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INSPIRING THE NEXT GENERATION

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"WE HAVE TO PULL THE INNER INNOVATOR OUT OF EVERYONE."

GITANJALI RAO

At just 17, Gitanjali has invented three health technologies, taken part in four TED talks and written a book called *A Young Innovator's Guide to STEM*. What's next for Gitanjali?

ALSO IN THIS ISSUE

DAVID AGUILAR AMPHOUX
CO-AUTHOR, LEGO PROSTHETICS BUILDER AND ROLE MODEL FOR MILLIONS WORLWIDE

JOEL GIBBARD
CO-FOUNDER OF OPEN BIONICS, A COMPANY TURNING DISABILITIES INTO SUPERPOWERS

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WELCOME

ISSUE 017

"We have to pull the inner innovator out of everyone."

So says Gitanjali Rao, a high school student and inventor of three health technologies (p 4). Gitanjali has been named *Time's* Kid of the Year, UNICEF Youth Advocate, National Geographic Young Explorer and included in the Forbes 30 under 30 list. She is also the author of *A Young Innovators Guide to STEM* and holds online workshops to inspire the next generation of innovators.

David Aguilar is another young innovator who has surmounted many challenges to become an author, the star of his own documentary, *Mr Hand Solo*, and role model to millions worldwide (p 56). Having built prosthetic arms with LEGO from the age of nine, he is more than qualified to say that the "true disability lies in believing you can't achieve anything".

According to the World Economic Forum, analytical thinking and innovation, as well as creativity, originality and initiative, will be among the top ten most in-demand skills of the future. Given the challenges currently facing society and the planet, this is hardly surprising. Gitanjali and David are shining examples of what can be achieved from a young age, but are they the exception? How skilled is the next generation, and what can we do to foster their talents?

As the researchers in this issue demonstrate, there are many questions needing creative, analytical thinkers in STEM and SHAPE to solve them, from understanding the structures that exist in the Earth's mantle (p 80) to investigating how the human body reacts to physical trauma (p 20). By sharing these research projects, and the stories of the researchers behind them, with students, we - and you - can inspire the inner innovator in everyone.

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"WE HAVE TO DIG IN AND PULL THE INNER INNOVATOR OUT OF EVERYONE."

© Sharif Hamza, TIME Magazine

GITANJALI RAO WAS ONLY 11 YEARS OLD WHEN SHE DEVELOPED **TETHYS**, A DEVICE THAT DETECTS LEAD IN DRINKING WATER. NOW AGED 17, SHE HAS INVENTED TWO MORE HEALTH TECHNOLOGIES, TAKEN PART IN FOUR TED TALKS AND WRITTEN A BOOK CALLED *THE YOUNG INNOVATOR'S GUIDE TO STEM*. GITANJALI TELLS US WHY SHE IS ON A MISSION TO HELP MORE YOUNG PEOPLE SOLVE WORLD PROBLEMS

WHAT INSPIRED YOU TO DEVELOP TETHYS?

I heard about the water crisis in Flint, Michigan, USA, which involves highly toxic levels of lead leaching into the city's water supply. This started around 7 or 8 years ago and continues to this day. The thing that hit me the most was that kids my age were drinking poison every single day, and that poison was in the water, which is something I take for granted on a daily basis. I saw an MIT *Technology Review* article online about using carbon nanotube sensors to detect hazardous gases in the air, and it seemed to me that we needed to tackle the lack of early detection solutions for drinking water.

HOW WERE YOU AWARE OF ISSUES LIKE THIS AT THE AGE OF 11?

That's a hard question to answer because it's always been built in me. I often watch the news with my parents and we used to discuss it during dinner. Being aware of issues like the water crisis, airline accidents, cyberbullying, etc. is sometimes a problem, because they keep me up at night thinking about how to solve them. I'm never really sure how to solve them at first, but the thought lingers and I write them down so that I can revisit them later.

WHY DID YOU DECIDE TO DEVELOP KINDLY, AN ANTI-BULLYING APP?

My own personal experience of bullying in elementary and middle school! I've also witnessed a lot of my friends being bullied and found that standing up to bullies isn't always a solution. Regardless of the number times I've stood up to bullies, or for my friends, it always backfired. I also learnt that there was no good reason for bullying, but it always seemed to be about someone claiming superiority and physical intimidation. So, I wanted to create a tool that tackled the root cause of the problem.

