropology is one of the few disciplines in which you will get a very strong background in both biology and culture," says Lisa. "We need people with expertise in both fields to understand how one affects the other." Studying the 1918 influenza pandemic has taught Taylor and Lisa the importance of investigating historical pandemics to prepare for the future. "Despite the wealth of knowledge we can glean from past pandemics, the world was still surprised by how social inequalities were reflected in differences in susceptibility and mortality during COVID-19," says Taylor. "Based on past pandemics, this should never have been a surprise."

Studying the 1918 influenza pandemic from a biological anthropology perspective will help prepare public health officials, medical professionals and the public for the consequences of the next inevitable pandemic.

WHY STUDY ANTHROPOLOGY?

"Studying anthropology will provide you with a worldview that you simply cannot get from any other discipline," says Taylor. She emphasises that you will understand humans more comprehensively from almost every angle after your anthropology classes than you did before. You will learn to understand others' worldviews and respect them for their individuality and importance. You will learn to think critically, read effectively, and write impactfully. If you want to understand how we live and interact and apply your skills and knowledge to improves peoples' lives, then anthropology could be you!

EXPLORE A CAREER IN ANTHROPOLOGY

- As an anthropologist, you could conduct research and teach in a university as an academic. However, the skills that you gain through studying anthropology are transferrable to a broad range of careers. You could find yourself working for an NGO, a museum, the health service or in community organisations.
- The American Anthropological Association has a wealth of information on its website, including information about careers in anthropology and listings of fieldwork and internship opportunities: **www.americananthro.org**
- For specific information about careers in biological anthropology, visit the American Association of Biological Anthropologists: **www.physanth.org**
- For news and podcasts about anthropology in general, explore *Sapiens* (**www.sapiens.org**), or for biological anthropology, visit the Human Biology Association (**www.humbio.org**).

A typical small island community off the coast of Newfoundland. Image credit: Stephen Booth

PATHWAY FROM SCHOOL TO ANTHROPOLOGY

- Taylor and Lisa recommend having a strong science background and a wide exposure to social sciences. Take a range of classes at school and university to expand your horizons.
- "There are so many different directions to go in anthropology," says Lisa. "Statistics and math are real assets no matter what path you choose to take."
- "No matter what subfield of anthropology interests you, knowledge of computer programming languages will be essential for conducting data analysis," says Taylor. "Critical thinking, creativity and strong writing skills are also extremely important."
- Many universities will offer degrees in anthropology. You will be able to specialise in biological anthropology as you progress through your studies.
- The American Anthropological Association (**www.americananthro.org**) publishes the *AnthroGuide* (**guide.americananthro.org**), a searchable database of anthropology courses at colleges and universities throughout the country.

HOW DID TAYLOR BECOME AN ANTHROPOLOGIST?

TAYLOR'S TOP TIPS

01 If you find yourself interested in something, pursue it! See where your interests take you.

02 Always be open to change. Sometimes, in life or in research, things happen that you cannot control, but this doesn't mean they are bad.

03 Don't be afraid to reach out to professors for research opportunities to gain experience.

I had so many interests when I was younger, to the point where it was really difficult for me to decide what to study or where I wanted to go with my life. I was always interested in science, specifically in biology and the natural world. As I got older, I started to become interested in health and infectious diseases, so I considered a career in medicine. I have always been interested in asking questions and pursuing answers, which ultimately led me to research.

I was never exposed to anthropology at high school, so I didn't know what the subject entailed. But I knew I wanted to become an anthropologist after attending my very first college class, Introduction to Cultural Anthropology. An anthropological perspective helped my interests in biology and behavior click into place, and my love for anthropology soon exceeded my desire to pursue medicine, so I switched paths.

I spent 15 years as a competitive swimmer, and this is a significant part of my identity. Athletics teaches young people about dedication, professionalism, teamwork and humility. At times it was challenging to balance the responsibilities of training, competing and studying, but having a structured plan allowed me to achieve highly across all areas.

One of the best things about my PhD journey so far has been the opportunities for international travel. Before graduate school, I had never left the United States. Now, I have attended research conferences in Sweden, Canada and Norway. I am extremely proud to have earned an NSF grant to travel to Newfoundland for my research. Graduate school has opened the doors to the world for me.

I am a mom to a wonderful and adventurous two-year-old daughter, and I love watching her grow, learn and try new things. I also love to cook, which is something I only picked up within the last year. When I have time, I love to exercise, read and go for long walks.

HOW DID LISA BECOME AN ANTHROPOLOGIST?

LISA'S TOP TIPS

01 Find one or two topics that captivate you and learn everything you can about them. Then, think about how other topics relate to these.

02 Don't feel you have to do everything on your own – talk to other people about what you are interested in and ask for their advice.

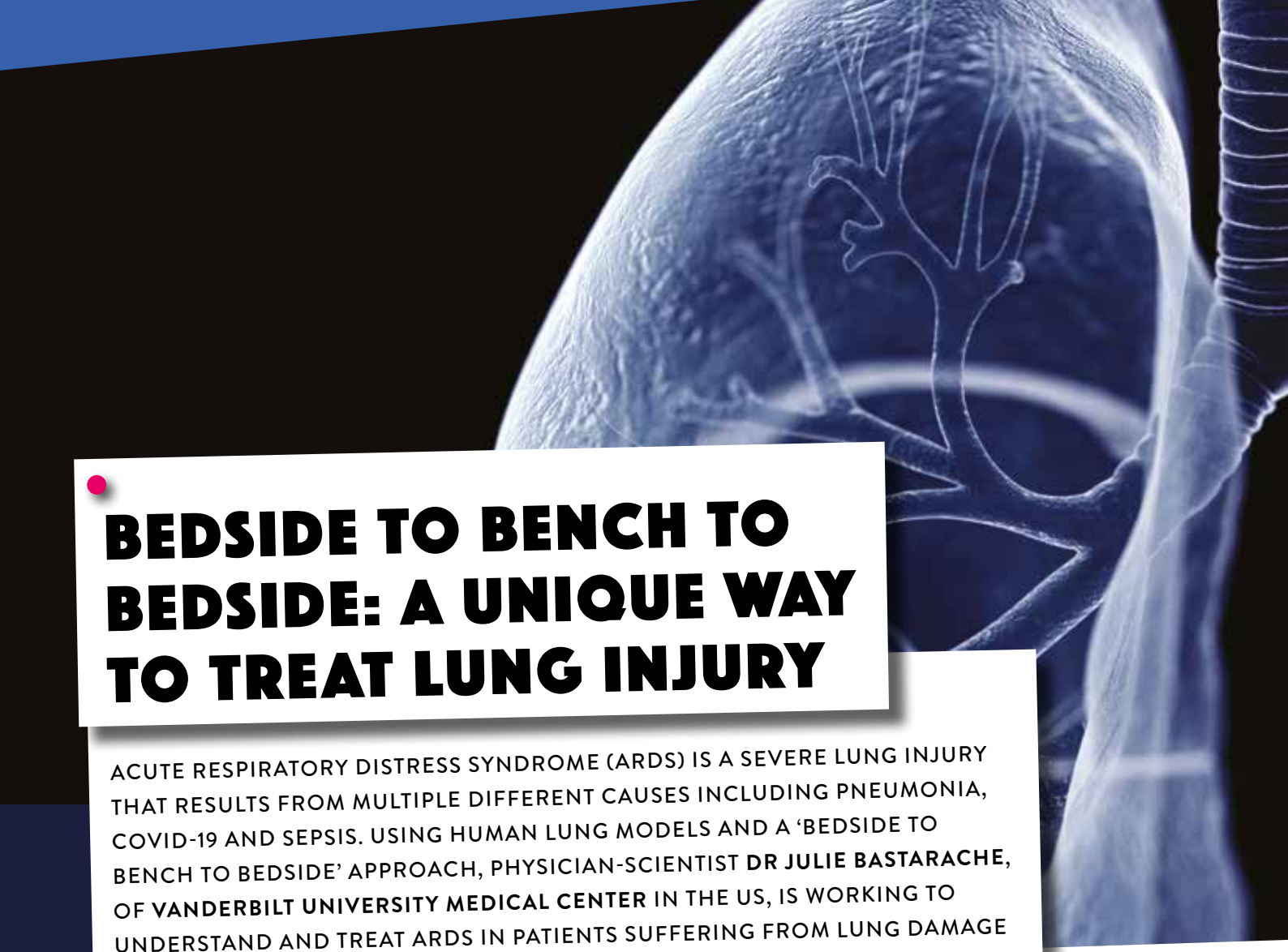
Growing up, I played tennis and the French horn. I also loved math, so thought I would major in math or music when I went to college. But I discovered I didn't like theoretical math and that music needed to be a hobby, not a profession.

When I went to college, my older brother recommended I take an anthropology class. I did, alongside a class in population biology, and I loved them both. I decided to design my own undergraduate major in human evolution, which combined coursework in anthropology, population biology, human genetics and mathematics. I knew I wanted to continue studying humans at the population level at graduate school, which was much easier to do within anthropology than within biology.

I am intrigued by the relationship between humans and pathogens. The ecological interactions are fascinating, requiring biological knowledge of both humans and pathogens as well as an understanding of the environment in which both are living and the behaviors they exhibit.

My hopes for the future are that we will continue to increase our understanding of infectious diseases in fundamental ways, and that detailed understanding of how humans promote or hinder their spread will become just as important to the world of scientists as developing the next vaccine or studying how diseases affect individual human bodies.

I still enjoy playing the French horn. I also read a lot of novels and I am currently learning Norwegian in preparation for a research visit to Norway. I love to spend time with my kids and grandkids. They live far away, but I visit them when I can.



BEDSIDE TO BENCH TO BEDSIDE: A UNIQUE WAY TO TREAT LUNG INJURY

ACUTE RESPIRATORY DISTRESS SYNDROME (ARDS) IS A SEVERE LUNG INJURY THAT RESULTS FROM MULTIPLE DIFFERENT CAUSES INCLUDING PNEUMONIA, COVID-19 AND SEPSIS. USING HUMAN LUNG MODELS AND A 'BEDSIDE TO BENCH TO BEDSIDE' APPROACH, PHYSICIAN-SCIENTIST **DR JULIE BASTARACHE**, OF **VANDERBILT UNIVERSITY MEDICAL CENTER** IN THE US, IS WORKING TO UNDERSTAND AND TREAT ARDS IN PATIENTS SUFFERING FROM LUNG DAMAGE

TALK LIKE A PHYSICIAN-SCIENTIST

ACUTE RESPIRATORY DISTRESS SYNDROME (ARDS) – a cause of severe respiratory failure as a result of a serious injury or infection

CELL-FREE HAEMOGLOBIN (CFH) – haemoglobin leaked from red blood cells due to a weakening of the cell membrane after illness

HAEMOGLOBIN – an iron-containing protein in red blood cells which is responsible for carrying oxygen and carbon dioxide around the body

SEPSIS – an infection in the body that can lead to ARDS

Acute respiratory distress syndrome (ARDS) develops after a triggering event, such as pneumonia (an infection in the lungs), sepsis (an infection in the body) or severe trauma (like that caused by a car accident). Patients have difficulty breathing due to low oxygen levels in the blood and fluid collecting in the air sacs of their lungs. Many people experiencing ARDS end up in hospital, some needing mechanical ventilation to provide oxygen to the lungs. Despite being a common problem, many people still die from ARDS and currently there is no specific treatment.

Dr Julie Bastarache is physician-scientist at Vanderbilt University Medical Centre, working in a hospital as a medical doctor alongside working in a lab, researching the medical issues she encounters while on the ward. Using a 'bedside to bench' method, she observes human patients directly and then investigates her observations in the lab. Julie is using this method to better understand ARDS, and she hopes to develop a treatment that will enable doctors to prevent or reverse lung damage.

HOW DOES CELL-FREE HAEMOGLOBIN CAUSE ARDS?

Healthy red blood cells are full of a protein called haemoglobin, which carries oxygen and carbon dioxide around the body. The membrane of these blood cells is very flexible, allowing them to squeeze through very small blood vessels. However, when people are ill, for example with sepsis, this membrane becomes thinner and stiffer, causing the membrane to burst when it tries to fit through blood vessels. This releases haemoglobin into the bloodstream, producing cell-free haemoglobin (CFH) that is no longer contained within red blood cells.

In addition to no longer binding oxygen, CFH also injures the cells that line the blood vessels (the endothelium) and the cells lining the air sacs in the lung (the epithelium). These layers become leaky, resulting in blood plasma entering the lungs and filling up the air sacs, causing inflammation and making it difficult for the patient to breathe and get oxygen into their blood.

FROM BEDSIDE TO BENCH

Julie describes her research methods as a 'bedside to bench' approach. Scientific discoveries begin as observations made at a patient's bedside, then the causes behind them are studied at a laboratory workbench. The hope

DR JULIE BASTARACHE

Vanderbilt University Medical Center, USA

FIELD OF RESEARCH

Physician-scientist

RESEARCH PROJECT

Studying the effects of cell-free haemoglobin on acute respiratory distress syndrome, in a dual role as a medical doctor and lab researcher

FUNDER

US National Institutes of Health (NIH)

is that results can then be translated back to the bedside, to provide treatments for the patients.

"To make sure we are studying molecules and pathways that are important in human disease, many of our studies start with observations that we make in human patients," Julie says. She collects, with permission, blood and lung samples from patients suffering from ARDS, which are later studied in her research lab to find proteins and other markers that may be part of the disease.

Julie's discovery of the link between CFH and ARDS was an example of this 'bedside to bench' method. "In one of our studies, we found that blood and lung fluid from patients with ARDS had high levels of CFH," Julie explains. "We then took this observation back to the lab to study how CFH might be helping to cause lung injury." Using this method, Julie can start to understand the role that CFH plays in causing ARDS and hopefully develop a treatment to prevent it.

THE HUMAN LUNG MODEL

To develop treatments, Julie first needs to understand the biological pathways that cause CFH to damage the lungs. This requires the use of experimental models. "Experimental models allow the scientist to change variables to test the effects of those changes," explains Julie. No individual model is perfect, so these types of studies normally involve multiple models to focus on different aspects of a biological pathway.

This was the case in the experimental models set up by Julie. One of Julie's models cultured cells in a dish to study the molecular pathways of CFH effects, another used mouse models to test the effect of CFH in a living system. As well as this, a unique model of human lungs was used to test different therapeutic treatments in patients.

The human lung model is incredibly important in understanding how to treat ARDS. Only specialised research groups have access to human lungs, donated by people who allow their organs to be used for scientific purposes when they die. If the lung is not healthy enough to be transplanted into another person, the lung can be used by researchers like Julie for a more accurate way to test the effect of treatments on the lungs, which models in mice and cells cannot provide.

TREATING PATIENTS WITH ARDS

Once in the lab, Julie provides the lungs with oxygen, then studies what the effects of CFH are on the lung. During her research, Julie found that a very common over-the-counter medicine, acetaminophen/paracetamol, can fight the effects of CFH in patients with sepsis. Thanks to Julie's access to patients suffering from ARDS, she was able go back to the 'bedside' to do an early-stage clinical trial to see if this treatment works. "The results of this small study were positive," says Julie, "and we are now working on a larger study to test this in more patients." This link between laboratory research and patients is essential to quickly find a treatment that is effective at preventing ARDS.

Looking to the future, Julie hopes to continue learning more in the lab, focusing on understanding other biological pathways important in ARDS, as well as the genetic and environmental factors that may be important in causing ARDS. "Our hope is that we can take more things we learn in the lab and test them in patients with ARDS," she says. Julie's 'bedside to bench back to bedside' approach has, "established a natural cycle of scientific discovery". Physician-scientists are therefore essential in providing a link between hospitals and research labs, not only making it easier to quickly diagnose diseases, but also to develop treatments and cures.

ABOUT PHYSICIAN-SCIENTISTS

The unique feature of a physician-scientist is that they perform a dual role, working as a doctor in a hospital while also undertaking research in a laboratory. Physician-scientists are incredibly important in providing a link between patients in hospitals and research labs trying to treat the diseases these patients have. Without physician-scientists like Julie, many diseases would not be thoroughly researched, and research in labs may not lead to therapeutic treatments given to patients. Physician-scientists are, therefore, key figures in medical research.

WHAT DOES JULIE FIND MOST REWARDING AND CHALLENGING ABOUT HER ROLE?

Julie loves her dual role as a physician-scientist, though she found it difficult to switch between roles when she began. With more experience, the transition came more naturally, and each role motivates her for the other. "When I am working in the intensive care unit (ICU), I get excited about new clinical observations and questions that arise in the ICU that I can take back to the lab," she says. "And similarly, when I've been working in the lab for a couple of months, it's exciting to take a break from that and care for patients."

WHY IS COLLABORATION IMPORTANT FOR JULIE'S RESEARCH?

Julie is one of three principal investigators leading her lab. This is an uncommon set-up, despite the highly collaborative nature of science. Each principal investigator approaches the problem of treating ARDS in a different way, so Julie's work involves a lot of collaboration, without which a 'bedside to bench to bedside' approach would not work. "It's also incredibly fun to work so closely with my colleagues on a daily basis," says Julie. "I wouldn't want to work any other way!"

WHAT DOES THE FUTURE LOOK LIKE FOR PHYSICIAN-SCIENTISTS?

"Physician-scientists require work environments that value their special contribution to both medicine and science," explains Julie. Unfortunately, governments, hospitals and academic medical centres face financial pressures which make it difficult for them to support the unique position of physician-scientists. "It is important that the current and future generations advocate for support of physician-scientists at all levels, from international to national to local."

EXPLORE A CAREER AS A PHYSICIAN-SCIENTIST

There are several different paths to becoming a physician-scientist. These websites contain a lot of information, including funding opportunities available to support physician-scientists:

www.aamc.org/what-we-do/mission-areas/medical-research/physician-scientist

www.physicianscientists.org

Julie's lab, The Laboratory for Science and Translation in Critical Illness (**www.lstci.org**), hosts summer students through programmes run by her institution for high school and undergraduate students.

Talk to a physician-scientist to see what their job is like. Most work at large academic medical centres such as university hospitals. Don't be afraid to email and ask to meet them! You can contact Julie and her team through their website:
www.lstci.org

PATHWAY FROM SCHOOL TO PHYSICIAN-SCIENTIST

Alongside the traditional pre-medical courses needed to get into medical school in the US, Julie encourages students to take the subjects that interest them. "Everything you need to know to become a physician-scientist is taught during medical school and post-doctoral fellowship training," says Julie, "so pursue whatever interests you as a high school or undergraduate student." Julie majored in biology, but took other classes in English, art and music during her undergraduate degree.

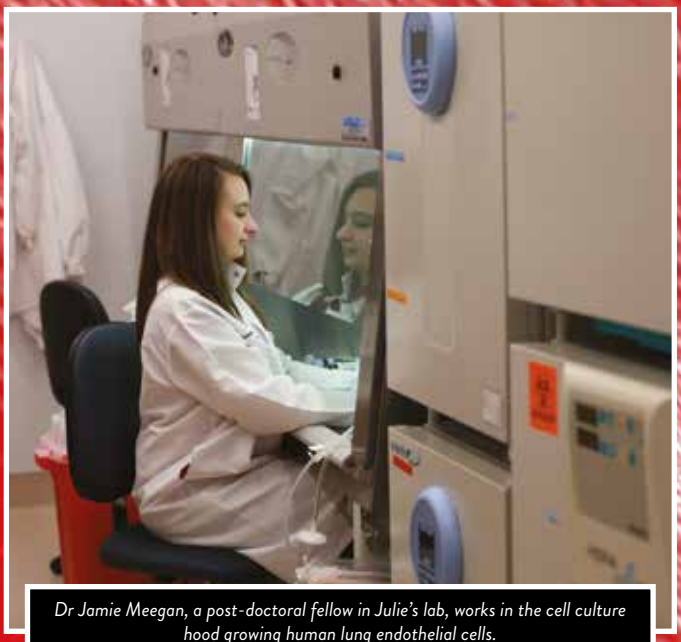
To learn what subjects you should take at school to study medicine, visit the following links:

- US and Canada: **www.medapplications.com/pre-medical-programs**
- UK: **www.ucas.com/explore/subjects/medicine-and-allied-subjects**
- Europe: **www.mastersportal.com/articles/1801/what-are-the-entry-requirements-for-medical-schools-in-europe-and-the-us.html**

JULIE'S TOP TIPS

01 Work and study hard.
02 Keep an open mind.
03 Be curious and ask questions.
04 Take advantage of opportunities.
05 Step out of your comfort zone.