Kindly uses artificial intelligence and machine learning, and the interesting thing about it is that it's a non-punitive mechanism for detecting bullying messages. It works almost like spell check in that it tells you that you're about to send a message that might not be very nice. But it doesn't stop you from sending anything.

The inspiration behind this was drawn from an article I read that said it only takes 7 seconds for a teenager to want to unsend something they've sent. Giving people those 7 seconds, and the opportunity to decide whether they want to send a particular message, could prevent bullying in the long run. The service evolves with our language and self-learns, since teens are notorious for coming up with new slang words every single day.

DO YOU FEEL THAT BULLYING IS PERVASIVE AMONG TEENS?

I've moved to lots of different schools over the past 12 years and the longest I've been at the same school is 5 years. Across the 7-8 schools I've attended, I've seen every version of bullying. People being targeted for what they look like or what they're interested in, but also people being targeted just for 'fun'. That's why bullying is challenging to deal with because there are so many different causes.

EPIONE WAS INSPIRED BY A FAMILY FRIEND WHO BECAME ADDICTED TO PAINKILLERS. WHY IS TECHNOLOGY NEEDED TO DETECT EARLY SYMPTOMS OF OPIOID ADDICTION?

While I was doing an internship for an opioid response programme at the Colorado Department of Law, I learnt that people don't necessarily go to a doctor when they have an opioid addiction or are on the verge of one. By the time doctors diagnose an addiction to opioids, it's too late to do anything about it. Also, in the early stages, there are limited symptoms. The only thing doctors can check is how often patients take their prescriptions, but no doctor has the time to monitor patients that closely.

There are lots of preventative measures and treatment solutions in place, such as behaviour questionnaires, but no diagnostic solutions. Patients are handed a survey in the doctor's office, but anyone who has an addiction will lie because their brain wants them to keep using the opioids.

ARE ALL THREE OF THESE TECHNOLOGIES IN USE OR IN THE DEVELOPMENT STAGE?

Tethys is a patented product and I've been trying to partner with a manufacturing company for about three years now to start field testing in schools. In partnership with UNICEF, Kindly has been launched worldwide for everyone to start using. Epione is at the prototype stage.

DO YOU HAVE ANY OTHER TECHNOLOGIES OR IDEAS IN DEVELOPMENT?

Yes, a couple of things! One of the bigger things I'm working on is a test strip to detect parasites in drinking water in third-world countries, specifically *cryptosporidium*. I'm excited about using biotransducers for detection – taking in a biological input like DNA and protein and receiving an electrical output, like resistance in an electrical current.

WHY *CRYPTOSPORIDIUM*, IN PARTICULAR?

We've looked at other parasites as well, and worked with *E. coli* and *legionella*, but I wanted to look at something that wasn't widely known but causes so many problems in third-world countries, like those in Africa and Southeast Asia. The nice thing about this technology is that it's repeatable; it can be used for different parasites.

YOU WERE RECENTLY A RESEARCH INTERN AT THE KOCH INSTITUTE FOR INTEGRATIVE CANCER RESEARCH. HOW DID YOU GET INVOLVED WITH THAT?

I reached out to Dr Sangeeta Bhatia at the Koch Institute and said I was coming to Boston for the summer. I've known Dr Bhatia for a very long time and have always looked up to her and followed her work. She is an innovator, an accomplished professor, an entrepreneur and runs multiple labs. She was kind enough to invite me to her lab at the Institute for a month. I met her PhD graduate researchers and worked with them on a project investigating how to improve drug delivery for lung tumours. Dr Tahoura Samad was my mentor. She was such an inspiration, and guided me and allowed me to shadow her research.

HOW DID YOU BENEFIT FROM THIS EXPERIENCE?

Being in a lab for a good length of time meant that I felt like a graduate student. I'd never had the opportunity to have work experience over a longer period. It also gave me an insight into the discipline, diligence, perseverance and motivation you need for research, and the basic methods.

Gitanjali undertaking research in cell and developmental biology © Dr Michael McMurray

YOU HAVE DONE FOUR TED TALKS SO FAR. HOW DO YOU PREPARE FOR THESE?