Julie runs her research group with two other principal investigators. Pictured here (left to right) are Dr Ciara Shaver, Dr Julie Bastarache and Dr Lorraine Ware.



Dr Jamie Meegan, a post-doctoral fellow in Julie's lab, works in the cell culture hood growing human lung endothelial cells.

HOW DID JULIE BECOME A PHYSICIAN-SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I always loved science as a kid. I had a chemistry set in the 1980s, when chemistry sets were allowed to contain actual chemicals. I loved going to the science museum and learning about science in any way I could. My favourite show was Mr Wizard's World, a show where Mr Wizard would do science experiments and demonstrations with kids. Although I loved science, I did entertain other careers such as becoming a magician or detective. Interestingly, being a scientist is kind of both.

WHO OR WHAT INSPIRED YOU TO BECOME A PHYSICIAN-SCIENTIST?

I grew up in a very small town and didn't know any physicians, let alone physician-scientists. I didn't even know that physician-scientists existed until I was finished with medical school and was a physician myself. As part of my fellowship training in pulmonary and critical care medicine, I had to do two years of research. I chose to work with Dr Lorraine Ware on a basic science project studying a blood coagulation protein called tissue factor. I completely fell in love with research and decided that I wanted to pursue a career as a physician-scientist.

HOW IMPORTANT HAS MENTORING BEEN IN YOUR CAREER?

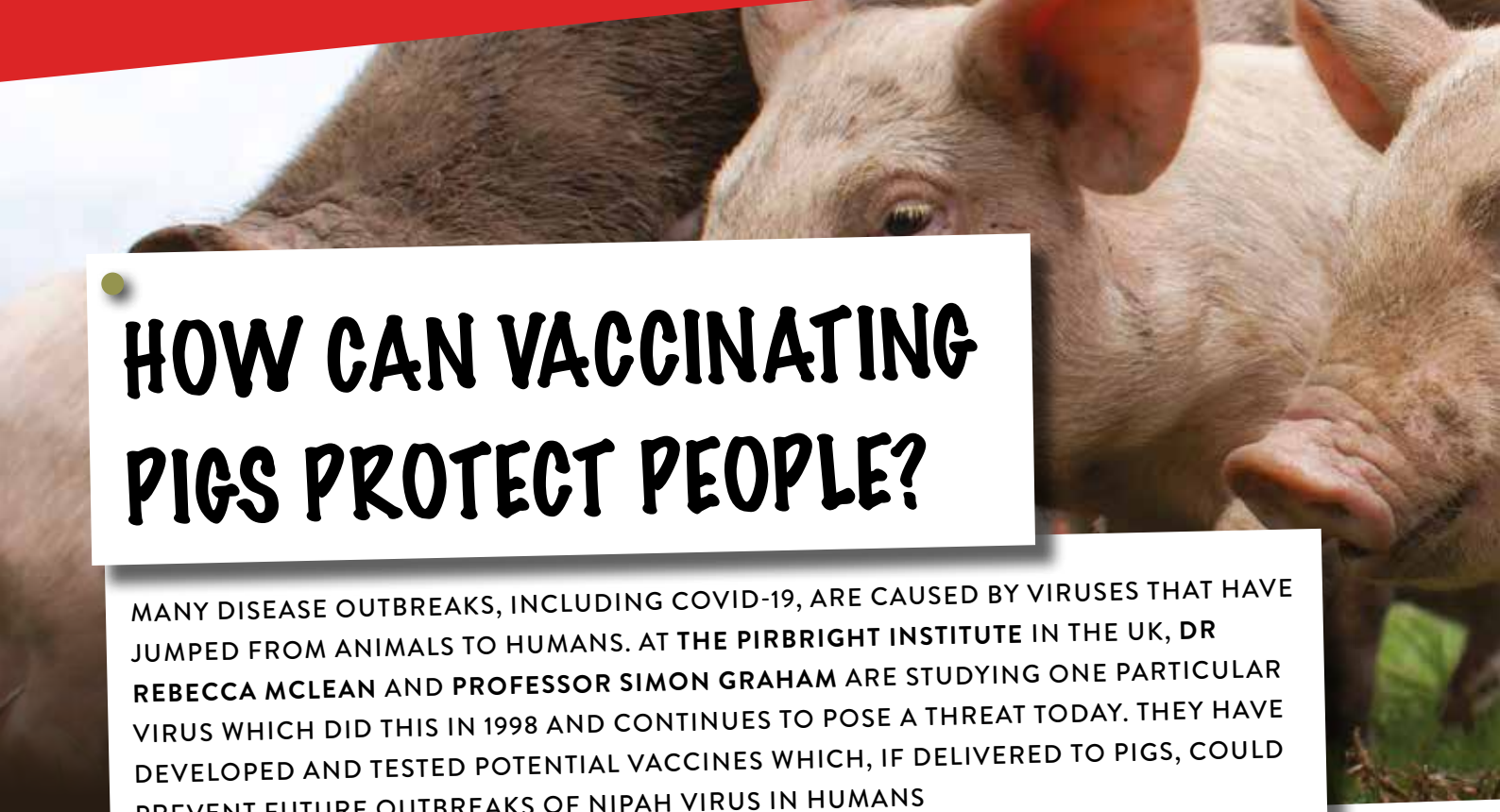
Mentorship is probably the most important factor in a physician-scientist's success and happiness, even more important than the actual project. I was fortunate to have an amazing mentor in Dr Lorraine Ware. We had such a great working relationship that as I grew as a scientist, we decided to continue working together as colleagues. Then, my first mentee, Dr Ciara Shaver, made the same decision and stayed on as part of our group. Now, we are three physician-scientists who lead our large lab group.

HOW DO YOU SWITCH OFF FROM YOUR WORK?

I have young children so as soon as I go home, I become 'mom' and enjoy my time with family. When I had children, I made a conscious decision to spend as much time as possible with them when I was home. When I get home, it's family time and I don't do any more work until the kids go to bed. I also enjoy reading lots of non-fiction and jogging when I have time.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Being a mentor is so rewarding. It is amazing to see my mentees succeed. I am also proud of the incredible group of students, technicians, research nurses and trainees in our lab. We have an amazing group and work hard to foster an inclusive, supportive environment in which people can thrive.



HOW CAN VACCINATING PIGS PROTECT PEOPLE?

MANY DISEASE OUTBREAKS, INCLUDING COVID-19, ARE CAUSED BY VIRUSES THAT HAVE JUMPED FROM ANIMALS TO HUMANS. AT **THE PIRBRIGHT INSTITUTE** IN THE UK, **DR REBECCA MCLEAN** AND **PROFESSOR SIMON GRAHAM** ARE STUDYING ONE PARTICULAR VIRUS WHICH DID THIS IN 1998 AND CONTINUES TO POSE A THREAT TODAY. THEY HAVE DEVELOPED AND TESTED POTENTIAL VACCINES WHICH, IF DELIVERED TO PIGS, COULD PREVENT FUTURE OUTBREAKS OF NIPAH VIRUS IN HUMANS

TALK LIKE A VACCINOLOGIST

AMPLIFICATION – when a virus infecting a particular species can replicate itself extremely rapidly

ANTIBODY – a protein used by the immune system to prevent viruses infecting cells

HOST – an organism within which a virus resides

IMMUNE SYSTEM – the complex network of biological processes which organisms use to protect themselves from diseases

PATHOGEN – an organism that causes disease

T CELLS – white blood cells that destroy infected cells

VACCINE – a substance containing molecules or weakened pathogens, which stimulates the body's immune system to prevent or control real infections more effectively in the future

VIRUS – a microscopic structure which replicates itself by invading living cells, usually causing damage to the host

ZOONOTIC DISEASE – an infectious disease that jumped from animals to humans

As COVID-19 has shown us, the risk of viruses transferring from animals to humans presents a very real threat. What is more, there is no way to tell when or where this will happen next. Although COVID-19 is now the best-known example of zoonosis, previous animal viruses that passed to humans have also had deadly consequences.

In 1998, Nipah virus (NiV) was first identified following infection of pig farmers in Malaysia. While the disease can be mild in pigs, if the virus transfers to a human host, it is far more dangerous. Initial symptoms in humans include fever, headache, coughing and breathing difficulties, followed by brain swelling leading to a coma. "The lack of specific symptoms in pigs makes NiV hard to diagnose, so it can spread quickly," says Dr Rebecca (Becca) McLean, a vaccinologist at The Pirbright Institute. "If a human becomes infected with NiV, the chance of death varies from 45% to 75%."

While the original outbreak of NiV was contained by 1999, the danger it presents has not disappeared.

HOW CAN NIPAH VIRUS BE CONTAINED?

NiV passed to pigs from wild fruit bats, which are native to Southeast Asia, Africa and Australia. NiV has been detected in wild bat populations in Malaysia, Bangladesh, India, Singapore and Thailand. "When pigs live in close proximity to fruit bats, there is a chance that NiV can be transmitted to them through the bat's urine, faeces or saliva," says Professor Simon Graham. "When pigs become infected, they can amplify the virus. This can cause humans who have contact with these animals to become infected."

To contain the 1998 NiV outbreak, over a million pigs were slaughtered in Malaysia and, to this day, pig farming is still banned in many parts of the country. The outbreak had devastating consequences for Malaysia's economy as the government had to pay over US$500 million in compensation to farmers who lost their jobs and livestock.

To eliminate the threat of a future NiV outbreak requires an effective vaccination against the virus. It would not be possible to vaccinate wild populations of fruit bats, so Becca, Simon and their colleagues are developing a vaccine to prevent the spread of NiV in pigs.

HOW WOULD A NIPAH VIRUS VACCINE WORK?

To protect itself against infection, the body's immune system must learn to identify and destroy viruses. When NiV infects a cell, it uses two proteins, named glycoprotein (G) and fusion protein (F). Vaccinologists can include these proteins in vaccines to 'teach' the immune system to fight NiV before it enters the body.

By replicating the exact G or F proteins unique to NiV, a successful vaccine would activate two important elements of the immune system – Y-shaped proteins named antibodies and white blood cells named T cells. "T cells have a role in not only destroying virus-infected cells, but also in helping other cells of the immune system to respond better," says Becca. "Antibodies can bind to the NiV G and F proteins, preventing the virus from infecting cells." The vaccine would therefore teach cells how to identify and destroy the real virus, without becoming infected by it.

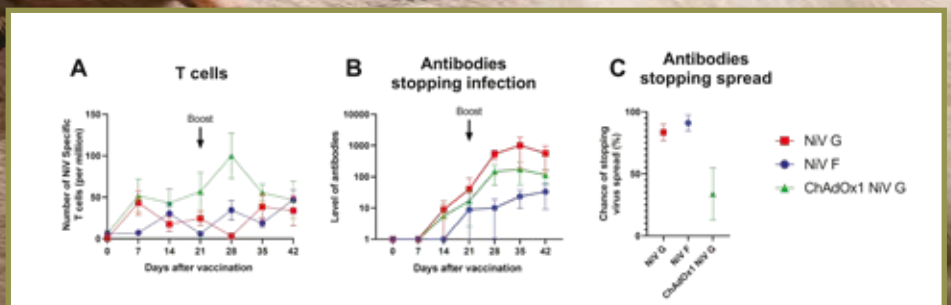


Figure 1: *NiV vaccine candidates induce different immune responses in pigs. A) ChAdOx1 NiV G (green) produced the greatest T cell response. B) NiV G (red) produced the antibody response best able to prevent infection of cells. C) NiV F (blue) produced the best antibody response to limit the spread of NiV between cells (fusion).*

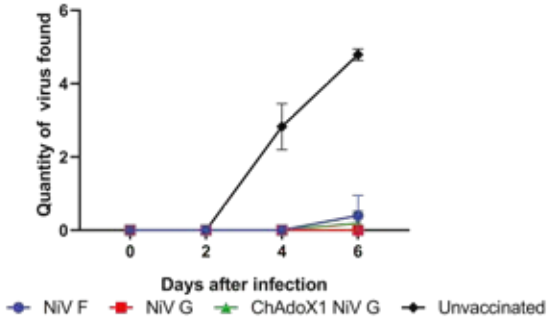


Figure 2: *All three vaccines protect pigs against NiV. Alongside pigs which remained unvaccinated, we experimentally infected pigs vaccinated with our three vaccines. We then took swabs from the nose to see if any virus could be found there. Very minimal amounts of virus could be detected from the vaccinated pigs, but lots of virus could be found in the pigs that were not vaccinated. This suggests that the vaccinated pigs cannot transmit NiV.*

HOW DO BECCA AND SIMON TEST VACCINES?

Becca, Simon and their colleagues are developing and testing three different NiV vaccine candidates to determine which is most effective at preventing NiV. One vaccine contains the NiV G protein, one contains the NiV F protein and the third delivers the NiV G protein using a weakened form of a virus, known as a 'vaccine vector'. The specific vaccine vector they are testing is 'ChAdOx1', which was also recently used as the basis for the AstraZeneca COVID-19 vaccine.

To test the vaccines, the team immunised pigs with two doses of each vaccine candidate and then collected blood samples to analyse the immune responses they initiated. Becca and Simon discovered that each vaccine offers its own unique advantages. While antibody responses to the NiV G protein were best at preventing the virus from infecting cells, the NiV F protein was most effective in preventing the virus from spreading from cell-to-cell, and the ChAdOx1 vector stimulated the strongest T cell responses (Figure 1).

Three weeks later, the team exposed pigs to real NiV. This allowed Becca and Simon to compare the protection provided by each vaccine. "Despite the differences in immune responses between the three vaccine candidates, all three vaccines provided a comparable high level of protection," explains Simon (Figure 2). These results are incredibly promising, and researchers can now consider how vaccines could be used to prevent and control future NiV outbreaks. This may include emergency 'ring vaccination' campaigns, where pigs surrounding an outbreak are immunised, or routine vaccinations of pig populations to prevent outbreaks from arising in the first place.

WHAT CHALLENGES STILL NEED TO BE OVERCOME?

Although Becca, Simon and their colleagues have shown their vaccines are effective, vaccination campaigns cannot yet be carried out. To determine the success of a vaccination campaign, researchers would need to carefully monitor virus-neutralising antibodies in the blood of pigs. Currently, however, there is no way to tell the difference between pigs which gained these antibodies from a vaccine, and those that were infected with the real virus.

"Unless a new diagnostic test is developed which can distinguish between infected and vaccinated animals, a NiV vaccine for pigs could not be used for routine vaccination, as it would interfere with surveillance for the virus," explains Becca. Therefore, the team is now focused on designing this test.

If successful, the team can begin conversations with local governments and vaccine regulators about how the vaccine could be rolled out in pig populations. Ultimately, these efforts are an important part of the wider work of vaccinologists. Many other viruses in wild animal populations have the potential for zoonosis. We will not know which ones can successfully infect humans until it is too late, so the work of future generations of vaccinologists will be crucial to prepare for this eventuality.

DR REBECCA MCLEAN

PROFESSOR SIMON GRAHAM

The Pirbright Institute, UK

FIELD OF RESEARCH

Vaccinology

RESEARCH PROJECT

Developing a vaccine against Nipah virus in pigs

PROJECT PARTNERS

University of Oxford, UK; Australian Centre for Disease Preparedness, Australia; University of Queensland, Australia; International Centre for Diarrhoeal Disease Research, Bangladesh; Zoetis, USA

FUNDERS

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ABOUT VACCINOLOGY

Vaccinologists contribute to all steps of the vaccination process, from investigating the responses vaccinations trigger in the immune system, to developing the strategies and technologies required to deliver them in the real world. When West Africa was struck by an outbreak of Ebola virus in 2014, the world realised just how underprepared we were for large-scale outbreaks of zoonotic diseases.

Since then, the World Health Organization (WHO) has created a list of diseases that urgently require research and development of vaccines, and NiV has been identified as one of these priority diseases. "Because of these efforts, the scientific community was better prepared to respond to the COVID-19 pandemic," says Simon. "Vaccines were developed against an entirely new virus in less than one year, which was a major achievement."

WHY ARE VACCINES TESTED ON ANIMALS?

To ensure vaccines are safe for use, it is often crucial to study their effects on animals like pigs, whose immune systems behave in very similar ways to ours. "There are rightly lots of regulations and ethical considerations around the use of animal models," says Becca. "We must use the fewest number of animals to get a significant result, and ensure we minimise any suffering." Once a vaccine is proven to be safe, and that it enables the immune system to fight a virus effectively, it can then move on to human trials.

WHAT DOES A TYPICAL DAY OF WORK INVOLVE?

"Like all scientists, the life of a vaccinologist is always very varied," says Simon. Some days will be spent at the desk, either planning new experiments, analysing data from past experiments, or getting up to speed with the latest research by reading academic journals. Other days will be spent in the lab, processing and analysing samples. No two days are ever the same!

WHY SHOULD YOU CONSIDER A CAREER IN VACCINOLOGY?

Vaccinology is a fast-moving field of science. It considers a huge range of diseases and organisms, and draws from many different fields of research. And there is still a lot of work to be done. New vaccine technologies are being developed constantly and there is a pressing need to prepare for viruses which we know are out there, but which have not yet been discovered. "This means there are pioneering discoveries occurring all the time, making it a very exciting area of research," says Becca.

EXPLORE A CAREER IN VACCINOLOGY

- As a vaccinologist, you could work for a pharmaceutical company or in a research institute. You might find yourself responsible for any or all stages of vaccine development, from microbiological investigation of pathogens, to designing and testing new vaccines, to getting a vaccine onto the market and into public use.
- The Pirbright Institute (**www.pirbright.ac.uk**), where Becca and Simon work, hosts many vaccinologists who are working to prevent and control viral diseases.
- The British Society for Immunology has a wealth of information about careers in the field (**www.immunology.org/careers**) and is running a campaign to celebrate vaccines (**www.immunology.org/celebrate-vaccines**).
- World-leading vaccinologist Professor Robin Shattock wrote an article titled 'How to get a job in vaccine development' for Nature: **www.nature.com/articles/d41586-021-03057-6**

BECCA AND SIMON'S TOP TIPS

01 Keep persevering! There will be times when you feel a door has been slammed in your face, but remember, as one door closes, another opens.

02 To quote Einstein, "It's not that I'm so smart, it's just that I stay with problems longer".

PATHWAY FROM SCHOOL TO VACCINOLOGY

- "Having a passion for science is a must," says Becca. As it is a multidisciplinary science, there is no specific route to get into vaccinology, but you should be passionate about your chosen pathway.
- At school, biology, chemistry and maths will be useful subjects to study to enter relevant university degree programmes.
- Undergraduate degrees in biology, biochemistry, medicine, veterinary medicine or immunology could all lead to a career in vaccinology.
- Some pharmaceutical companies offer apprenticeships, allowing you to train as a vaccinologist while also working. In the UK, Pfizer supports the National Apprenticeship Programme: **www.pfizer.co.uk/careers/apprenticeships**
- Completing a PhD after university will allow you to follow an academic career path as a vaccinologist.

HOW DID BECCA BECOME A VACCINOLOGIST?

I have always had a passion for science and animals. When I was younger, I thought I wanted to be a vet, but I changed my mind after completing work experience. I knew I loved science and animals, so I decided to study a bio-veterinary science degree.

My PhD supervisors were huge inspirations to me. They taught me the foundations of my vaccinology knowledge, which I have been able to grow and develop in my post-doctoral job.

I love how varied each day of my job can be. I also really enjoy problem solving, which is something you have to do every day in science!

There are a number of challenges to overcome when developing vaccines. These include the initial design of the vaccine, testing the immune responses it creates, seeing whether it is protective and, finally, trying to get the vaccine onto the market. This relies on collaborating with lots of other scientists and regulatory bodies.

The highlight of my career has been getting involved in the COVID-19 response. I helped lead a team to assess the immune response to six different vaccine candidates in pigs, including the Oxford/AstraZeneca vaccine. My ambition for the future is to develop vaccines against other emerging infectious zoonotic diseases.

When I'm not working, I love spending time with my new little family. I have an 8-month-old son who is growing and changing all the time.

HOW DID SIMON BECOME A VACCINOLOGIST?

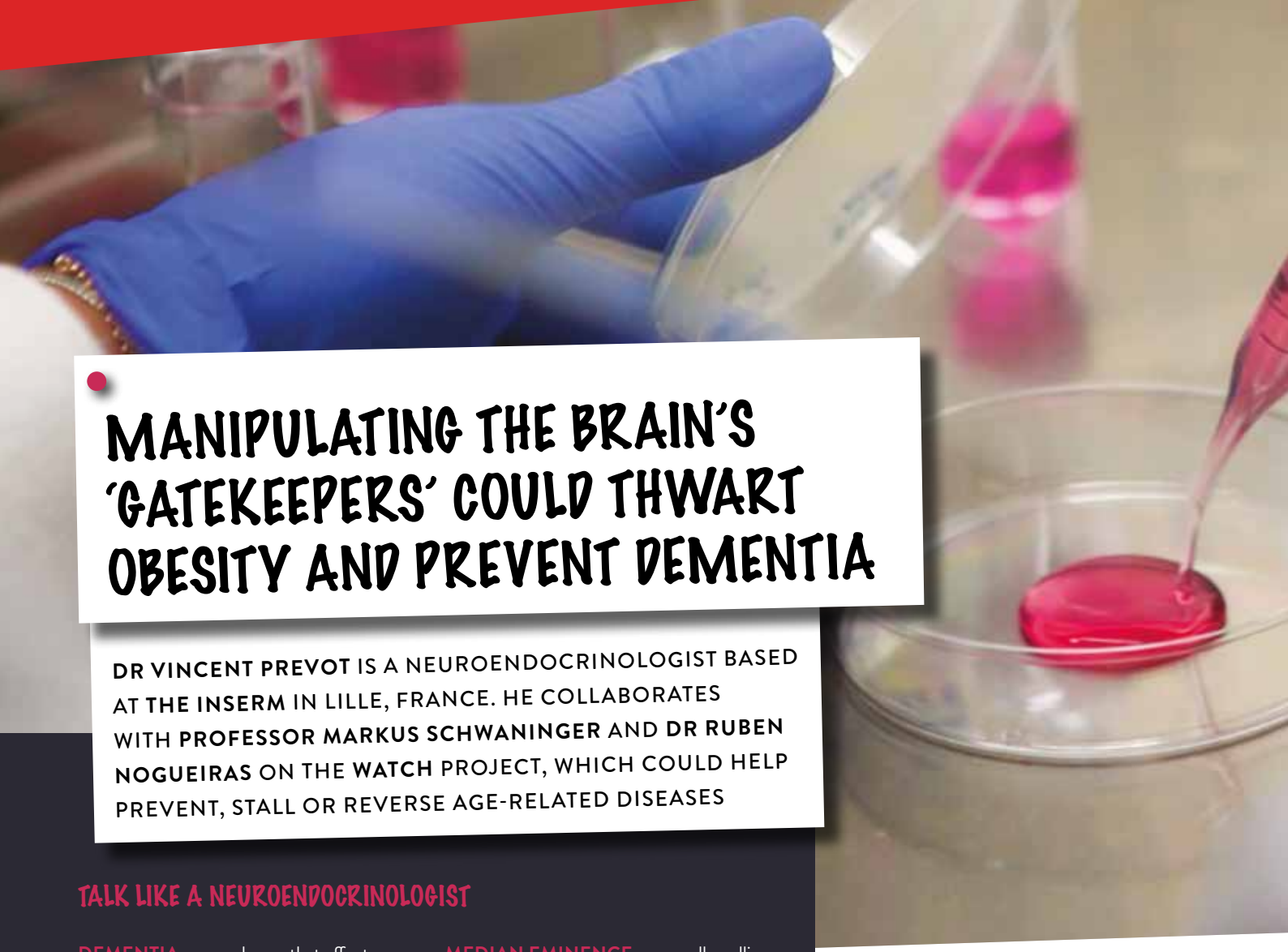
I have always had a love for animals – my earliest career ambition was to be a zookeeper! Over time, this passion evolved into science and my career in veterinary science marries these two interests.

I studied immunology and microbiology at university. I was fascinated by the 'arms race' that exists between the immune system and disease-causing microorganisms. But what really inspired me to pursue my career was the understanding of how vaccination can have such a major impact on controlling diseases.

Teamwork is what I enjoy most about my job. It involves working with lots of interesting people from different backgrounds. Science is a truly international business, and we collaborate with scientists in Europe, the Americas, Asia and Australia.

The challenges we face when developing new vaccines differ hugely, depending on the disease we are targeting. In some ways we were lucky with COVID-19, in that safe and effective vaccines were rapidly developed in such a short space of time. Compare that with HIV: after almost 40 years of research and billions of dollars spent, we still have no vaccine. But exciting progress is being made, and we are getting closer.

I spent six great years working in Nairobi, at the Kenyan International Livestock Research Institute. I worked as part of a team that made significant steps towards the development of a much needed next-generation vaccine for East Coast fever, a disease that kills at least one million cattle each year in Sub-Saharan Africa.



MANIPULATING THE BRAIN'S 'GATEKEEPERS' COULD THWART OBESITY AND PREVENT DEMENTIA

DR VINCENT PREVOT IS A NEUROENDOCRINOLOGIST BASED AT **THE INSERM** IN LILLE, FRANCE. HE COLLABORATES WITH **PROFESSOR MARKUS SCHWANINGER** AND **DR RUBEN NOGUEIRAS** ON THE **WATCH** PROJECT, WHICH COULD HELP PREVENT, STALL OR REVERSE AGE-RELATED DISEASES

TALK LIKE A NEUROENDOCRINOLOGIST

DEMENTIA – a syndrome that affects memory, language, problem-solving and other thinking abilities severely enough to interfere with daily life

HYPOTHALAMUS – a small region of the brain located at the base, near the pituitary gland. It plays a crucial role in many important functions, such as releasing hormones and regulating body temperature

LEPTIN – a protein made in the fat cells, which circulates in the bloodstream and goes to the brain

MEDIAN EMINENCE – a small swelling on the underside of the hypothalamus that gives rise to the pituitary stalk

METABOLISM – all the chemical processes that go on continuously inside your body to keep you alive and your organs functioning normally, such as breathing, repairing cells and digesting food

TANYCYTES – specialised cells with long processes that are found along the walls of the third and fourth ventricles of the brain

There is an adage that states we know more about the Universe than we do the human brain and, while that is not strictly true (it has to be understood in context), it is perhaps fair to say that relative to the opportunity for discoveries in the future, we do know much more about the Universe than we do our own minds!

Fortunately, some of the very best minds are engaged in the Well-Aging and the Tanycytic Control of Health (WATCH) project. The project sees a collaboration between Dr Vincent Prevot, a neuroendocrinologist based at the Inserm in Lille in France, Professor Markus Schwaninger, a neurologist at the University of Lübeck in Germany, and D Ruben Nogueiras, an expert in molecular metabolism at the University of Santiago de Compostela in Spain. The team wants to understand more about the role that peripheral hormones play in proper brain functioning, and how a lack of communication between the brain and the periphery may lead to cognitive decline in adulthood. The WATCH project is focusing on tanycytes, cells found in certain areas of the brain.

TANYCYTE TRAITS

Tanycytes, a type of nerve cell known as glia, line the walls of the third ventricle in the hypothalamus. Some tanycytes still divide in the adult brain, giving rise to new neurons, a phenomenon that only occurs in two or three other brain regions. They also have several other fascinating and unique features. In particular, tanycytes of the hypothalamic median eminence have a special advantage – they dip their 'end-feet' (the expanded tips of their processes) directly into the blood circulation, since the capillaries underlying this region have fenestrations or 'windows' in their walls. This sets them apart from capillaries in most other parts of the brain, which have leak-proof walls to separate brain cells from circulating molecules, constituting a 'blood-brain barrier'. "The fact that the tanycytes in this region contact both the blood and, at their other end, the ventricular liquid or 'cerebrospinal fluid', which constitutes a kind of canal system connecting different parts of the brain, is why they are part of our focus," explains Vincent. "It means that they are peculiarly qualified to sense what is going on in the rest of the body, and to allow messages from other tissues to bypass the blood-brain barrier and, thus, gain access to brain circuits."

DISCOVERIES

Through experiments in animal models over the last few years, the team has shown that tanycytes are not passive bridges between the

DR VINCENT PREVOT

Lille Neuroscience & Cognition Inserm, University of Lille, France

FIELDS OF RESEARCH

Neuroscience, Neuroendocrinology

PROFESSOR MARKUS SCHWANINGER

University Of Lübeck, Germany

FIELD OF RESEARCH

Neurology

DR RUBEN NOGUEIRAS

University Of Santiago De Compostela, Spain

FIELD OF RESEARCH

Molecular Metabolism

JOINT RESEARCH PROJECT

Well-Aging and the Tanycytic Control of Health (WATCH): Studying the tanycytic hormonal shuttle and whether it is the missing link between impaired brain function and metabolic imbalances, with the aim of preventing or reversing age-related conditions such as obesity, diabetes and dementia

FUNDER

European Research Council (ERC)

two liquids but play a handful of very active and peculiar roles. Firstly, tanycytic end-feet, by alternately advancing and retreating, participate in a complex 'dance' with the terminals of hypothalamic neurons, which need to get close enough to the fenestrated capillaries during certain periods to secrete their hormonal signals into the blood circulation. Secondly, although tanycytes replace the blood-brain barrier by forming another barrier at the ventricular wall, this layer, made up of their cell bodies, is more or less tightly sealed depending on whether the biological state of the animal requires signals from the blood to enter the brain or not. Thirdly, tanycytes themselves actively transport some of these signals into the brain, allowing them to reach responsive neurons that would otherwise be insulated from them.

"It is because of this very special role as controllers of the access of signals from other tissues to the brain that tanycytes are often referred to as the 'gatekeepers' of the brain," explains Markus.

TRANSPORTING MESSAGES

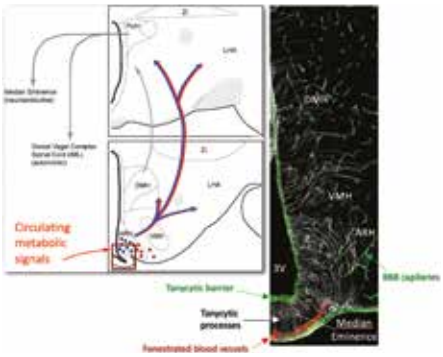
Any gatekeeper has the ability to allow or deny entry. But a properly functioning brain needs neural circuits in the brain to detect the state of the rest of the body and direct appropriate functional or behavioural responses. In the case of hunger, for example, the hormone ghrelin is secreted in the stomach that sends a message telling us we are hungry, while the hormone leptin tells us we are full. However, in some instances, the messages do not get through, so an individual's brain might never receive leptin, letting the person continue eating, eventually becoming overweight. It is believed that tanycytes play a role in our ability to transport the messages to the appropriate neuronal circuits.

Although this example is specifically related to a metabolic disease like obesity, it shows there is a tangible link between brain function and metabolic state. If tanycytes play the role of 'gatekeeper' in conditions such as obesity, they could also play a role in the onset of dementia or other cognitive issues – because the processes involved are essentially the same.

LOOKING AHEAD

In order to see whether the tanycytic hormonal shuttle is the missing link between impaired brain function and metabolic imbalances, and how exactly this link works, the team needs to be able to see two things. "We need to know what happens when we deliberately disrupt the transport of hormones into the brain, and also determine what happens if, in individuals where the transport has already been disturbed, we use drugs or other methods to restore the function," says Ruben. "To do this, we will use genetically-modified mice or cultured cells to investigate the functions of certain genes or cellular processes."

If the team can show that restoring the transport of hormones into the brain has a positive effect, it may be possible to restore cognitive function in patients that have experienced a decline. Ultimately, the team wants to find a cure for obesity, as well as prevent cognitive decline – ambitions that the mechanisms they have uncovered could facilitate. WATCH this space.



Tanycytes of the hypothalamic median eminence have a special advantage – they dip their 'end-feet' directly into the blood circulation.

ABOUT NEUROENDOCRINOLOGY

The endocrine system is the collection of glands in the body that produce hormones that regulate a range of different functions, such as metabolism, growth and development, tissue function, sexual function, reproduction, sleep, and mood. The brain also produces hormones, through which it controls the activity of other organs and glands. Neuroendocrinologists study the interaction between the nervous system and the endocrine system. Neuroendocrinologists are especially focused on how the two systems communicate together – a principle that is the backbone of the WATCH project.

"In terms of concepts, the biggest challenge facing the field is connecting the dots linking neuroendocrine dysfunction (that is, defects in the way the hypothalamus works) and various psychiatric and metabolic diseases as well as pathological ageing," explains Vincent. "From the point of view of the tools and technology needed, I would say that it is understanding how to exploit and interpret big data efficiently, accurately and productively."

EXPLORE A CAREER IN NEUROENDOCRINOLOGY

- The Endocrine Society's website is comprehensive. We recommend taking your time to read through relevant sections, especially the one dedicated to careers and professional development: **www.endocrine.org/our-community/career-and-professional-development/endocareers**
- The Society for Endocrinology is a wonderful resource, including lots of information about career pathways: **www.endocrinology.org/careers/career-pathways**
- According to Indeed.com, the average salary for an endocrinologist in the UK is £96,000.
- You can explore salaries on offer across Europe on the careers section of the BMJ website: **www.bmj.com/careers/jobs/diabetes-and-endocrinology/europe**

PATHWAY FROM SCHOOL TO NEUROENDOCRINOLOGY

Vincent recommends that students consider taking neuroscience, endocrinology and the biology of reproduction modules during their time at university. These will provide budding neuroendocrinologists with a broad understanding of the matters at hand.

You will need to study biology or chemistry at an undergraduate level, before moving on to scientific research or medicine. In the WATCH team, Vincent and Ruben are scientists and Markus is a medical doctor.

THE IMPORTANCE OF COLLABORATION

Science is carried out at a level of detail which makes it impossible for any single laboratory or team to study all aspects of a problem. A project as ambitious and wide in scope as WATCH is only possible with the combined and synergistic efforts of several groups with complementary interests, expertise and skills. The three groups involved in WATCH (Vincent's team in France, Markus' in Germany, and Ruben's in Spain), have a common interest in deciphering the role of the hypothalamus, and of the tanycyte in the functions necessary for bodily homeostasis, as well as normal cognitive function and ageing-associated changes and disorders. However, each specialises in the study of different biological processes, using different models and techniques, so when they join forces, they manage to obtain results and insights that each group would be unable to achieve on its own.

THE TEAM'S TOP TIPS

01 Try your best to develop a passion for something. I have always been curious about biology and it has helped me enormously throughout my career.

02 Taking courses in your native language can be a big help. So much of scientific work relies on effective communication and taking some language classes will certainly help with that.

03 History is another important subject to consider studying – even if only in your spare time. It can help put things into context, which is very important within science.

MEET THE TEAM

PROFESSOR MARKUS SCHWANINGER

I enjoyed Latin and ancient Greek in school, but I loved the sciences and conducted chemistry experiments on my own at home.

Several people inspired me to become a scientist, but my main inspiration was the supervisor of my thesis, Willhart Knepel.

The best way to overcome obstacles in my work is to consult with others, talk with colleagues and read their scientific papers.

I am amazed by the endless complexity of life. Evolution has brought up such a magnitude of ingenious and stunning mechanisms.

There have been eureka moments in my career when I have been able to predict how cells or organisms will behave.

I'm proud of research papers I've written and the tools my group has produced that have helped the wider scientific community. Most importantly, I'm proud of seeing the people I've worked with progress.

You should always keep in mind that science is a craftmanship that can be learned.

DR RUBEN NOGUEIRAS

As a child, I loved being with my friends and playing basketball. In terms of school subjects, biology was my favourite by far.

I spent extra hours in the lab during my degree. Then I did my master's and loved the lab work – and decided to become a scientist.

Any successful scientist needs three qualities. Motivation (because science can be frustrating), perseverance (because hard work is essential, no matter how talented you might be), and the ability to choose the right environment to work in (because being part of a good team is vital).

Patience enables me to overcome challenges. It allows scientists to spend time looking for new solutions to old problems.

Many aspects of my career are rewarding. I enjoy it when my colleagues find my work interesting, but I love to see the career progression of former students.

Convincing reviewers and panels can be challenging. Part of a scientist's work is explaining why your work deserves funding more than many other excellent proposals.

I am proud of securing an ERC Starting Grant, and becoming part of the Synergy Grant was pleasing. Contributing to our understanding of how the brain and peripheral organs are communicating is something I am very proud of.

Enjoy what you do. It is so important to get up each morning and want to go to the lab. Such a mindset will help you throughout your career.

Many experiments do not work. The important thing is to realise that and to keep going. Thankfully, Vincent and Markus make working together fun, so we can overcome any challenges we face.

DR VINCENT PREVOT

Living in Perú as a child, I raised caterpillars and watched them become butterflies. When I was ten, I collected scorpions and insects with my father in the Andes. At 14, with very permissive parents, I built a zoo at home with snakes, turtles, geckos, scorpions, piranhas, salt-water fishes, a ferret and a dog! I was breeding snakes and became a member of the French Herpetology Society at the age of 16. With my interest in breeding reptiles and the obstacles that often arise, I wanted to understand the mechanisms that control how animals reproduce and became fascinated with neuroendocrinology.

Passion for my subject, perseverance, open-mindedness, willingness to question dogma and acceptance of the fact that I do not know everything have made me successful. Surrounding myself with competent and well-disposed people who possess a strong team spirit has also been key.

It sounds simple, but to overcome obstacles, I sleep on them! I usually find that the solution presents itself in the morning.

I practise martial arts, avoid talking science at night with my family, and engage in constructive activities like gardening or doing odd jobs around the house.

I am proud of having been able to make real contributions to our understanding of how the brain controls reproduction and metabolism. I am also proud of having been able to build a top-notch laboratory and an ERC Synergy consortium with internationally renowned scientists and a real spirit of teamwork.