In the beginning, I was very nervous but now these talks are second nature to me. I think the biggest thing I've learnt is that I know my content more than anyone else. If I mess up, I learn from it and I make it work next time. I used to write out a speech and memorise it, word for word, but now I write down the points that matter and go from there. As long as I have made it valuable for the audience with some key messages I want to share, I believe I have accomplished my goals.

WHY DID YOU WRITE *THE YOUNG INNOVATOR'S GUIDE TO STEM?*

It was at the beginning of the COVID-19 pandemic, and I realised that one girl can't solve all the world's problems and we need more young innovators, so I started conducting online workshops and guiding students through a five-step process where they can start their own

"ACROSS THE 7-8 SCHOOLS I'VE ATTENDED, I'VE SEEN EVERY VERSION OF BULLYING."

Sabeti Lab © Michael Butts

Gitanjali at the Wings Over the Rockies Air and Space Museum

> **“THE BOOK ALSO TALKS ABOUT MY FAILURES AND INTENDS TO SHOW STUDENTS THAT FAILURE IS THE FIRST STEP TO LEARNING AND NEED NOT BE STIGMATISED.”**

innovation journey. But I wanted to reach out to more educators and students globally. I wanted to write a prescriptive guide on how to innovate and come up with solutions. To sustain the workshops beyond schedule and time constraints, I saw the book as a way to reach many more students across the world.

This book is targeted at students, but also has lesson plans for teachers as well as sections for parents. It’s a short read and has a list of competitions that students can participate in. The book also talks about my failures and intends to show students that failure is the first step to learning and need not be stigmatised.

YOU HAVE SO MANY WORK INTERESTS AND HOBBIES. WHICH DO YOU FIND THE MOST REWARDING?

The workshops. Whenever I finish a workshop, whether I’m working with 100 or 5,000 students, or sometimes even five, I feel like there are 100 or 500 or 5,000 new ideas brewing. I’ve never seen a student, among the 70,000 I’ve worked with, who hasn’t been interested in innovating something. I think you have to dig in and pull the inner innovator out of everyone. When I do that in my workshops, I feel hugely motivated because there are more young people like me who are looking to solve world problems.

I learn from them as well. I understand their cultures and constraints better now so that I can provide the right resources, if needed. For example, I recently helped find funding to build a space with better internet access for Kakuma refugee camp students. That was a basic need we had to tackle before inspiring the students to innovate.

WHAT ARE YOU HOPING TO STUDY AT UNIVERSITY?

I would like to focus my area of study at the intersection of biogenetics and product development. My research, and work, so far includes biological and biomedical solutions that address health problems in communities.

I would love to minor in public administration to make innovation and problem-solving part of K-12 education, by exploring and influencing educational policies. I’m applying to colleges right now and I hope to

Gitanjali receiving a patent © USPTO

get admitted in a university where I can continue with my research and global outreach.

WHAT DO YOU IMAGINE YOURSELF DOING IN 10 YEARS' TIME?

My eventual goal is to develop solutions into high-quality and cheaper consumer-products. In addition to core research areas, I plan to pursue supplemental public administration, business courses in product development and/or entrepreneurship.

WHAT VALUABLE LESSONS HAVE YOU LEARNT SO FAR?

The biggest thing I've learnt is that risk-taking is worth it. I wouldn't be here if it weren't for the risks I took along the way and for my mentors. Another big thing I've learnt is that innovation and creativity don't have deadlines – everything is an ongoing cycle that starts and stops, and starts up again. Last, but not least, failure is such an integral part of the process. My teacher once told me there's no such thing as failure, there's just another way of doing it. This message often works for me.

> **"MY TEACHER ONCE TOLD ME THERE'S NO SUCH THING AS FAILURE, THERE'S JUST ANOTHER WAY OF DOING IT. THIS MESSAGE OFTEN WORKS FOR ME."**

CAN YOU GIVE AN EXAMPLE OF WHEN YOU HAVE MESSED UP?

Oh, lots of examples! You can't go into a lab and not expect to mess up the first few times until you get something right. A lot of my work is about fine-tuning and testing. That's one of my favourite things about science. It gives you the opportunity to reboot and restart.

Gitanjali undertaking research in cell and developmental biology © Dr Michael McMurray

Be kindly

As Gitanjali Rao says, teens come up with new slang words all the time. You can contribute to Kindly by typing in bullying words for the algorithm to self-learn and recognise.