SHINING A LIGHT ON THE ROLE OF TRACE METALS IN NEURODEGENERATIVE DISEASES

A TEAM OF RESEARCHERS WITH EXPERTISE IN PHYSICS, ENGINEERING AND BIOLOGY ARE FINDING OUT WHETHER TRACE METALS IN THE BRAIN ARE LINKED TO NEURODEGENERATIVE DISEASES. USING INNOVATIVE SYNCHROTRON TECHNIQUES AT **DIAMOND LIGHT SOURCE**, THE UK'S NATIONAL SYNCHROTRON FACILITY, THEIR WORK IS PAVING THE WAY FOR IMPROVED DIAGNOSIS AND TREATMENT

GLOSSARY

METALLOMICS – the study of the role of metal elements in living systems

HOMEOSTASIS – the regulation of conditions in the body such as temperature, water content, carbon dioxide, glucose and levels of chemical elements (**www.bbc.co.uk/bitesize/guides/z4khvcw/revision/1**)

DEMENTIA – a group of related symptoms (such as memory loss and difficulties with problem-solving or language) associated with an ongoing decline in brain functioning

ALZHEIMER'S DISEASE – the most common form of dementia, leading to symptoms such as memory loss

PARKINSON'S DISEASE – a neurodegenerative disease that includes loss of nerve cells in part of the brain called the substantia nigra

AMYLOID PLAQUES – insoluble protein-rich deposits, including assembled fibres of amyloid protein

TRANSITION METALS – metals in the central block of the periodic table, including iron

TRACE METALS – metals that are present in small but measurable concentrations in animal and plant cells and tissues

MAGNETIC RESONANCE IMAGING (MRI) – a medical imaging technique that uses the magnetic properties of biological tissue to look in detail at anatomy and can identify and locate some ions and molecules

BEAMLINE – an experimental station at a facility, where a beam emitted from a particle accelerator (such as photons at a synchrotron facility) is used for a particular type of measurement (e.g. diffraction, tomography, fluorescence)

BIO-AVAILABLE METAL – a measure of the degree to which a metal ion or metal compound can be used in biochemical reactions

According to the World Health Organization (WHO), around 25-30% of people aged 85 or older have dementia. Indeed, diseases such as Alzheimer's and Parkinson's are an increasing problem in ageing populations worldwide, but it is not only the older populations who are suffering from dementia: around 1 in every 20 cases of Alzheimer's disease affects people aged 40 to 65. Finding out the causes of dementia, and how to cure or slow the development of neurodegenerative diseases such as Alzheimer's and Parkinson's, is therefore crucial.

Surprising as it may seem, the human brain (and body) is full of trace metals. These metals are essential if our brains are to work properly. For example, the human brain contains about 6 milligrams of copper, enough to produce a small circuit board! Higher-than-usual levels of iron were first reported in the brains of people with Alzheimer's disease in 1953. Since then, researchers have discovered altered concentrations of trace metals such as copper, zinc and iron in certain regions of the brains of deceased Alzheimer's patients – and many of these metals have been found concentrated in amyloid plaques. It is known that when there is an imbalance of metals in the body, things start to go wrong. But it is not yet fully understood how changing metal levels affect the onset or progression of dementia.

HOW DO WE FIND OUT?

Professor Joanna Collingwood is the Head of the Trace Metals in Medicine Laboratory at the University of Warwick. She is collaborating with a team of researchers with physics, biology and engineering expertise to investigate the role trace metals play in the development of Alzheimer's and Parkinson's disease. They are using a state-of-the-art synchrotron technique, called X-ray spectromicroscopy, to image and analyse the brain in innovative ways.

"We need to think about the brain as a dynamic system, about the balance (homeostasis) being disrupted, to determine if too much of one metal, or not enough of another, is preventing cells from functioning properly," says Jo. "When we study neurodegenerative diseases that happen in humans, we normally look at brain tissue that has been donated to a brain bank after someone's death. This means we're looking at evidence from a single point in time. To try and understand the timeframe over which chemical changes in the brain have happened (quickly, or slowly – maybe over decades), we have to use evidence from medical imaging studies (where available)."

WHY IS IT IMPORTANT TO STUDY CHANGES IN METAL HOMEOSTASIS?

Studies of post-mortem brains have revealed that iron concentrations change as we get older. However, changes in metal chemistry appear to be more marked in diseased brains than in healthy brains. "People with Alzheimer's disease may exhibit metal-rich deposits of proteins, called plaques, in their

brain tissue," Jo explains. "Meanwhile, with Parkinson's, concentrations of iron in some vulnerable neurones are higher compared to healthy individuals of the same age."

Jo continues: "Because the changes in metal homeostasis depend on the type of disorder, we think it is important to describe these changes as well as possible. Firstly, because it might be possible to detect these changes with medical imaging techniques (such as magnetic resonance imaging (MRI), which can be sensitive to iron), to help obtain an earlier and/or more accurate diagnosis. Secondly, because a better description of how brain chemistry is changing in these disorders might create opportunities for better treatment."

WHAT HAPPENS WHEN X-RAYS INTERACT WITH METALS IN THE BRAIN?

The elements that make up the biological tissue in the brain have different arrangements of electrons around their central nuclei. This gives each element a unique set of energy levels – a signature that shows up when X-rayed. When an X-ray beam interacts with a sample of brain tissue, only those elements with an excitation energy at or below the energy of the X-rays will exhibit fluorescence. "Scientists have already made lists of energies that are absorbed by different elements, so we can identify the different chemical elements with high accuracy," says Jo.

Biomedical imaging has progressed in leaps and bounds in recent years thanks to technological advances, but imaging changes in metal homeostasis is challenging. Conventional imaging techniques are not sensitive enough to detect low concentrations of certain metals, to differentiate between the various trace metals and their chemical properties. Moreover, these techniques can damage or change the metal chemistry within brain samples. Jo and the team are taking advantage of X-ray spectromicroscopy and other imaging techniques to advance our understanding of the brain in new ways.

WHAT IS SPECTROMICROSCOPY?

"Synchrotron X-ray spectromicroscopy is fantastic because it can be used without damaging the sample. It is very accurate for identifying the different elements, and can be used on samples that are as close as possible to their 'native state' to preserve their properties," says Jo. "Spectromicroscopy is not commonly used to study brain tissue, so there is still a lot to discover and develop in the way that we can apply this approach." So, what is spectromicroscopy?

You can think of spectromicroscopy as a series of maps overlaid one on top of the other, like different maps of a city. One map might show where the shops are, another where the train stations are, a third where the parks are. Each of these maps is useful on their own, but to really understand how a city works you need to know, for example, whether train stations are close to shops or parks close to restaurants. In a similar way, spectromicroscopy not only allows scientists to see the distributions of metals such as iron, copper and zinc individually, but also to investigate the correlation between the three distributions.

Spectromicroscopy also contains detailed information about how the X-rays have been absorbed by the elements, allowing the scientists to extract detailed information about individual features. This is what makes the technique more powerful than other element-mapping methods. In the city map example, this might be the equivalent of not only seeing the relative location of facilities such as stations and restaurants, but also being able to see their opening hours and customer reviews. "Spectromicroscopy not only allows scientists to see the relationship between the element distributions, it also allows investigation of individual elemental properties, such as chemical state, crystal structure and magnetic properties," Jo explains.

WHAT DOES JO'S RESEARCH MEAN FOR DIAGNOSTICS AND THE TREATMENT OF NEURODEGENERATIVE DISORDERS?

"The work we do is contributing small pieces of information into a huge and complex jigsaw of knowledge," says Jo. Indeed, a better understanding of trace metals' role in the development of neurodegenerative disorders such as Alzheimer's and Parkinson's will certainly help clinicians make earlier and more accurate diagnoses. For example, if higher concentrations of iron in the brain are found to be linked with these diseases, then MRI, which can be sensitive to iron, might be used to detect changes in iron levels.

The information that the team is gathering will also pave the way for better treatments. "There are drugs that can bind metals and remove them from tissue if levels are too high, and this might protect cells," says Jo. "But, if the problem is that a metal element is accumulating in one particular type of cell, causing shortages elsewhere, then lowering levels in the tissue with a drug might not solve the problem."

What is exciting is that the team is able to use synchrotron techniques that were originally developed for other applications. "By using unusual techniques, we are able to approach really difficult questions from different perspectives," Jo concludes. "This can encourage new ways of thinking about problems, and hopefully help us move understanding forward in areas where progress is urgently needed."

PROFESSOR JOANNA COLLINGWOOD

Head of Trace Metals in Medicine Laboratory, School of Engineering, University of Warwick, UK

FIELDS OF RESEARCH

Metallomics, Biomedical Engineering

RESEARCH PROJECT

Using spectromicroscopy and other techniques to understand changes in brain chemistry linked to neurodegenerative disease

FUNDERS

Engineering and Physical Sciences Research Council (EPSRC), Diamond Light Source, LGC Ltd., Alzheimer's Society

ABOUT SYNCHROTRONS AND DIAMOND LIGHT SOURCE

Diamond Light Source is the UK's national synchrotron facility, located in Oxfordshire. A synchrotron is a type of circular particle accelerator that works like a giant microscope, harnessing the power of electrons to produce light that is 10 billion times brighter than the Sun! These bright beams of light are delivered to instrument stations known as beamlines, which scientists can use to study anything from fossils to jet engines, viruses to ancient paintings - and to brain tissue. Over 14,000 researchers from academia and industry currently use Diamond Light Source.

As well as operating Diamond Light Source, the UK is also a member of the European Synchrotron Radiation Facility (ESRF) in France. There are more than 50 synchrotrons in the world that are either in operation or under construction.

Jo has worked with synchrotrons in Switzerland, France, and in Chicago and California in the US. She tells us more.

HOW LONG HAVE YOU BEEN WORKING WITH SYNCHROTRONS?

Since I was a PhD student, when I did my first synchrotron experiments at the ESRF in Grenoble (measuring the magnetic properties of metal alloys).

ARE SYNCHROTRONS DANGEROUS TO WORK WITH?

No. In principle they could be if you were exposed to the X-ray beam, but in practice there are multi-stage safety systems in place so that you should never be shut into the enclosed experiment chamber (the 'hutch') when the beam is on.

WHAT DO YOU LOVE ABOUT WORKING WITH DIAMOND LIGHT SOURCE?

The community, the opportunity, the constant discovery. People from around the world come together at Diamond Light Source from so many different backgrounds: to run the organisation, build new instruments, create software to help the scientists make better measurements, and to conduct research. It's valuable to emphasise the diversity of the research that can be done at synchrotrons, from art history to astrophysics to clinical imaging. And then there's the diversity of scales – sizes, temperatures and pressures – that can be accessed. For example, large turbine blades can be imaged for structural flaws and the structure of a virus or binding in a tiny molecule can be analysed.

EXPLORE A CAREER AT DIAMOND LIGHT SOURCE AND OTHER SYNCHROTRONS

- Diamond Light Source offers school work experience, 'Year in Industry' placements, summer placements and PhD studentships: **www.diamond.ac.uk/Careers/Students.html**
- The work experience is offered to GCSE and A-level students and spans many areas, including communications, data analysis, digital content creation, electronics, health physics, mechanical engineering, project planning and software development: **www.diamond.ac.uk/Careers/Students/Schools-Work-Experience.html**
- If you're looking for an apprenticeship, Diamond Light Source has information about possible apprenticeship opportunities at the facility: **www.diamond.ac.uk/Careers/Apprenticeships.html**
- It is also worth browsing through the 'Careers' section of the website to have an idea of the breadth of skills needed at Diamond Light Source: **www.diamond.ac.uk/Careers.html**
- If you are not based in the UK, visit the websites of synchrotrons near you. Many will provide similar opportunities: **lightsources.org/lightsources-of-the-world/**

MEET JO

I did my first synchrotron experiments on metallomics at a facility in Chicago. The site there is out in the windswept countryside, and gets very cold in winter. Arriving there in the dark of night, I spotted coyotes as well as deer crossing the site!

When I was a teenager, I wanted to be an archaeologist and I studied history and art as well as maths and physics at A-Level. I eventually decided that, whilst I could always enjoy history or art as a hobby, I wanted to study either physics or engineering at university. The advice I got was that I could always move from physics to engineering, but that it would be harder to move the other way. I took physics, and now find myself working in an engineering department, so perhaps this was good advice!

Studying physics can give you tremendous opportunities, allowing you to delve deep into the origins and matter of the universe around us. At the same time, it creates a strong foundation to study other subjects – personally, I really enjoy expanding my knowledge of biology and chemistry from the perspective of having studied physics to postgraduate level.

JO'S TOP TIPS

01 Do something that interests you and that you are curious about.

02 Try to find an environment where you are supported to reach your potential.

03 There is no pre-defined formula for success – I wish that when I was younger I had known how much scope for creativity and variety there would be in my career!

MEET THE TEAM

PROFESSOR NEIL TELLING

RESEARCH DIRECTOR AND PROFESSOR OF BIOMEDICAL NANOPHYSICS, SCHOOL OF PHARMACY AND BIOENGINEERING, KEELE UNIVERSITY, UK

I first started working with synchrotrons to study the artificial materials used in technologies such as computer storage. Over time, I realised that many of the techniques we were using could also be applied to biological materials and, for the past ten years, I have been working with Jo to develop these techniques for the study of metal deposits in brain tissue.

Performing a synchrotron experiment is intense, but it can also be an exciting and rewarding experience. A typical experiment may only last a few days, but over that period we work on a 24-hour rota to make best use of time. I have had many 'Eureka' moments, often in the small hours of the morning, when we have discovered some fundamental new science. In most cases, these breakthroughs would be impossible without access to the state-of-the-art labs and equipment available at a synchrotron.

After initially studying physics, I was based in an Earth Sciences department at a university for some time, studying how bacteria use metals to form magnetic materials on a very small scale. Some of the synchrotron techniques we are now using to study Alzheimer's disease were originally developed from this earlier work trying to understand bacteria.

I had a very good physics teacher at school. They helped me understand physics at a fundamental level and grasp the basic concepts of the subject. I see physics as being very powerful because it overlaps with many other areas of science, from astronomy to Earth sciences to medicine. It also trains you to be both systematic and creative in the way you approach problem solving – which is important in your life outside science, too!

A background in physics gives you incredible flexibility to move into different fields. For example, as a child, I was interested in becoming a doctor, then went down a different route, but due to my training in physics I have ultimately ended up being able to work in medical sciences!

DR JAMES EVERETT

RESEARCH ASSOCIATE, SCHOOL OF PHARMACY AND BIOENGINEERING, UNIVERSITY OF KEELE, UK

In my role as a research associate, I am mainly responsible for co-ordinating and conducting novel experiments. Following the completion of the experiments, I analyse and interpret our results, before reporting our findings in scientific journals, in news articles and at conferences.

We make exciting new discoveries about the brain quite consistently, thanks to the unique chemical and spatial sensitivity which synchrotron techniques offer. For example, we recently discovered extremely small particles of metal iron and copper (approximately 1/10000th the size of a pinhead) in human brain tissue for the first time. Until now, only metal oxide forms had been observed.

The discoveries we make about metals in the brain also suggest new ways to diagnose disease. By using MRI scans to spot iron accumulation in the brain, we may be able to identify people with Alzheimer's at an earlier stage in the disease, in turn allowing us to start treating them sooner.

I chose to study biology because I had a particular interest in how the bodies of humans and other animals work. Whilst at university, I spent time volunteering in research labs, where I had the opportunity to witness some ground breaking experiments in biology, and this work has real potential to improve people's lives. This inspired me to go on to postgraduate biology research.

Biology is an incredibly diverse area, with plenty of room to find a topic where you have a deep interest. I would recommend a career in biology for anyone with an interest in the natural world!

DR JAKE BROOKS

RESEARCH FELLOW, SCHOOL OF ENGINEERING, UNIVERSITY OF WARWICK, UK

One of my roles is to prepare the brain tissue samples before they undergo synchrotron analysis. Since I finished my PhD, I have been a research fellow in the Trace Metals in Medicine group at Warwick, where I spend much of my time doing hands-on work in the Trace Metals Lab. However, I am also a core member of the synchrotron data collection team, regularly participating in experiments at Diamond Light Source.

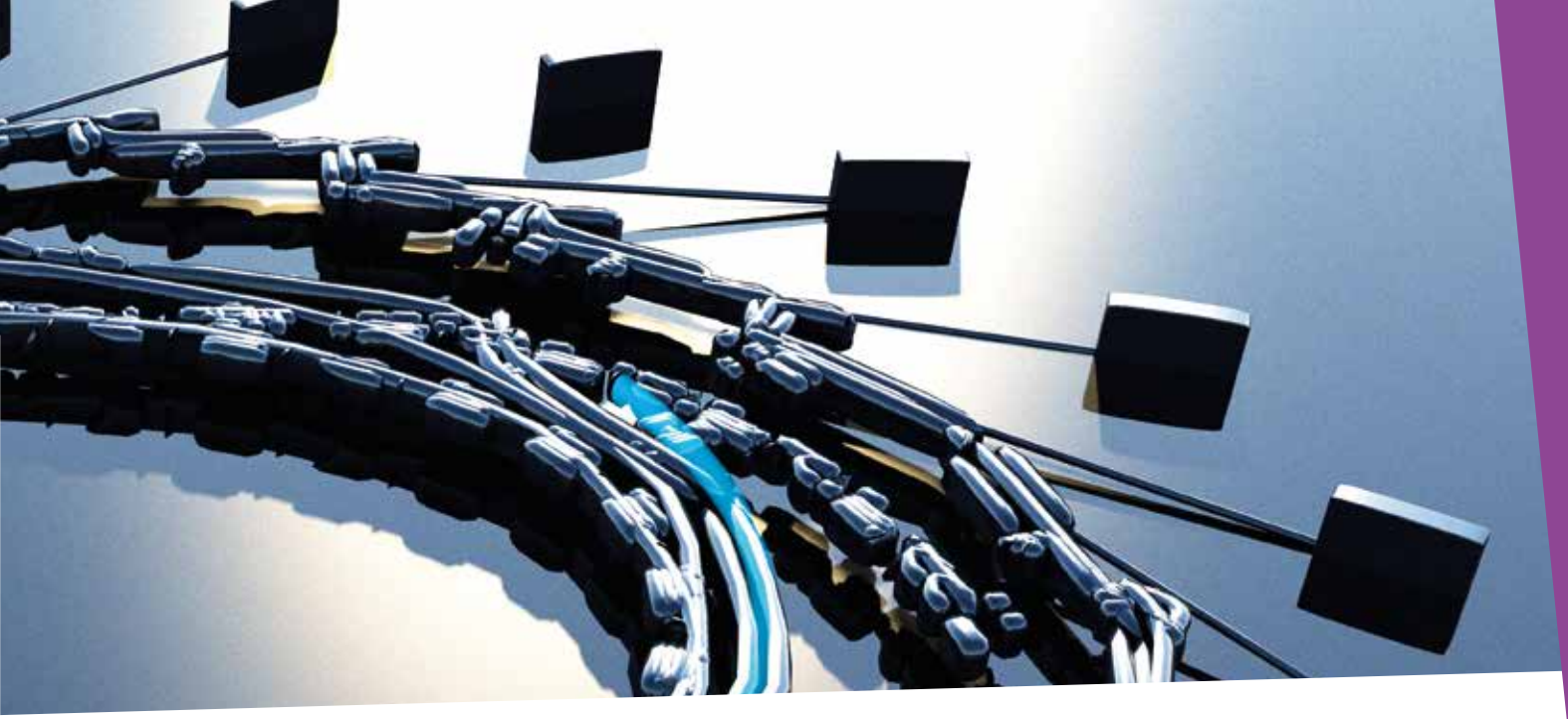
I enjoy learning from more experienced members of the team as we collect data from the sychrotron, sharing in the highs and lows of the experiments. Spending time at a synchrotron facility is also a chance to escape the normal lab environment and experience a change of scenery. The Advanced Light Source near San Francisco in California is particularly scenic, situated at the top of a steep hill overlooking the bay with the Golden Gate Bridge in the distance!

As someone with a background in materials engineering, I am enjoying the process of learning more about neurology. My training equipped me with some fundamental knowledge of microscopy techniques, which I am now applying in a biological context. In my current research, I am particularly interested in the disruption to brain metal chemistry which takes place during Parkinson's disease. With age-related neurodegenerative diseases set to become an increasing problem in the ageing population, I feel there is scope to make a significant impact working in this area.

I have always been fascinated by medicine, even though I didn't study biology or chemistry at A-Level. So, after going to university to study materials engineering, I specialised in biomedical engineering for my PhD.

The skills in microscopy and image analysis, which I was provided with during my materials engineering degree, have proved highly valuable to my current research. You never know where your chosen subject might take you!

I think it is vital that we promote diversity in STEM careers and bring as many different perspectives as possible to tackling some of the world's biggest scientific challenges. I believe it is important that there are no barriers to higher education and that there should always be a pathway for those who wish to follow an academic route.



DR TINA GERAKI

BEAMLINE SCIENTIST, DIAMOND LIGHT SOURCE, UK

My position at Diamond Light Source means I can offer more specialised X-ray expertise as part of the team. This complements Jo's broader focus on the big biological questions we can investigate using our instruments.

It is my responsibility to prepare the instruments, so my role bridges the worlds of engineering, physics and biology.

As a beamline scientist I get to work with visiting scientists from a variety of research areas – so I can learn something new every day! Facilitating the thrill of a new discovery, however small, is a worthy reward for the sometimes long and stressful hours spent chasing photons.

In the past few years, it has been refreshing to see many young scientists and engineers join Diamond Light Source. Our staff are diverse, making Diamond a uniquely exciting place to work.

I originally studied physics at university, then specialised in medical physics for postgraduate studies. During the first year of my PhD, I visited the ESRF in France, and at the end of my three-day visit I knew this was the route I wanted to pursue.

I am still fascinated by invisible particles, but, at the same time, I have developed an interest in biological questions. Finding how to make the two disciplines meet in the most productive way possible is what drives me.

NATALIE ARIGUNDIYA

PHD STUDENT, ANALYTICAL SCIENCE CENTRE FOR DOCTORAL TRAINING (AS-CDT), UNIVERSITY OF WARWICK AND DIAMOND LIGHT SOURCE, UK

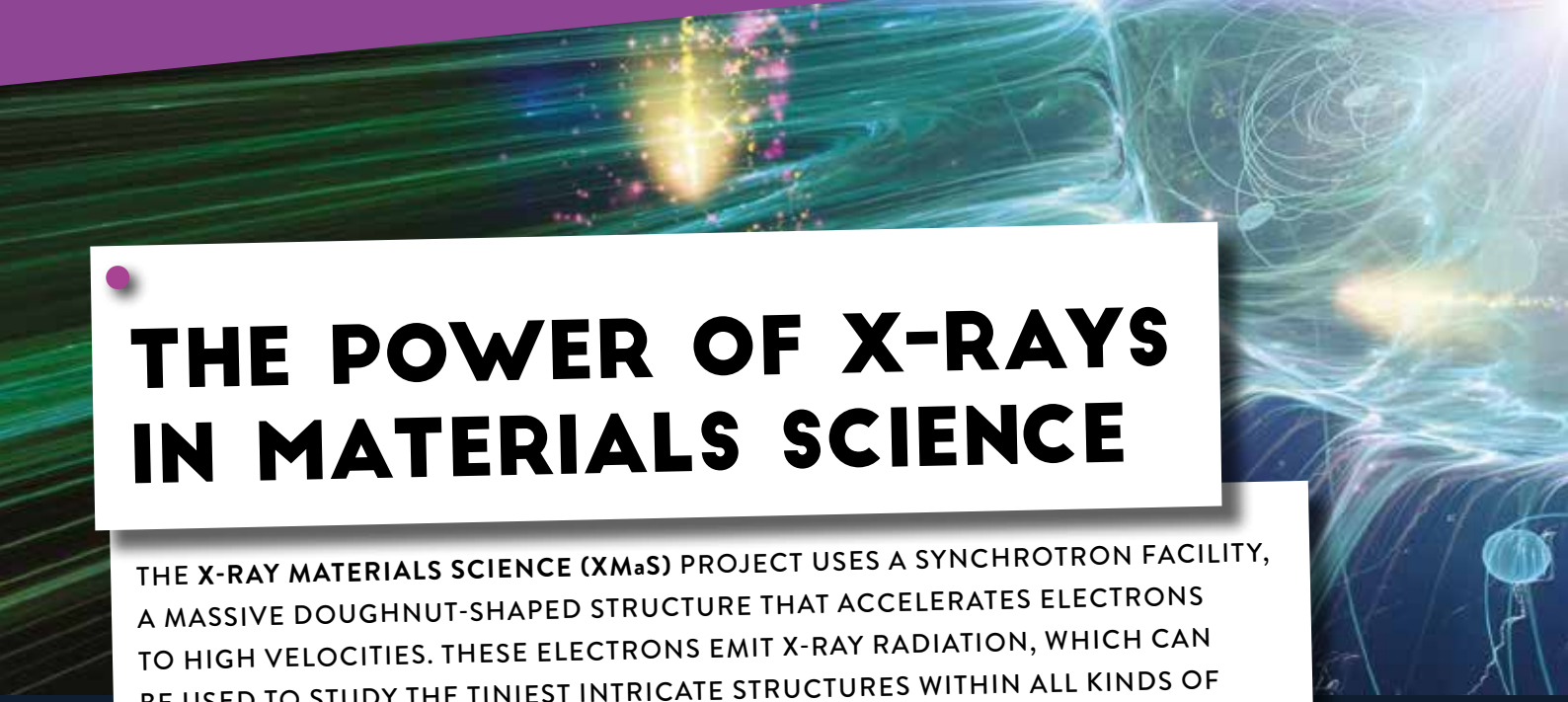
My role in the team is to lead a project to understand a rare form of Parkinson's disease, called progressive supranuclear palsy. I will use the microfocus beamline to map metal element distributions in human brain tissue samples at Diamond Light Source, and I will be supervised jointly by Tina at Diamond and Jo at Warwick.

This research pushes me out of my comfort zone by mixing physics, biology and chemistry. So far, I've been using very standard equipment to address my difficulties and conduct my research. Working at The Diamond Light Source alters all of that, allowing me to work with a more complex set of equipment that provides far greater resolution than typical laboratory microscopes.

Throughout my bachelor's and master's degrees, I became very comfortable in the laboratory setting, which allowed me to hone my problem-solving, data-handling, and communication abilities.

I thoroughly loved studying biomedical science and would strongly recommend it. Biomedical science helped me discover where my interests were. My studies in cellular biology, neurology, molecular genetics, immunology, anatomy and virology enabled me to explore many routes before deciding on what I wanted to specialise in.

There are plenty of careers that you may have not heard off. For those reasons going to careers fairs and networking is very beneficial. More often than not, networking often gets you in the door.



THE POWER OF X-RAYS IN MATERIALS SCIENCE

THE **X-RAY MATERIALS SCIENCE (XMaS)** PROJECT USES A SYNCHROTRON FACILITY, A MASSIVE DOUGHNUT-SHAPED STRUCTURE THAT ACCELERATES ELECTRONS TO HIGH VELOCITIES. THESE ELECTRONS EMIT X-RAY RADIATION, WHICH CAN BE USED TO STUDY THE TINIEST INTRICATE STRUCTURES WITHIN ALL KINDS OF MATERIALS. WHAT DOES THIS MEAN FOR SOCIETY AND OUR FUTURE?

GLOSSARY

EUROPEAN SYNCHROTRON RADIATION FACILITY (ESRF) - a synchrotron research facility in Grenoble, France

SYNCHROTRON – a machine that accelerates electrons inside a circular ring to speeds close to the speed of light and bends their paths using magnets. As the electrons are accelerated along a curved path, they emit electromagnetic radiation whose energy spectrum is proportional to the speed of the electrons

X-RAY – a form of high-energy electromagnetic radiation

BEAMLINE – there are three definitions of a beamline: 1) a physical space within the ESRF's experimental hall, consisting of an optics cabin, an experimental cabin and a control cabin; 2) equipment that brings the X-ray beam to the material being studied and records the findings; 3) a research space in which experiments are done in collaboration. For a more detailed explanation, visit: **www.esrf.fr/about/synchrotron-science/beamline**

BLUE SKY RESEARCH – also known as blue sky science or fundamental research, this is driven by curiosity and the outcomes or practical impact are uncertain. However, the blue sky research of 100 years ago underpins the whole of modern technology and scientific research

DIFFRACTION – the way that electromagnetic waves (at the ESRF, X-rays) bend and interfere when they encounter a particular obstacle

ELECTRON – a subatomic, negatively charged particle

SCATTERING – in physics, this is where an electromagnetic wave (at the ESRF, an X-ray) changes its path or direction when encountering physical objects like atoms

SPECTROSCOPY – the study of the absorption and emission of light and other radiation by matter. It strongly depends on the energy (or wavelength) of the radiation and includes the study of the interactions between particles, such as electrons, protons and ions, as well as their interaction with other particles. See **www.britannica.com/science/spectroscopy**

XMaS – a research facility based at the ESRF that supports the UK materials science communities and is funded by the Engineering and Physical Sciences Research Council (EPSRC): **www.ukri.org/councils/epsrc/facilities-and-resources/find-an-epsrc-facility-or-resource/**

On the edge of the city of Grenoble in the French Alps can be found a huge ring-shaped structure. This is the European Synchrotron Radiation Facility (ESRF), designed to accelerate electrons to extremely high speeds. When these high-energy electrons change direction, thanks to magnets within the ring, they emit electromagnetic radiation which, due to the speed of the electrons, results in many high-power X-rays being produced. These X-rays are directed into structures off the main ring, called beamlines, and are used in experiments. Each beamline is configured slightly differently and targeted at specific scientific research areas.

"The 'acceleration' within the storage ring is not to make the electrons go faster (like a car entering a highway), but to bend them in a circular trajectory, like the acceleration, or force (F = m a), you feel when you take a sharp turn in your car," explains Dr Didier Wermeille, who is based at the ESRF. "It is the acceleration of the electrons (the bent trajectory of a charged particle) that produces the X-rays we use."

Researchers from across Europe use the X-rays to shed light on the position and motion of atoms in any substance of interest, like a 'super-microscope'. Why is this exciting? Well, synchrotrons can help scientists explore the structures of both inorganic and organic substances in fine detail. For instance, they have revealed the structures of proteins and viruses, helped develop more efficient catalysts and batteries, and identified the chemical states of heavy elements such as uranium.

"Modern technologies are underpinned by advances in our knowledge and function of the materials of which they are made," says XMaS Co-Director, Professor Tom Hase. "In many cases, researchers are trying to understand

the correlation between a material's useful properties and its structure. This information can help us make better and more efficient devices and materials." Given that materials behave differently under certain conditions, this involves creating complex sample environments to test their properties under realistic operating conditions.

THE XMAS BEAMLINE

Each beamline at the ESRF is home to a particular research team who uses the X-rays produced by the synchrotron for their own areas of research. One such beamline hosts the XMaS (X-ray Materials Science) research project, which is run by two UK universities. Tom directs the project from the University of Warwick, alongside Professor Chris Lucas from the University of Liverpool. "It is our job to oversee, monitor and manage this multi-million-pound project," says Tom. "This includes both overseeing the research and ensuring the project remains within budget."

On the ground, the XMaS beamline is run by a multinational team of four scientists who support and help users to tackle a wide range of scientific challenges. "Our research involves scattering, diffraction and spectroscopy," says Didier, who is known as the 'Beamline Responsible'. "I facilitate these experiments, supervise technical upgrades to the beamline, organise the team, liaise with the ESRF's wider facility, and take care of health and safety."

Indeed, if high-powered X-ray radiation encounters living organisms, it can be very harmful – but this is not an issue at the ESRF. "The X-ray beam and all equipment and samples are contained in lead-lined, interlocked rooms called hutches, through which no radiation can escape," says Didier. "Radiation levels can get dangerously high within these rooms, but strict operational safety protocols make it impossible for any person to be in there when the beam is on."

SYNCHROTRON HISTORY

Synchrotrons have been around in some form for over half a century. They have helped scientists of many disciplines make grand strides in their knowledge, using X-rays to examine the structures and behaviour of minute and hidden objects. "Synchrotrons can produce much more intense sources of X-rays compared to conventional lab-based equipment," says Tom. "This means that experiments can be performed incredibly quickly. It also means that it's possible to perform experiments that otherwise would be inconceivable."

The ESRF was built in 1989, first used in 1994, and world-leading in its capabilities. "The ESRF was built by a consortium of European countries, including the UK, but competition for its use was inevitably fierce," says Tom. "It was decided to allow individual nations to add their own user facilities, or beamlines, onto the ESRF, and the UK managed to secure a place." The negotiated deal means that the XMaS beamline is dedicated to UK-led science for two-thirds of the time. Other international ESRF researchers can also use it in the remaining time available.

INTERDISCIPLINARITY AND COLLABORATION

Though the XMaS beamline principally investigates materials science, this does not mean the research exclusively involves materials scientists. "Materials science can be a surprisingly broad term," says Tom. "At XMaS, we have embraced dental researchers studying hierarchical teeth structure, and scientists investigating the decay of museum artefacts such as the Mary Rose, which was King Henry VIII's war ship, or baroque organ pipes. We often work at the interface between disciplines, exploiting advances in one scientific area to impact others."

Currently, XMaS is investigating energy-related issues, including the behaviour of catalysts, the operation of batteries, and the photovoltaics used in solar panels. The findings could assist the transition to clean energy, which is needed to help mitigate climate change. Excitingly, these energy-related projects are working alongside blue-sky research, too. "There are studies taking place into unusual magnetic materials, which might one day have some practical use," says Didier. "There is also research into substances with zero electrical resistance and this could have great commercial applications if they can be made to operate closer to room temperature."

As a pan-European facility, the ESRF (and XMaS) is a vital hub for attracting cutting-edge research and the finest minds from across Europe. "The best science emerges when the brightest scientists meet and discuss what they are doing," says Tom. "These conversations can help stimulate new ideas and approaches that would not have emerged if they were working in isolation, leading to productive collaborations."

TACKLING SOCIETY'S GRAND CHALLENGES

Much of the equipment at XMaS is expensive to replace, but after 10-20 years of use, XMaS has been upgraded. "The ESRF was updated to produce higher-brilliance X-rays, which meant it was time to update the equipment on the XMaS beamline," says Didier. "This means we can investigate materials and matter in much finer detail and at an even faster pace. And now there is room for more scientists!"

As Tom goes on to explain, this step-change will enhance XMaS's capabilities for the next influx of researchers: "XMaS enables UK scientists to do experiments at the forefront of international science. The young students and researchers being trained on the beamline now will become research leaders in time, tackling the greatest challenges our society faces."

PROFESSOR TOM HASE

XMaS Co-Director, Department of Physics, University of Warwick, UK

DR DIDIER WERMEILLE

XMaS Beamline Responsible, European Synchrotron Radiation Facility (ESRF), France; Department of Physics, University of Liverpool, UK

FIELD OF RESEARCH

Materials Science

RESEARCH PROJECTS

Using high-powered X-rays to investigate the minute properties and behaviour of a range of materials under different conditions

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

MEET SOME OF THE RESEARCHERS USING XMaS

PROFESSOR MAISOON AL-JAWAD

PROFESSOR OF BIOLOGICAL PHYSICS AND BIOMINERALISATION, SCHOOL OF DENTISTRY, UNIVERSITY OF LEEDS, UK

I am interested in how teeth and bones grow; what happens to their structure when they are broken or damaged; and how we can design better ways to repair or replace them when damaged.

I carry out 2D synchrotron X-ray diffraction and X-ray fluorescence experiments at the XMaS beamline to study tooth and bone tissues. Teeth and bones are made of soft tissue (a mixture of proteins, water and other biological molecules) and hard tissue (calcium and phosphate ions calcified into a crystalline mineral called hydroxyapatite). Combined, the soft and hard tissues give teeth and bones the properties they need to function correctly.

Bones comprise around 60% mineral and 40% organic molecules, which means they are strong but have elastic properties, so they don't break under load. In contrast, dental enamel (the outer coating of a tooth) is made up of 96% mineral and 4% organic components. This makes enamel hard and resistant to wear, such that your teeth should last a lifetime. The mineral within these hard tissues is organised in a very precise way, from nano-sized building blocks to microscopic bundles of mineral, to a whole macroscopic tooth or bone. This is called hierarchical structure and I am interested in how this hierarchical structure grows biologically.

This process is called biomineralisation and I'm interested in how it can be destroyed e.g., through tooth decay, which breaks down the mineral structure of the tooth enamel, and how it can be restored through careful remineralisation treatments.

XMaS enables us to look in great detail, deep inside tooth and bone samples, to probe structural and chemical features from length scales smaller than a nanometre ($x10^{-9}$ metre), to micron-scale ($x10^{-6}$ metre).

We have found out that, with careful remineralisation treatments, it is possible to restore the complex hierarchical crystal structure of dental enamel when it has been damaged. This is encouraging because we might be able to suggest better ways to prevent tooth decay in the future, which, in turn will save the health service a lot of money.

We have also found that bone from different sites (e.g. skull bone versus limb bone) looks very different at the sub-nanometre and nanometre length scales. This gives us an insight into the role that crystal structure might play in the effects of osteoporosis on bones in later life.

DELVE INTO DENTISTRY AT THE UNIVERSITY OF LEEDS

- Open Wide, a student-led project based at the University of Leeds' School of Dentistry, works with children aged 4-18 and prioritises pupils from backgrounds that are under-represented in dentistry: **www.openwidedentists.co.uk**
- The Dentistry Summer School is designed to give Year 11 and 12 students an insight into life as part of a dental team, and the science behind dentistry: **www.healthsciences.leeds.ac.uk/events/dentistry-summer-school-2021**

PROFESSOR WUGE BRISCOE

PROFESSOR OF PHYSICAL CHEMISTRY, SCHOOL OF CHEMISTRY, UNIVERSITY OF BRISTOL, UK

At XMaS, my team and I have studied how molecules (called surfactants, lipids and polymers) organise at interfaces – surfaces that form the boundary between different matter. This interfacial structural information is important for nanoscience, understanding biological processes, and industrial applications.

Typically, we shine an X-ray beam at the interfaces and the reflected X-ray beam can be analysed to obtain information, such as the thickness, density and packing in the molecular layer at the interface.

XMaS uses the world's brightest light, and we can make use of it to probe buried interfaces that cannot be accessed through other methods. The molecular details of the structures are sometimes surprising, and this helps us advance our understanding of how molecules behave at interfaces.

Beyond scientific curiosity, such knowledge has wide ranging implications. For instance, we have applied our research findings and knowledge to formulate eco-friendly artificial snow, which has been used in many Hollywood films and public events. We are also helping people in industry understand how interfacial molecular layers can be optimised for their functionalities in personal care products and lubricants for future transport.

DISCOVER BRISTOL ChemLabS

- The Bristol ChemLabS Outreach programme engages with teachers, schools and students of all ages: **www.chemlabs.bris.ac.uk/outreach/chemnet**
- Bristol ChemLabS also has a YouTube channel, courtesy of Dr Jonny Furze, which includes teacher training videos: **www.youtube.com/channel/UCD7Gud4DucBvmw_zCTKe70g**
- The Bristol Outreach Project has a website aimed at post-16 students, which showcases the research done at the University of Bristol: **bristoloutreachproject.wordpress.com**

PROFESSOR MARKYS CAIN

TECHNICAL DIRECTOR ELECTROSCIENCES LTD, UK

I have always loved physics and dreamt of running my own research company from a young age. I managed to secure a dream job at the UK's National Physical Laboratory (NPL), setting up a new research group devoted to 'functional' materials. These are materials that have useful sensing or actuation properties. They're sometimes called 'smart materials' because they respond in a useful way to changes in their local environment.