Visit: www.unicef.org/innovation/kindly

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THE MILK OF HUMAN KINDNESS

DR NATALIE SHENKER IS THE CO-FOUNDER OF THE **HEARTS MILK BANK** – A UK-BASED CHARITY THAT PROVIDES DONOR HUMAN MILK TO VULNERABLE BABIES WHO, FOR WHATEVER REASON, ARE UNABLE TO RECEIVE MILK FROM THEIR BIRTH MOTHER

TALK LIKE A HUMAN MILK RESEARCHER

DONOR HUMAN MILK (DHM) – breast milk donated by a woman who is not the birth mother of the baby receiving it

FORMULA MILK – liquid feed for babies, usually based on cow's milk and supplemented to meet nutritional needs

MASTECTOMY – the removal of a breast, usually due to breast cancer

MATERNAL MILK – breast milk provided by a baby's birth mother

NECROTISING ENTEROCOLITIS (NEC) – a condition in which some or all of the gut becomes inflamed and can die

NEONATAL INTENSIVE CARE UNIT (NICU) – the hospital unit where premature or very ill newborn babies are cared for

PREMATURE – a baby born before the 37th week of pregnancy (pregnancy usually lasts between 37 and 42 weeks)

When you think about lifesaving donations, you might think of blood or organs, but you probably do not think about milk. However, for the most vulnerable babies, born prematurely or with other health conditions, not being fed with human milk can risk their life. There are many reasons why a baby might not be able to receive milk from their birth mother, and in these situations, milk banks can provide lifesaving donations of human milk.

WHAT IS MILK?

Milk is produced by all mammals to feed their young and support the development of their immune system. Crucially, each species has milk specifically evolved to meet the needs of their own young, and so species-specific milk is important for feeding any mammalian infant.

Biochemically, human milk is very different to that produced by other mammals. Highly specialised fatty acids support central nervous system neurons to make connections in the infant brain, which develops so rapidly over the first year. Over 100 modified sugars, called human milk oligosaccharides, have multiple functions that support immune system, gut and brain development. Human milk even contains an enzyme which reacts with saliva in the mouth to destroy harmful bacteria, cleaning new teeth to prevent plaque.

Maternal milk is tailor-made to meet the needs of the baby. The composition of human milk varies hugely. Antibodies in milk are produced within hours of exposure to pathogens. The hormonal content changes over a 24-hour cycle, helping babies develop a diurnal rhythm, and even varies over the course of a single feed. In hot and humid weather, milk will have more water, and some immune components are only produced at certain times of the year. Formula cannot replicate this responsiveness or immune protection, but if mothers face breastfeeding challenges, families have little choice but to feed their baby with formula.

Dr Natalie Shenker, a medical researcher at Imperial College London, hopes to change this. Along with Gillian Weaver, a nutrition expert who specialises in human milk banking, she founded the Hearts Milk Bank, where she not only provides an essential service for mothers and babies, but also conducts research to understand how more families can be supported by milk banks. The chief aim of Hearts is to provide every vulnerable baby with the opportunity of being fed with human milk, while ensuring mothers have the best support to reach their own breastfeeding goals.

HOW DOES A MILK BANK WORK?

A milk bank is a lot like a blood bank, and the process is similar to the blood transfusion service. "We recruit mothers who have extra milk," explains Natalie. "There are lots of

reasons why mums may build up an oversupply of milk and our teams help them to manage this." Each mum undergoes extensive health screening before donation to identify any factors that could affect the milk (such as smoking). This includes blood tests for HIV, hepatitis B and C, syphilis and HTLV. Mothers pump milk and keep it in their home freezer, until volunteer blood bikers collect the frozen milk from across the country and transport it to Hearts. Once defrosted, the milk is pasteurised and tested for bacteria to ensure it is safe for use. "Hospitals who need milk in Neonatal Intensive Care Units (NICU) are always the priority to receive our donor milk," says Natalie. "Any surplus is used for mothers facing breastfeeding challenges."

WHY MIGHT PREMATURE BABIES REQUIRE DONOR HUMAN MILK?

When a baby is born prematurely, the mother's body may not yet be ready to produce milk. In addition, delivering a baby prematurely is extremely stressful, and stressed mothers often struggle to produce milk. Sometimes, mothers may be very ill themselves after a premature birth, and so unable to feed their newborn baby. In these instances, babies need to be given milk until their mother can produce enough for their needs. Usually, this substitute is cow's milk-derived formula.