I left NPL and launched my new company, Electrosciences Ltd, in 2015. My main interests are piezoelectric, ferroelectric and other smart/active materials used for medical scanning systems, sonar, haptic touch screen technology, nanometre precision actuators and other sensors for a whole range of industrial applications.

I have collaborated with the wonderful team at XMaS for probably a couple of decades now. My research is centred on the development of *in situ* or operando methods of characterising functional materials. I use X-rays to probe the materials' electrical, dielectric and functional performance. The neat thing is that we have worked out ways of synchronising all these measurements. This is important because we can now start to paint a picture of why a material behaves in the way that it does.

Electrosciences Ltd. works with many industrial companies that are developing new materials or using novel materials in new ways. One example is the use of piezo-materials in the treatment of arthritis. All of these materials benefit enormously from discovering the links between their function and fundamental crystalline structure, as we test them in conditions that match their real applications (stress, temperature, strain, magnetic and electric fields, and so on).

CONTACT INDUSTRIES NEAR YOU

Markys has demonstrated the use of smart materials to a class of 4–5-year-olds, which shows that many companies are dedicated to sharing their work with students and schools. It is well worth contacting companies near you to see what they can offer.

PROFESSOR MARK DOWSETT

EMERITUS PROFESSOR IN PHYSICS, THE UNIVERSITY OF WARWICK, UK

HONORARY FELLOW IN CHEMISTRY, GHENT UNIVERSITY, BELGIUM

Since I was a small boy, I've been fascinated by making things. Back then (in the 1950s) it was Meccano™ cranes, wooden model boats and spaceship interiors inspired by Dan Dare (from *The Eagle* comic). In the 60s, my interest evolved into making real sailing boats, rockets, radio sets and hi-fi. Now, it's scientific instruments!

Through XMaS, I work with Professor Mieke Adriaens from the Electrochemistry and Surface Analysis Group at Ghent University. She and I use XMaS to watch chemical reactions on surfaces in real time: that is, as they happen. We can see intermediate reactions, how reactions start and when they come to an end. We use a special electrochemical and environmental cell (eCell) to watch how surfaces change when they are exposed to gases, in corrosive liquids, or coated with protective coatings.

These experiments are important in a huge range of applications, from the study of contraception devices to the corrosion of metals (especially heritage metals), and the development of protective coatings.

Recently, we had the privilege of working with scientists from the Mary Rose Trust to examine metal artefacts recovered from the seabed over 30 years ago. When objects are taken from the sea they rapidly corrode in air and need immediate special treatment if they are to survive. This is even more important if they're put on long-term display in a museum or used for archaeological study. Using X-ray diffraction, we were able to identify unusual compounds on the surfaces of the metal artefacts, show that their conservation had been very effective, and discover traces of other metals – possibly from the tools used by Tudor metalworkers.

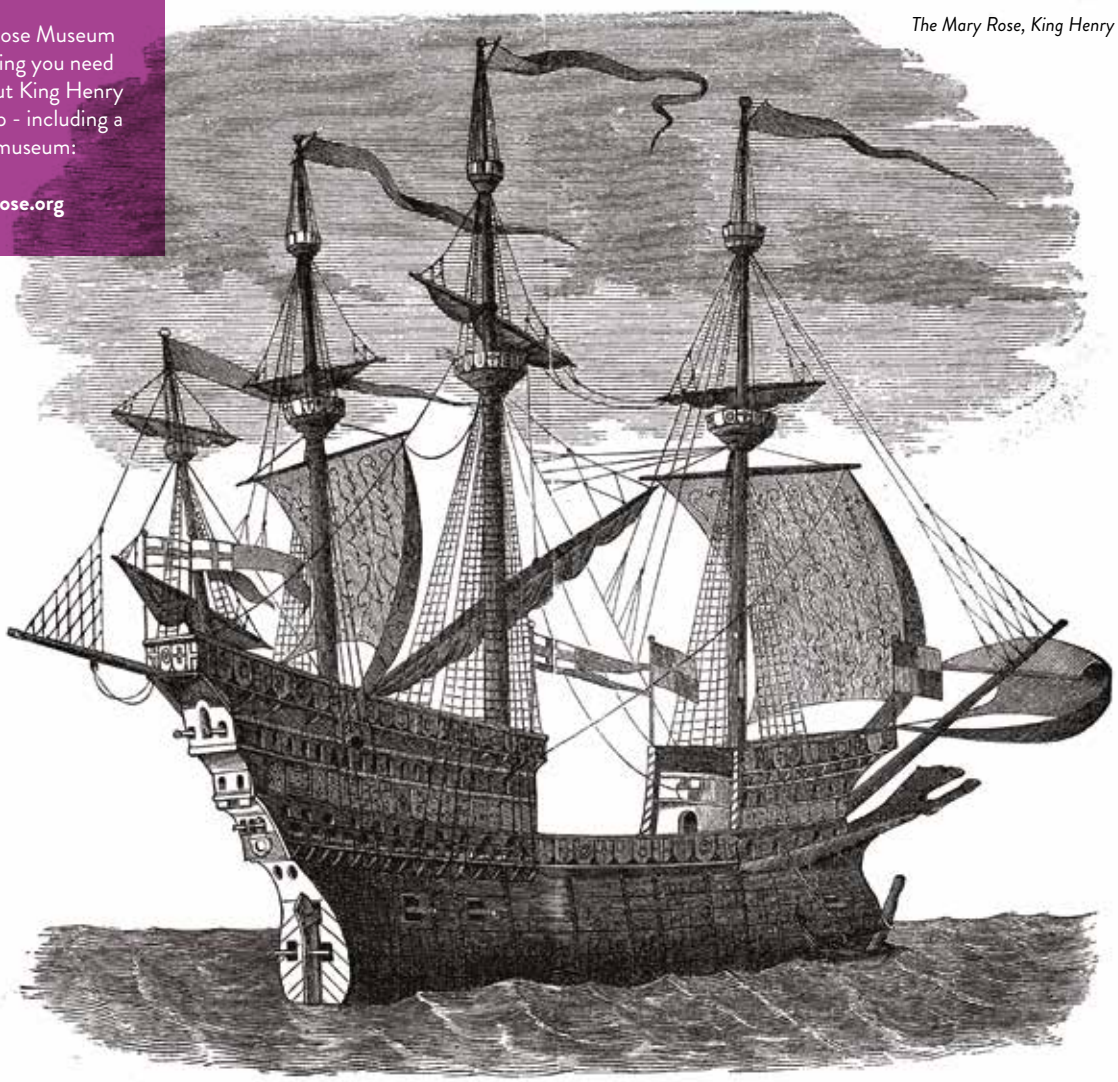
Another study we are involved in looks at the design of less intrusive and more effective intra-uterine devices (IUDs). IUDs, also known as the coil, are used for birth control and release copper in the womb. In a PhD project, we made a version of the eCell to simulate the chemical environment of the uterus and measured the chemical changes on the surface of the copper used to make the device. It's important to know how IUDs actually work before you can improve them!

It's demanding but enormous fun to work on XMaS with the XMaS team. Between us, we have come up with a couple of new instruments to try and, lately, I've also been writing software codes to help other researchers on XMaS analyse their data.

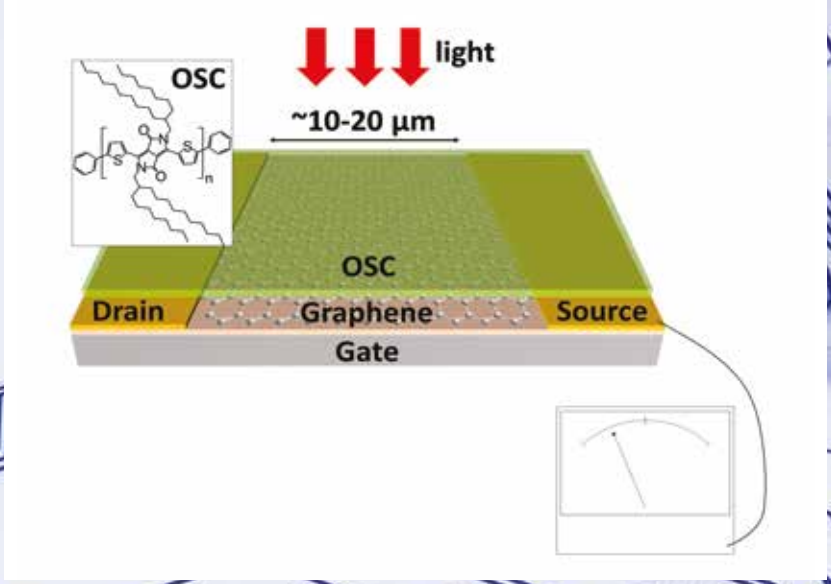
EXPLORE KING HENRY VIII'S MARY ROSE

The Mary Rose Museum has everything you need to know about King Henry VIII's warship - including a virtual museum:

maryrose.org



The Mary Rose, King Henry VIII's war ship



Hybrid photodetector consisting of an organic semiconductor (OSC) on top of graphene. Incoming light gets absorbed by the OSC and causes an electrical signal to be detected.

DR JAKOB KJELSTRUP-HANSEN

ASSOCIATE PROFESSOR, UNIVERSITY OF SOUTHERN DENMARK, DENMARK

DR MATTI KNAAPILA

DEPARTMENT OF PHYSICS, NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY, NORWAY

We are interested in organic electronics, which is a new branch of electronics based on plastic materials. In contrast to most electronic devices today, which are hard and rigid, organic electronics enable devices to be mechanically flexible (bendable and possibly stretchable). These materials could be used to create wearable devices that are integrated into clothing, or stretchable OLED displays that wrap around objects. OLED stands for organic light-emitting diode, which is basically a light source used widely in electronics, like smartphones.

Organic electronic devices are still at an early phase. We develop and study such devices to find out how we can improve these to a level where they can be used in real-world applications.

The plastic materials used for organic electronics consist of microscopic molecules that form a thin layer on a substrate. The performance of the organic electronics component strongly depends on how the molecules are organised on the substrate – the so-called microstructure. Our research at XMaS uses X-rays to characterise the microstructure to better understand how we should fabricate thin layers. Our findings will help us develop organic electronics components that perform well.

XMaS allows us to use very intense X-ray beams and sophisticated detectors, beyond what is possible with small-scale equipment in university laboratories. Using a technique called grazing incidence X-ray diffraction (GIXRD), we can study the features and functions of thin layers; in particular, how the organic molecules are organised when they form thin layers on the substrate.

Our research projects are mostly fundamental and curiosity driven, but the intended impact is to improve organic electronic devices for the future. Our research at XMaS connects us with other researchers who have similar focus areas, which means we can work on exciting collaborations that go way beyond what is possible in individual universities alone.

STUDY AT A UNIVERSITY IN DENMARK OR NORWAY

- Many of the engineering programmes at The University of Southern Denmark and all the master's programmes at the Norwegian University of Science and Technology are taught in English. Students from all over the world are welcome.

www.sdu.dk/en/uddannelse/ingenioer

www.sdu.dk/en/uddannelse/moedsdu/studerende_for_en_dag/ingeniorstuderendeforendag

www.ntnu.edu

DR PETER WELLS

ASSOCIATE PROFESSOR, SCHOOL OF CHEMISTRY, UNIVERSITY OF SOUTHAMPTON, UK

GEORGE TIERNEY

PHD STUDENT SCHOOL OF CHEMISTRY, UNIVERSITY OF SOUTHAMPTON, UK

The main focus of our research is the study of catalytic processes. Catalysis underpins vast aspects of modern society: it is essential for transportation, the production of food, the development of active pharmaceuticals, and many other important industries. Furthermore, new catalytic technologies are essential as we transition towards a net-zero carbon future.

A catalyst promotes chemical transformations by lowering the energy input required, whilst not being consumed in the process. However, there is a significant distinction between not being consumed and remaining unaltered.

Our projects at XMaS focus on two major strands: i) the upgrading of waste plant matter (i.e., biomass) to useful products, and ii) automotive exhaust after-treatment applications for clean air.

Many current chemical commodities – that are needed for our material world – are based on fossil resources. However, there is a need to develop a new supply chain, based on recycling waste material into useful chemical building blocks. Here, waste biomass is a plentiful and renewable feedstock. A feedstock is any renewable, biological material that can be used directly as a fuel, or converted to another form of fuel or energy product.

NOx emissions from diesel cars contribute globally to many premature deaths. For exhaust after-treatment, we have been investigating the role of palladium (Pd) nanoparticles for the selective oxidation of ammonia – by selective, we mean to only produce the benign products of nitrogen and water.

Our results on supported nanoparticle catalysts that were measured at XMaS are very exciting. The work on ammonia oxidation confirmed the presence of a type of Pd structure that had not been reported previously. This interstitial Pd nitride structure – where N sits within the voids of the metallic Pd sponge – had a very important role in stopping the formation of harmful NOx products.

Whilst there are large numbers of papers that discuss catalyst design, very few of them provide an understanding to how these remnants from catalyst preparation influence catalyst operation. By using XMaS, we have been fortunate to add to the growing understanding of how minority components, not removed during catalyst preparation, can play a crucial role in the functioning of catalysts.

VISIT SOUTHAMPTON UNIVERSITY - OR GET A RESEARCHER TO VISIT YOUR SCHOOL

Southampton University offers an extensive programme of outreach activities for all ages:
www.southampton.ac.uk/chemistry/outreach/index.page

Contact a university near you to find out if it offers similar experiences.

The X-rays are delivered to the beamline in a lead covered vacuum pipe to ensure no radiation escapes and to protect people!

The XMaS diffractometer on which the samples are placed and moved. The scattered X-rays are recorded by movable detectors, which look at the sample. The bottom arm is a 2D area detector and the top arm is a high resolution point detector.

The incident X-ray tube uses highly polished and bendable silicon mirrors, which are over one metre long.

BE PART OF THE XMaS SCIENTIST EXPERIENCE AND MORE...

XMaS is committed to training students and early career researchers and, as such, has a wide range of outreach activities to fulfil this goal. "Students are our future, the next generation of X-ray scientists," says Tom. "Moreover, they often have exciting new ideas to offer us, meaning we benefit from the interaction as well as providing students with a unique training experience."

The students who will become the next generation of materials scientists are not only those doing research degrees, but also undergraduate and school students. The **XMaS Scientist Experience** is a UK competition for Year 12 female physics students to win an all-expenses-paid four-day trip to the ESRF. "The competition is designed to encourage female students into scientific careers where they are seriously under-represented," says Tom. "Winners get the opportunity to visit the ESRF, see synchrotron beamlines in action, take part in lab experiments, and talk with successful female scientists." The competition involves completing an assignment on the achievements of a leading female scientist. For more information, visit: **warwick.ac.uk/fac/cross_fac/xmas/impact/outreach/xmas_scientist_experienceb**.

The XMaS team at the University of Warwick organises a **Science Gala** every year. "The Gala showcases all physics, from astronomy to particle physics, as well as materials science," says Tom. "There are activities suitable for ages 6-18, all with the message that science is fun and exciting and can lead to a wide range of careers." More information can be found at: **warwick.ac.uk/fac/cross_fac/xmas/impact/outreach/sciencegala**.

The XMaS team and the latest research findings can be found on the XMaS website: **www.xmas.ac.uk**. The Twitter page also provides an insider view into the XMaS beamline: **twitter.com/XMaSBeam**.

Accessing XMaS through the website and Twitter is a great way to keep up to date with outreach activities that might interest you.

The XMaS team is part of a wider ESRF network, which also offers its own range of outreach activities. This includes site visits for schools, internships and summer schools, and the **Synchotron@School** programme, a one-day programme of experimental workshops and site visits for high school students. Visit the ESRF website: **www.esrf.fr/home/education.html**

The ESRF sits within the EPN campus, an international science hub in the French city of Grenoble. The institutions within the campus have a wide range of career opportunities, from core science to administration, outreach, publications, and many others. Site visits can often be arranged. If you want to learn more, visit: **www.epn-campus.eu**.

PATHWAY FROM SCHOOL TO MATERIALS SCIENCE

Materials science is a broad-ranging subject based on investigating and manipulating the properties and behaviour of different artificial and natural materials. This involves understanding the physics and chemistry of matter, and the manufacturing and engineering of materials.

At school, key subjects to take to prepare for a degree in materials science include physics, engineering, mathematics and chemistry. Other scientific subjects such as computer science and biology could also prove useful. As Tom says, "Many people do not start out as material scientists. A 'materials scientist' can cover a multitude of disciplines; it's really about working at the interface between different subjects and understanding how fundamental processes work in real systems."

Career Explorer offers a good explanation of what a materials scientist does, including the salary range (in US dollars): **www.careerexplorer.com/careers/materials-scientist**

"The good news is that the materials industry is well-regarded as it contributes £200 billion each year to the UK economy," says TheUniGuide, which gives a great introduction to studying materials science at the university level: **www.theuniguide.co.uk/subjects/materials-science**

Prospects provides a list of careers open to graduates with a degree in materials science: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/materials-science-and-engineering**

WHAT DID HUMAN COMMUNITIES LOOK LIKE 20,000 YEARS AGO?

MUCH OF THE EVIDENCE OF PAST HUMAN ACTIVITIES HAS PERISHED OVER TIME – WHICH IS WHY THE WORK OF **DR LISA MAHER**, AT THE **UNIVERSITY OF CALIFORNIA**, AND **DR DANIELLE MACDONALD**, AT THE **UNIVERSITY OF TULSA**, IN THE US, IS EXTREMELY IMPORTANT. USING ARTEFACTS LEFT BY HUMANS LIVING 20,000 YEARS AGO, THEY ARE GIVING US AN INSIGHT INTO HOW ONE OF THE EARLIEST SOCIETIES LIVED

TALK LIKE AN ARCHAEOLOGIST

ARCHAEOLOGY – the study of past human activity through excavation and analysis of material artefacts and their associated contexts

ARTEFACT – an object made by humans at a certain point in time, which indicates how they lived and interacted

AUROCH – a form of cattle

EPIPALAEOLITHIC – a prehistoric period occurring during the Old Stone Age, 20,000-10,000 years ago, when humans existed as hunter-gatherers

EQUID – an animal of the horse family

FAUNA – the animal life present in a region or time

HUNTER-GATHERER – a human lifestyle where food is obtained primarily through foraging, fishing and hunting

JORDAN – a country in Western Asia

KHARANEH IV – an archaeological site in Jordan, containing evidence of human activity in the Epipalaeolithic

LITHIC – a chipped stone tool and its associated debris, often used for hunting, scraping and cutting

NEOLITHIC – the period directly after the Epipalaeolithic, 10,000-4,500 years ago, when modern humans began farming practices and domestication of animals

MATERIAL CULTURE – items made and used by humans in the past and present that can represent how people live, including their worldviews

SEDENTISM – living in one place for a long period of time (as opposed to being nomadic)

Life was very different for human societies 20,000 years ago. Humans hunted animals for food and had just started living in settlements. Unfortunately, very little evidence from this period exists. Archaeologists rely on the artefacts found from these times, such as stone tools, animal bones and human remains, as well as the contexts within which these artefacts were made, used and discarded (or lost), to reconstruct the past.

These items often concentrate in prehistoric sites where humans spent time; the longer they spent there, the greater the quantity and diversity of material cultural that can be found. One such site, Kharaneh IV in eastern Jordan, has been studied by archaeologists Dr Lisa Maher and Dr Danielle Macdonald, at the universities of California and Tulsa, where they discovered multiple 20,000-year-old hut structures alongside other archaeological remains. Their studies indicate this area was intensively occupied by hunter-gatherers, who were responsible for the birth of architecture in the region.