However, premature babies have not completed their development process in the womb, so their brain, intestines and immune system are all much weaker and under-developed. This means they are at greater risk of harm from being fed non-human milk. Necrotising enterocolitis (NEC) is a serious condition that causes the gut to die. Premature babies are much more likely to develop NEC, and this risk increases if the baby is formula fed. Between 25-40% of babies who develop NEC will die.

As well as supporting the mother, by acting as a bridge to breastfeeding, donor human milk (DHM) can be used like a medicine in this situation. DHM will never be as good as the mother's own milk, but it greatly reduces the risk of NEC and other complications of premature birth as it is species-specific.

WHY MIGHT FULL-TERM BABIES REQUIRE DHM?

Prior to the establishment of Hearts, only a handful of full-term babies in the UK had ever received DHM. "Yet there are lots of reasons why mums of full-term babies may not be able to produce a full milk supply," says Natalie. "They might have had a difficult birth or have an underlying medical condition. In most cases, with the right support, women will go on to produce a full supply. If that gap can be bridged by donor milk, our research is showing that those mums are more likely to go on to breastfeed. They are more likely to see this as part of a supportive journey that they are on to establish a full milk supply."

Other women may never be able to breastfeed. They may have had a mastectomy to remove breast tissue due to cancer, or they may be undergoing chemotherapy. "Donor milk can make a huge difference in these cases," says Natalie. "A frequent comment from mothers diagnosed with cancer during pregnancy is that they worried more about how they would feed their baby than their own prognosis. Our research is showing that being able to access DHM can help mothers come to terms with this loss and reduce anxiety and depression."

WHAT RESEARCH IS NATALIE ENGAGED IN?

"The fabulous thing about working in a field of science where there's almost no research published is that you've got plenty to work on!" says Natalie. "When we started, there were only two scientific papers published about the composition of human milk after the first six months of a baby's life. We needed to understand this to know whether mothers could donate milk if their babies were older."

DR NATALIE SHENKER

Research Fellow, Faculty of Medicine, Imperial College London, UK

Co-founder of the Hearts Milk Bank

FIELD OF RESEARCH

Implementation science of human milk banking

RESEARCH PROJECT

Researching the properties of human milk and how donated milk can protect the health of infants and mothers and support breastfeeding journeys

FUNDER

UK Research and Innovation (UKRI)

As a medical researcher, one of Natalie's current focuses is on the changes in the composition of maternal milk as a baby grows. To collect pilot data before beginning a larger study, Natalie asked women who were breastfeeding babies of any age to express milk for analysis. This provided a snapshot of milk composition for feeding children aged three months to four and a half years. "We had a day at Imperial College London where 120 women turned up with all their babies and toddlers," she says. "There were young children everywhere – it was total chaos, but we made some amazing discoveries, including that human milk remains nutritionally complete far beyond six months after birth."

After analysing the composition of maternal milk being fed to children of different ages, the research team discovered that most of the metabolites and fatty acids in human milk do not change in the first two years of an infant's life.

Ultimately, human milk evolved to support infant development and immune protection. With many reasons why a baby may not be able to receive milk from their birth mother, donor human milk is hugely important for providing a positive start in life for many babies.

ABOUT MEDICAL RESEARCH

Medical research is the quest to understand human health and diseases, which ultimately leads to the development of improved treatments. Researchers work across the entire range of medical topics, which means you can identify which aspect is of interest to you and tailor your studies accordingly. Medical researchers may find themselves working in a laboratory conducting experiments, on the frontline of the NHS, or running clinical trials testing new drugs. Perhaps, like Natalie, you might establish your own organisation to address whichever health-related issue you are passionate about.

WHAT ARE THE REWARDS OF MEDICAL RESEARCH?

Natalie's research is split between fundamental science and performing clinical trials to establish the impacts of the science. "The most rewarding thing is watching the translation of my research into real impact that helps families," explains Natalie. "It is phenomenal to be watching rapid changes in clinical care and even shifts in breastfeeding, in part because of our work."

WHAT CHALLENGES DID NATALIE FACE WHEN ESTABLISHING THE HEARTS MILK BANK?