A REVEALING SITE

Today, Kharaneh IV is situated in a barren desert. However, during the last Ice Age, eastern Jordan was populated with rivers and wetlands, creating a perfect environment for hunter-gatherers to settle in. Large numbers of people congregated here for prolonged periods of time. This attachment to location, and introduction of social networks within Kharaneh IV and connecting it to other nearby sites, is normally associated with cultures living thousands of years later.

For this reason, Kharaneh IV is the densest and largest Epipalaeolithic open-air site in the region. Over 4 million lithics have been excavated over the last 15 years and animal remains have been extracted in similar numbers. Lisa and Danielle have collected over 4,000 marine shells, brought to the site from the Red and Mediterranean seas, over 250 km away. "The team has even recovered rarer items, such as bones with regularly incised lines and a fragment of limestone with geometric carved patterns," says Lisa. This points to complex interweaving of social, symbolic and ideological behaviours with everyday activities at the site.

EXCAVATION AT KHARANEH IV

Lisa and Danielle's team start work as soon as the sun rises, around 4:45 am, excavating during the cooler morning. In the afternoon, when temperatures exceed 40 °C, lab work takes place. Ancient plant remains are separated from other artefacts using a water flotation system. Artefacts are also washed, sorted and analysed.

The most common artefacts found by the team are small, blade-like and trapezoid-shaped microliths, a type of stone tool. Comparing microscopic traces on lithics to archaeological tools, Danielle and Lisa think these were used by communities in the Epipalaeolithic for a variety of tasks, such as hunting, whittling wood and butchering animals. The lithics changed shape during the time the site was

occupied, as more of the landscape was explored and new materials became available. "This allowed them to use more aesthetically beautiful raw materials, like purple and pink cherts," explains Danielle.

Faunal data also shows what the occupants of Kharaneh IV were eating. Evidence of aurochs, equids, foxes, birds and tortoises was found, but around 90% of the faunal assemblage is composed of gazelle bones. Faunal specialists working with Lisa and Danielle can tell how animals were cooked by their findings. "There is evidence people were smoking and drying meat in the later phase of occupation," says specialist Anna Spyrou. Evidence was found of fire pits surrounded by small post holes, too small for an architectural structure. "We interpret these to be the remains of drying racks, where strips of meat would have been hung to smoke over the fire," she adds.

THE IMPORTANCE OF ARCHITECTURE

Lisa and Danielle have fully excavated two hut structures, about 2-3 metres in dimension, with foundations dug into the ground. The walls and roof were made of brush and thatch over wooden frames, with earthen floors covered in grass and reed mats. After the huts were abandoned, they were burned and their remains sealed in sand. It appears this was intentional, as burnt piles of gazelle horn cores, clumps of red ochre pigments, and hundreds of marine shells were found inside.

The team can identify if the burning was intentional by the footprint the fire leaves. Burning is normally confined to the boundaries of the structure, with other features outside this area remaining unaffected. The intentional burning of structures appears to be a pattern throughout Kharaneh IV. The two structures display a similar sequence of construction, use and destruction. There is also evidence of human remains inside one of the huts. "As far as we are aware, this is the first known instance of the dead being placed within a structure that was intentionally burned," says Lisa.

How humans treated their deceased relatives is hard to study, as the evidence of burnt structures with human remains inside is uncommon. "We know the woman found in the hut was intentionally placed there shortly after her death," Danielle explains. "Analysis by human osteologists Jay Stock and Emma Pomeroy conclude that the completeness of the skeleton indicates she was placed on the floor prior to decomposition, where she was wrapped in a covering or buried in sand, dampening the effect of the fire." It appears the fire burned fast and hot, consuming the organic framework, but only partially cremating her remains.

This displays an early link between architecture and burial of the dead. Lisa and Danielle believe the woman may have been cremated in the structure because it belonged to her or was no longer habitable to anyone in the community. This ceremony connects the life history of a person to the life history of a building. "It may be that the burning of these structures was commemorative, marking both death and transformation, and a fresh start for the living," says Danielle.

HUMAN SOCIETIES

"The more we look, the earlier we find evidence for the complex social, technological, economic and ideological lives of past peoples," Lisa explains. Features traditionally used to define the Neolithic – domestication, elaborate art, sedentism, long-distance exchange networks – are appearing earlier in the prehistoric record. Rather than a rapid Neolithic 'revolution', it seems there was an extended transition from the Epipalaeolithic to Neolithic.

Instances of hunter-gatherers building structures, creating communities, and burying their dead are still rare in the Epipalaeolithic. "Many of the burial practices we see hint at practices that become more common during the Neolithic," explains Lisa. "But, we may find these exist even earlier if we continue to excavate these sites."

WHAT IS NEXT?

Although many artefacts have been collected from Kharaneh IV, this only represents about 0.05% of the total present at the site. Lisa and Danielle still have a new hut structure to excavate and they want to answer questions relating to the shift towards more communal living at later stages, and how this relates to the major climate changes documented in the region.

Using their marine shell and lithic knowledge, they also want to understand how far networks stretched. They are studying sites in the surrounding regions, such as Azraq, as well as those further afield in Cyprus, to understand the extent of hunter-gatherer movement before agricultural village life. "We are definitely interested in continuing working at the site, especially with an incredible international team of specialists and well-trained, bright students," says Lisa.

DR LISA MAHER

University of California, Berkeley, USA

FUNDERS

US National Science Foundation (NSF), National Endowment for the Humanities, Social Sciences and Research Council of Canada, National Geographic Society, Wenner-Gren Foundation, Arts and Humanities Research Council of Britain, Council for British Research in the Levant, American Center for Overseas Research, Hellman Fund, University of California, Berkeley

FIELDS OF RESEARCH

Prehistoric Archaeology and Geoarchaeology

DR DANIELLE MACDONALD

University of Tulsa, USA

FUNDERS

US National Science Foundation, National Endowment for the Humanities, Arts and Humanities Research Council of the UK (AHRC UKRI), The University of Tulsa

FIELDS OF RESEARCH

Prehistoric Archaeology and Anthropological Archaeology

JOINT RESEARCH PROJECT

Investigating how early hunter-gatherer communities lived and interacted, through analysis of artefacts from the Kharaneh IV site in eastern Jordan

ABOUT PREHISTORIC ARCHAEOLOGY

Prehistoric archaeology is the study of the human past, before historical records began, and allows us to connect with those who lived in a completely different time and place. "The experience of uncovering something that has not been seen or thought about for thousands of years is exciting," says Lisa. We rely on material remains and belongings to understand how people lived in the past. "It's a giant puzzle that has no right answer; our understanding changes every time we collect new data, or use a new theory to interpret the past," says Danielle.

Lisa and Danielle agree that working with local communities is an important part of archaeology. The experience of returning to the same villages every year gives a different experience from that of a tourist and provides a reminder of the diversity of people around the world. "These places become a second home; you become part of a new community," says Lisa. "The connections built with the past and present are invaluable."

Danielle highlights the importance of working alongside a team of international archaeologists. "It's a rare chance to be with a community of people who have a similar love of the ancient past," she says.

However, being away from home for months at a time presents a challenge. Although Lisa's partner is also an archaeologist, she now has a young family, which means travel is more limited in scope and duration. Danielle also experiences this problem but says this is easier now their dig house has an internet connection.

EXPLORE A CAREER IN PREHISTORIC ARCHAEOLOGY

There are national organisations, with information and resources for students who are interested in learning more about the past. These include the Society for American Archaeology (**www.saa.org**) and the American Anthropological Association (**www.americananthro.org**).

The University of Tulsa runs a programme called the Tulsa Undergraduate Research Challenge (TURC): Junior Program. This brings high school students into the lab during summer, where they work alongside faculty and graduate students to help with data collection and analysis: **utulsa.edu/research/turc**

LISA AND DANIELLE'S TOP TIP

Be curious and proactive. While you are in school, reach out to your local archaeological society and attend lectures, workshops and dig schools. When you go to university, contact professors and ask if they have any volunteer opportunities in their lab. You will be surprised how many professors are thrilled with having an extra set of hands to help with analysis!

PATHWAY FROM SCHOOL TO PREHISTORIC ARCHAEOLOGY

Archaeology and anthropology encompass a wide range of disciplines. To do a degree in either, a foundation in history or sociology is a good start. These will teach you to engage with human cultural diversity through different lenses.

Lisa highlights geology as a good foundation. "Geography allows you to connect geographic information systems (GIS) and remote sensing with archaeology, and biology is good if you want to go into biological anthropology," she adds. Other useful subjects include sciences, maths and English.

You can combine archaeology with other courses at university. For example, psychology can address questions about the evolution of modern human behaviour.

MEET LISA

I have always been interested in the past and puzzling over what the material traces of past people can tell us about their lives. As a high school student, I had a history teacher who thought that everyone should become an archaeologist. His classes were so engaging and my hand would ache after each class from taking notes!

I completed my degree at Lakehead University, in northern Ontario, and dug for the first time on the west coast of Canada. I finished my PhD at the University of Toronto, where I experienced fieldwork in Jordan for the first time and was hooked. After a post-doc and research position at the University of Cambridge, I joined the Anthropology Department at Berkeley as an environmental archaeologist. Focusing on reconstructing human-environment dynamics, I have been running archaeological projects in Jordan for over twenty years. I have also worked in many other countries throughout the world, and recently broadened my horizons to explore island archaeology and the arrival of humans in Cyprus and Hawaii.

As an undergraduate student, I was often the only woman in my geology classes, and the only one combining archaeology and Earth sciences. I am committed to diversity in the archaeological sciences and hope to promote opportunities for women and other underrepresented groups on campus and in the various places where I conduct field research. In Jordan, archaeology is an underrepresented and underpaid profession. We want to contribute to training future generations of Jordanian archaeological scientists, for whom professional training opportunities are traditionally limited. Being a female professional archaeologist in Jordan is a challenging career path.

I love what I do because prehistoric archaeology matters in today's world! There are important lessons to be learned from how we interacted in the past. Humans have a complicated and branching evolutionary and social history. If I have learned anything from recent global events and ongoing social movements, it is that the past has much to tell us and teach us. Knowledge about the past is enlightening; it provides a way forward, a way to connect people, initiate conversations, and provide tools for change today and moving forward.

MEET DANIELLE

I always wanted to become an archaeologist! I grew up in Toronto, Canada, and my parents would take me to the Royal Ontario Museum. I was fascinated by the Egyptian collections, the mummies and the dinosaurs. I knew that I wanted to study the past and enrolled in archaeology courses once I started my undergraduate degree.

Both my aunt and uncle were anthropologists, so I grew up with anthropology around me. They taught at two different colleges in Chicago – my aunt was a cultural anthropologist and my uncle a biological anthropologist. Seeing adults with careers as anthropologists made me realise that I could be one too.

The most important attributes that have guided me through my journey as an archaeologist are curiosity and the desire to learn. Wanting to explore and discover new things keeps me focused and inspired to do research. Archaeology is a process of discovery, and when we learn about the past, we also discover new things about the present, gaining a better understanding of our own relationship with material culture and the world around us.

Spending time away from work is so important! Sometimes, you need some space away from a problem to see it more clearly, or to understand the bigger picture. To switch off, I like to go hiking with my dogs (one of which I adopted from Jordan) and spend time with friends.

THE GREAT DYING: UNPICKING THE PERMO-TRIASSIC EXTINCTION EVENT

252 MILLION YEARS AGO, OVER 90% OF ALL SPECIES ON EARTH WERE WIPED OUT. LED BY **PROFESSOR PAUL WIGNALL** AT THE **UNIVERSITY OF LEEDS** IN THE UK, A TRANSNATIONAL PROJECT INVOLVING BRITISH AND CHINESE RESEARCH TEAMS IS INVESTIGATING THIS COLOSSAL AND ANCIENT CRIME SCENE, ATTEMPTING TO UNDERSTAND THE RELATIONSHIPS BETWEEN SPECIES EXTINCTIONS AND ENVIRONMENTAL CHANGES. THEIR CONCLUSIONS COULD AFFECT HOW WE APPROACH TODAY'S CLIMATE AND BIODIVERSITY CRISIS

TALK LIKE A GEOLOGIST

BIODIVERSITY – the biological variety of an area, from the species to the ecosystem level

ECOLOGY – a branch of biology involving the study of how organisms interact with one another and their environment

ECOSYSTEM – a community of interacting organisms and the physical environment they live in

MASS EXTINCTION EVENT – a period when large numbers of species all over the world are lost much faster than they are replaced during a short period of geological time

PALAEOBIOLOGY – a branch of palaeontology, involving the study of fossil plants and animals

PALAEOBOTANY – a branch of palaeontology, involving the study of fossil plants

PALAEONTOLOGY – the study of prehistoric life

PALYNOLOGY – the study of pollen and spores, especially those in archaeological or geological deposits

PERMO-TRIASSIC EXTINCTION EVENT – also known as the P-T event, End-Permian Extinction or Great Dying. A mass extinction event that occurred around 252 million years ago, that took place from the end of the Permian period and beginning of the Triassic period

PERMIAN PERIOD – a period of geological time from 299 to 252 million years ago, characterised by the formation of the supercontinent Pangaea, the evolution of conifers and the diversification of reptiles

RESILIENCE – the ability of something – such as an ecosystem – to absorb or avoid damage and remain functional

SPOROMORPH – a fossil pollen grain or spore

TRIASSIC PERIOD – a period of geological time from 252 to 201 million years ago, characterised by continental rifts, an increase in diversity following the P-T event, and the appearance of the first dinosaurs and mammals

TRILOBITES – a once-abundant group of marine arthropods that are prevalent in the fossil record but declined before the Permian period and were completely wiped out by the P-T event

In its long and chequered history, the Earth has seen five major mass extinction events – events characterised by a widespread and rapid decrease in biodiversity across the planet. Every one of these has been marked by major changes to the global climate, which has, in turn, decimated ecosystems around the world, leaving relatively few species behind. These species, over time, evolve and diversify to suit the new climate – until the next extinction event comes along.

Though the meteorite impact that led to the extinction of most dinosaurs is the most famous of these events, there was an even more cataclysmic event almost 200 million years earlier, before dinosaurs were on the scene at all. This event marked the border between the Permian and Triassic geological periods, and is known as the Permo-Triassic extinction event, or P-T event for short. This was the largest extinction event of all time.

The ecoPT project involves 22 researchers from across the UK and China, who are collaborating to examine not only what caused the P-T event but also how different types of organism recovered and eventually diversified into many different species once again. "The post-extinction world was highly unusual, recovery in many habitats was extremely slow and it took several million years for the first signs of recovery to begin," says Professor Paul Wignall, who leads the UK side of the project from the University of Leeds. "EcoPT aims to examine how communities began to recover and how ongoing environmental changes may have been involved."

THE BEGINNINGS OF THE END

The Permian period teemed with life. In the ocean, trilobites, accompanied by many other marine invertebrates, had been abundant for millennia. On land, forests and swamps were home to a multitude of plants, fungi, insects and the relatively recently-diverged ancestors of reptiles and mammals. Global temperatures were

PROFESSOR PAUL WIGNALL

Professor of Palaeoenvironments, School of Earth and Environment, University of Leeds, UK

FIELDS OF RESEARCH

Geology, Palaeoenvironments

RESEARCH PROJECT

Investigating the Permo-Triassic extinction event, aiming to understand how organisms and environments recovered

FUNDERS

Natural Environment Research Council of the UK (NERC), National Natural Science Foundation of China (NSFC)

relatively cool and the climate was stable, but this would not last.

Northern Russia contains a vast system of volcanic rock and old lava flows, many now buried or eroded, but estimated to have amounted to several million cubic kilometres when the eruptions that formed them took place. The presence of these rocks, known as the Siberian Traps, points to a series of massive eruption events at the end of the Permian period. "Each eruption likely lasted for a few years and emitted up to a few thousand cubic kilometres of lava," says Paul. "For comparison, a big volcanic eruption today would average at about one cubic kilometre in volume."

These eruptions had a profound effect on the global climate. They emitted vast quantities of carbon dioxide into the atmosphere, which led to global temperatures increasing significantly across several million years. "Annual ocean surface temperatures approached 40 °C – the warmest ocean waters today do not exceed 29 °C," explains Paul. "This disrupted the circulation of ocean waters; oxygen-rich waters near the surface were not carried to the depths. This meant large areas of the ocean became severely oxygen-depleted." On land, weather patterns became increasingly erratic, with periods of intense rainfall and floods followed by long droughts.

JOINING FORCES IN THE FIELD AND LAB

How these environmental changes affected life on Earth forms the crux of ecoPT's research. The assembled team comprises researchers from many different fields who can combine their areas of expertise to build a more complete picture of what the world looked like 252 million years ago. "Geologists study rocks in the field, to understand the composition of ancient sediments," says Paul. "Palaeontologists have the enjoyable task of carefully and systematically collecting fossils, with ancient pollen and spore fossils being especially useful for our work. Geochemists collect rock samples and decipher their chemical traits in the lab. And then, climate modellers use the sophisticated models that have been developed to make predictions about today's climate and weather systems, and modify them to model ancient climates."

Though the project entails a lot of lab and desk-based work, there have been valuable opportunities to collect samples in the field. "Fieldwork has been concentrated in China because there are many Permian and Triassic rocks in the country, and the road-building programme of recent years has led to the uncovering of new rock outcrops to study," explains Paul. "In addition, rocks can also be collected in quarries, from outcrops on hillsides and along streams and rivers." One area in south-west China has proved especially fruitful, containing a 100 km-long 'transect' that 252 million years ago began in a shallow sea, emerging into coastal swamps, and finishing among coastal plains and rivers. This area provides a useful comparison to examine what happened in different environments at the same point in geological history.

DETECTIVE WORK

EcoPT's research has helped piece together the sequence of events that led to the P-T mass extinction. Prior research tended to focus on ancient seas, since their fossil records tend to be more complete and rocks easier to date, compared to land-based environments. Now, however, improved techniques are helping researchers consider all environments as part of the big picture. "The crisis can be seen to have started on land about 252 million years ago, as plants in coastal swamps began to rapidly die off," says Paul. "Extinctions in the sea began tens of thousands of years later – a short period of time for a geologist!" As swamps dried out, wildfires became more prevalent, noticeable through an abundance of charcoal in the fossil record.

Eruptions from the Siberian Traps reached their peak as ocean life began to die off. We know this because sediments show a sudden increase in mercury levels, a heavy metal often present in vapour from eruptions. "As well as providing a tell-tale marker of eruptions in the geological record, mercury is also very poisonous to most life," says Paul. Of the relatively few plant species left on land after the initial extinction phase, many had deformities in their pollen that show up in the fossil record. It is theorised that mercury poisoning could cause these deformities, though it is possible that other environmental changes, such as ozone depletion, were responsible.

"There is still a lot we don't know about how eruptions in Siberia could kill off almost all life on the planet," says Paul. "This isn't surprising, given there are still big gaps in our understanding of the modern climate – how exactly clouds form, for example." Atmospheric scientists are working on filling these knowledge gaps, and their findings will improve understanding of ancient climates, as well as the current one. For geologists, there are always more rocks to analyse, to build a deeper and more precise understanding of what happened all those millions of years ago.

PALAEOBOTANY AND PALYNOLOGY

DR BARRY LOMAX
LECTURER IN ENVIRONMENTAL SCIENCE, UNIVERSITY OF NOTTINGHAM, UK

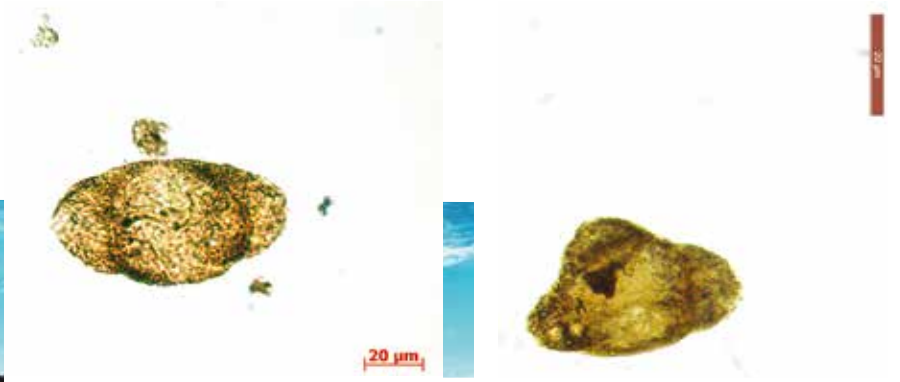
Barry's role on the ecoPT team involves the study of fossilised plants, in particular fossilised pollen and spores. "Plants produce large amounts of pollen and spores, and because of their small size and resilience, they can be found in very high numbers," he says. "They are an ideal fossil to work with if you are interested in understanding past vegetation and how ecosystems responded to periods of dramatic environmental change."

Barry carries out physical and chemical analyses of fossil pollen and spores – collectively known as sporomorphs – to see how their characteristics change at different points in geological time. "During mass extinction events, there is an increase in the abundance of deformed sporomorphs," he explains. "We think that these deformations indicate that the parent plant was stressed. The challenge is to match types of environmental stress to the types of deformation we observe."

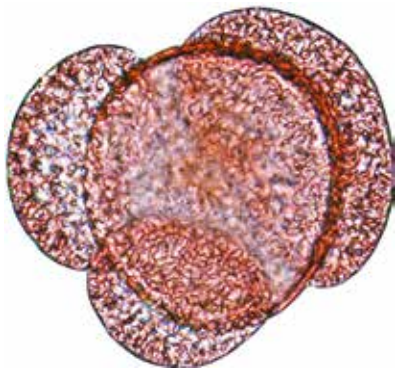
Extracting such tiny fossils from rocks involves the use of acid, to dissolve the surrounding rock until only the fossils remain. The residue is then sieved to remove larger fragments, and the remaining sporomorphs are collected. "Sporomorphs are very small and extracting them can be very frustrating," says Barry. "You need a great deal of perseverance and a steady hand to get your sample." Once extracted, the sporomorphs are examined using a technique called Fourier transform infrared (FTIR) spectroscopy, which is used to give details of their underlying chemical structure.

Sporomorphs are coated in a hardy substance called sporopollenin, which acts as a natural 'sunscreen' to protect pollen grains from the harmful effects of UV, and also helps pollen be preserved in the fossil record. Infrared spectroscopy picks up this compound, telling researchers how much 'sunscreen' is present in the sporopollenin of a pollen grain. "In modern times, when human activities were causing the depletion of the ozone layer, we found that plants were producing more 'sunscreen' within their sporopollenin," says Barry. The ecoPT team believe this effect likely stands true for ancient climates too – so, if they find fossil pollen with high amounts of these 'sunscreen' compounds, chances are they were produced in an ozone-depleted environment.

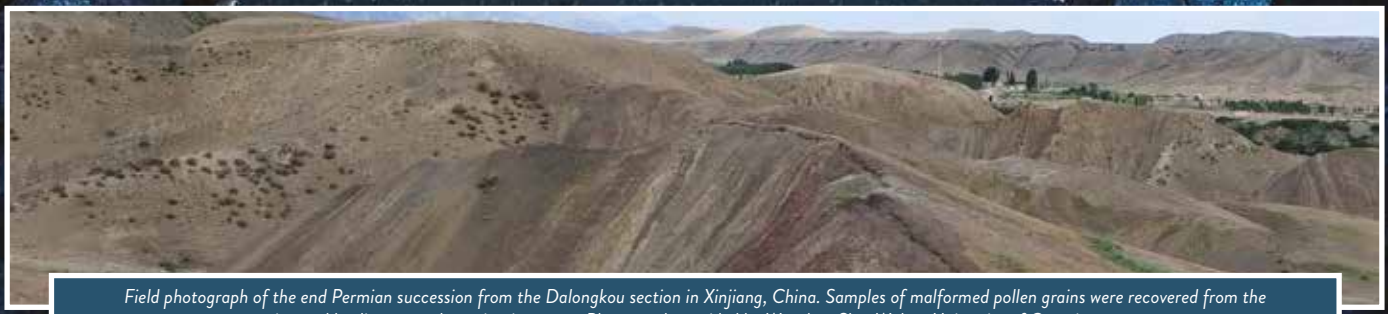
To expand on this research, Barry's team are getting involved in a new project that will examine what environmental conditions lead to what deformations. The team will grow modern-day plants related to the ancient plants present during the P-T event and subject them to particular environmental stressors. They can then match any deformations to pollen that occurs with similar deformations in the fossil record, giving clues as to what ancient conditions led to the fossilised deformations.



Normal (left) and malformed pollen (right) grain of Klausipollenites schaubergeri recovered from the Dalongkou section. Photographs provided by Wenchao Shu, Wuhan University of Geoscience. (An average human hair is 75 micrometres in width.)



Experimentally induced pollen malformation in Pinus mugo. Parent plant was grown under elevated UV-B at the University of California Berkley. Photograph provided by Dr Jeffrey P. Benca, University of California Berkley.



Field photograph of the end Permian succession from the Dalongkou section in Xinjiang, China. Samples of malformed pollen grains were recovered from the interval leading up to the extinction event. Photograph provided by Wenchao Shu, Wuhan University of Geoscience.

PALAEOBIOLOGY AND ECOLOGY

DR ALEX DUNHILL
LECTURER IN PALAEOBIOLOGY
UNIVERSITY OF LEEDS, UK

Alex is interested in examining how past ecosystems, and the species within them, responded to extinction events. "Traditionally, palaeobiologists have focused on the number of species that went extinct during these mass extinction events," he explains. "More recently, however, attention has turned to how these extinction events affected ecosystem function and structure."

"The majority of my research relies on giant global databases," says Alex. "We study many different types of organism, from hard-shelled molluscs in the oceans to vertebrates on the land." Alex uses these databases to look at how diversity changes over time for different groups, and whether there could be links between these changes.

"At the species level, we tend to think about an organism's ability to be resilient to environmental changes, usually through generalist characteristics that allow it to adapt," says Alex. "We can also look for resilience at the ecosystem level." Ecosystems involve every organism in an area, and how they interact with one another, so the extinction of a species will change these interactions. If the ecosystem has low resilience, a significant environmental change can lead to a cascade of extinctions, even if it only directly affects a few species. A more resilient ecosystem will be able to absorb these changes and become stable again.

Working out a modern-day ecosystem's resilience can be tricky enough, so deciphering that of an ancient ecosystem is very challenging. "We use a range of techniques, from modelling past climates and relating that to diversity patterns and extinction rates in the fossil record, to modelling communities of interacting organisms based on food webs," says Alex.

The team's work has yielded some intriguing results. "Today, biodiversity is highest in the tropical regions around the equator, and decreases towards the poles," says Alex. "However, the super greenhouse world of the early Triassic, which followed the P-T event, shows greatest diversity in temperate regions. This is likely because equatorial temperatures were too hot for most animal life."

There are some unsettling similarities between the P-T event and the climate change that we are experiencing today. Both involve a global temperature increase due to high volumes of carbon dioxide in the atmosphere. "The fossil record provides the only direct evidence of climatic changes and extinction events on the level of severity that we might expect," says Alex. "Whilst we hopefully won't experience a mass extinction on the scale of the Permo-Triassic, studying past extinctions caused by rapid warming can help us understand what parts of the biosphere are likely to be most under threat in the future." For instance, it is very plausible that tropical regions will see a decrease in biodiversity as temperatures become too warm to sustain some species.

Alex's future work will focus on understanding the role of ecosystem resilience in the P-T event, to understand exactly how ecosystems collapsed. "Was species extinction primarily in response to environmental pressures or did the removal of a few 'keystone species' lead to the collapse of communities via secondary extinction cascades?" he asks.

EXPLORE A CAREER IN GEOLOGY

- Besides academia, geologists are employed in a whole range of industries, including environmental consultancy, civil engineering, mining and the oil industry. Renewable energy and other emerging industries also frequently require geological expertise.
- In the UK, the Geological Society has a very broad array of outreach and educational activities. These include information on career pathways, opportunities for field trips and junior memberships: **www.geolsoc.org.uk**
- The Palaeontological Association has numerous outreach events, including 'fossil festivals' held in several sites in the UK. Alex mentions there are also countless 'amateur' palaeontologists who are active in research and have contributed to important discoveries: **www.palass.org**

PATHWAY FROM SCHOOL TO GEOLOGY

Paul says that geology draws on all core sciences, so all scientific subjects are relevant. Mathematics and physical geography are also useful within geology.

Palaeontology takes a similar broad scientific base, meaning there are many different scientific routes to a career in the subject. Barry notes that he studied geology at undergraduate level, yet now works in a biosciences department.

MEET PAUL

WHAT WERE YOUR INTERESTS GROWING UP?

I liked playing outdoors and was interested in the natural world – everything from butterflies to rocks. I was also lucky to grow up on the coast and so could spend summer days looking in rock pools.

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

Collecting fossils first got me interested in geology, together with a couple of fantastic books I read: Derek Ager's 'The Nature of the Stratigraphic Record' and Adrian Desmond's brilliant 'The Hot-blooded Dinosaurs'. They opened my eyes to deep time and how we attempt to understand it. Most of all, I became aware that science isn't hard facts at all, but a series of fascinating debates.

WHAT HAS BEEN A EUREKA MOMENT IN YOUR CAREER?

I did my PhD in the late 1980s on a Jurassic rock called the Kimmeridge Clay, the source of most North Sea oil, which formed in deep, oxygen-poor seas around the UK. I realised that similar oxygen-poor conditions occurred during the P-T event all over the world. It's not surprising that most marine life died. It took quite a few years, and a lot of fieldwork, to prove this though!

WHAT MOTIVATES YOU TO DO THE WORK YOU DO?

There is nothing more interesting than trying to understand what caused the greatest catastrophe in our planet's history!

WHAT OPPORTUNITIES WILL FACE THE NEXT GENERATION OF GEOLOGISTS?

Anything that involves digging in the ground or understanding what's happening beneath our feet requires geologists. The push for a battery-powered economy will create huge demand for metals such as lithium, which geologists will need to find. Geologists also aim to understand Earth's history and how our planet works, which is key to understanding and responding to climate change.

MEET ALEX

WHAT WERE YOUR INTERESTS GROWING UP?

I was fascinated by dinosaurs and the natural world in general from an early age. Even as a four-year-old, I would have said I wanted to be a palaeontologist when I grew up. Despite many changes of heart along the way, I've never really lost that passion for the natural world and fascination for evolution and the vastness of geological time.

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

Though I've always wanted to do something science-orientated, whilst at school I never really had the aim to become a professional scientist. It was only in my final year of studying an environmental science degree, whilst undertaking my final-year research project on dinosaur footprints, that I was inspired to embark upon a career in research. I suppose that rekindled my passion for the prehistoric world that had been slow-burning since I was a toddler.

HOW HAS YOUR CAREER LED YOU TO WHERE YOU ARE TODAY?

During my PhD, I became fascinated by periods of biodiversity crashes, which motivated me to pursue mass extinction research. This led to many successful projects on the geography, selectivity and causes of these catastrophes. I've recently gravitated towards multidisciplinary research, collaborating with modern ecologists, mathematicians and even social scientists. I've realised that to understand big concepts, you need to focus beyond your narrow area of expertise!

WHAT MOTIVATES YOU TO DO THE WORK YOU DO?

First and foremost, the amazing people I work with, whether that be my incredible research students or my collaborators across disciplines. I enjoy learning about other people's areas of expertise and how they can link with mine to answer complex questions I could never answer alone.

WHAT OPPORTUNITIES WILL FACE THE NEXT GENERATION OF PALAEOBIOLOGISTS?

I hope the field will continue to increase in relevance and move away from the caricature of stuffy old men looking at dusty fossils. I firmly believe the distant past can inform us about the present and future, helping society to make better decisions.

MEET BARRY

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I had a real love of natural history and being outside. I was often to be found messing around in woods, playing in the mud and hitting rocks with a hammer. The tools of exploration I use now have changed but the curiosity has remained.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

Though I loved the natural world, I hadn't really connected that interest with school or what I wanted to do when I grew up. That changed when I took an A-level in geology taught by a brilliant teacher (thank you, Mr Bellamy). We went away on field trips to different parts of the UK and he'd explain how you could read the rock record to tell you about past environments. Being outside, talking about the natural world, motivated me to take a geology degree. In my final year, I did a research project on fossils and palaeoenvironmental reconstructions and enjoyed it so much that it led to my PhD. After many years of being a research assistant, I got my lectureship at Nottingham.

WHAT HAVE BEEN THE EUREKA MOMENTS IN YOUR CAREER? HOW HAS YOUR CAREER LED YOU TO THIS CURRENT RESEARCH?

My Eureka moment was showing that the chemistry of plant spores had changed in response to human induced ozone depletion. As a child, I'd grown up hearing about the Antarctic ozone hole, and being able to detect the impact of this event was amazing. This finding has underpinned the last 15 years of my career and directly led to me working on the eco PT project

WHAT MOTIVATES YOU TO DO THE WORK YOU DO?

I want to try and understand how the natural world works, how the different parts of the system fit together and interact, and explore what happens when the system begins to break down.

WHAT OPPORTUNITIES WILL FACE THE NEXT GENERATION OF PALAEOBOTANISTS?

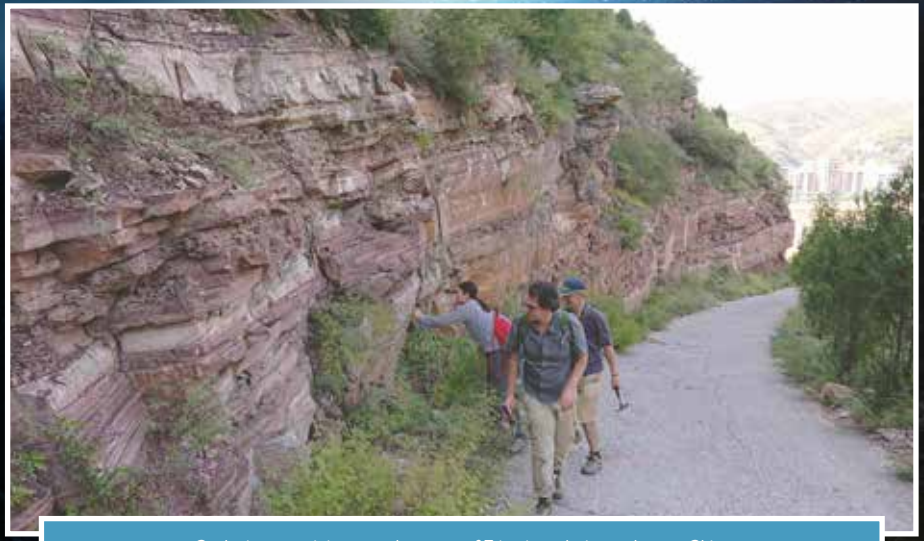
The joy of working with plants is that you can easily link the world of fossils to the present day. Many plants alive today have long fossil records, so we can use these plants to learn about a world that existed 100s of millions of years ago. Fossil plants are a great way to unpick past climates and that data can be used to help inform us about the challenges we will face in the future.

THE TEAM'S TOP TIPS

01 Be keen, motivated and curious about the natural world.

02 Follow your interests. If you have your heart set on a particular career, research what it entails and what the requirements are to get there.

03 Never be afraid to ask lots of questions. There's no such thing as a stupid question, after all!



Geologists examining a road outcrop of Triassic rocks in south-west China

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Find out how the researchers got to be where they are today

For example, János wasn't massively interested in biology when he was younger. He is now an immunologist!

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Answer questions linked to Bloom's Taxonomy and perform experiments and/or take part in activities that are relevant to the research articles.

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Our PowerPoints summarise our articles and include additional 'Talking Points'.

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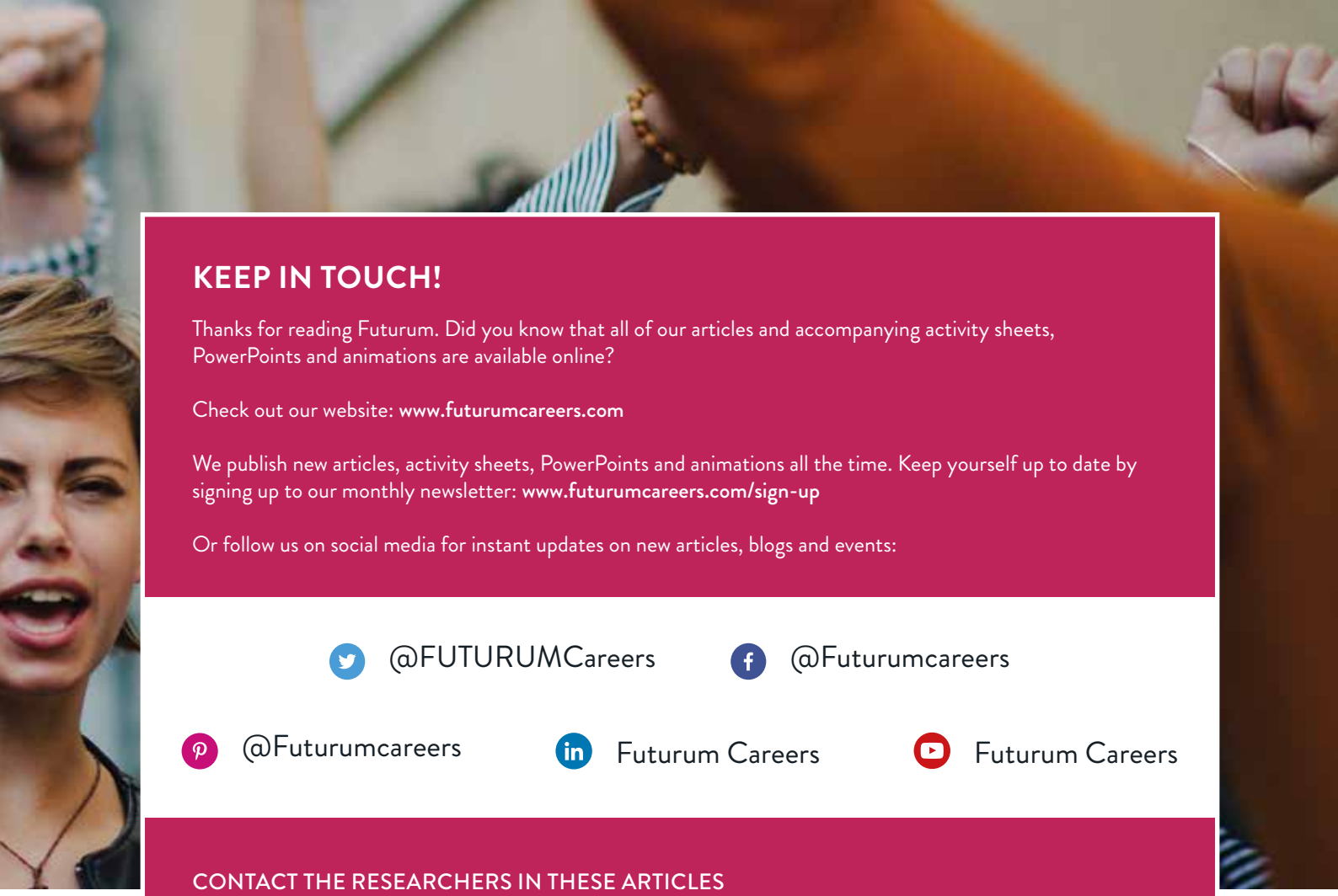
Use the animations (and scripts) in the classroom or at home to learn about and reflect on key elements of the research.



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