"Culture, prevailing medical views and public perception have been huge challenges," says Natalie. The UK has some of the lowest breastfeeding rates in the world, with only one in 200 women breastfeeding by the time their baby is one year old[1]. "As a society, we don't really want to talk about the issues women face during breastfeeding," says Natalie.

Medical researchers studying human milk must understand the cultural perceptions and industry influence associated with breastfeeding. The study of human milk was not a government priority so to gain funding, researchers have had to rely on the formula industry. Companies want to understand the composition of human milk so they can alter their cow's milk formula and claim it is similar to breast milk. "The truly unique thing we're doing with Hearts is we've never accepted money from formula companies," explains Natalie. "So, funding has been a huge challenge. Hearts was initially funded by crowdfunding, bake sales and people running marathons! But we had a clear vision of what could change if we persevered."

WHAT ISSUES WILL THE NEXT GENERATION OF MEDICAL RESEARCHERS FACE?

"We need formula milk, because there aren't enough human milk banks and because many women struggle with breastfeeding," explains Natalie. "I initially used formula to feed my own child. But knowing what I know now, my decisions would have been different if I had had more choices." However, it is important that there are pathways into the field of medical research that are not influenced by industry. Funding needs to be available from sources that do not have potential ulterior motives in the research, so-called conflicts of interest. "I think the next generation needs to be a lot more aware and critical of where they are taking funding from," says Natalie. "I believe we are beginning to witness this change."

[1] *Data from the last infant feeding survey in 2010*

EXPLORE CAREERS IN MEDICAL RESEARCH

Prospects (**www.prospects.ac.uk/job-profiles/research-scientist-medical**) and Target Careers (**www.targetcareers.co.uk/career-sectors/healthcare-and-veterinary-medicine/1014251-medical-research-jobs-and-qualifications**) have sections dedicated to medical researchers, containing a wealth of information on how to embark on a career in this area, including what qualifications you will need to gain and what salary you can expect.

The Medical Research Council (**www.ukri.org/councils/mrc**) has a section on its website dedicated to skills and careers (**www.mrc.ukri.org/skills-careers**) where you can learn more about careers in medical research and the support available to students.

NATALIE'S TOP TIPS

01 Follow your passions! Whatever your passions are, they can be incorporated into medical research or whatever role you choose.

02 Be a critical thinker – Who is telling you information? What might be their motivations? What are your own unconscious biases?

03 Transferable skills such as teamwork, collaboration and building trust are really important in medical research, so work on developing these as much as possible.

PATHWAY FROM SCHOOL TO MEDICAL RESEARCH

Natalie is refreshingly relaxed when it comes to suggesting which subjects to take. "I think that you should study whatever you love – whatever gets you out of bed in the morning and wherever your talents lie."

A typical pathway into medical research involves science and mathematics A-levels and an undergraduate degree in medicine or a related field (e.g., biomedical science, pharmacology, immunology, biochemistry). Most researchers will then gain a master's or PhD.

HOW DID NATALIE BECOME A MEDICAL RESEARCHER?

DID YOU ALWAYS WANT TO WORK IN MEDICINE?

I was always aware I really wanted to contribute to a better, healthier world. Medicine kept so many options open as it is such a diverse profession. After years specialising in paediatric surgery, it became clear that I was most passionate about using research and practical interventions to help improve societal health.

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was always really fascinated by exploration, the idea of people literally going out into the unknown but having adventures and facing down challenges along the way. Science brings that same excitement, but I get to work embedded within communities that can directly benefit from my research.

WHAT PERSONAL QUALITIES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Grit and determination. I've had some really challenging times in life but learning to bounce back and focus on the important things has been the most valuable lesson of my life. Being able to carry on when things go wrong is important, and now I understand that whenever negatives happen, there is always a positive, no matter how far you've got to dig down to find it.

WHAT DO YOU ENJOY DOING OUTSIDE OF YOUR WORK?

Life has been pretty hectic for the last few years, but we've just moved into the countryside. We've adopted a rescue puppy who is keeping us all on our toes and teaching us all the joys of 6 am walks.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Winning the UKRI Future Leaders Fellowship was undoubtedly the turning point for everything. It shone a light into the whole sector of infant feeding, showing that the work in this space is really important. But what makes me proudest is hearing stories from all the families who are benefitting from Hearts, talking with doctors across the world looking to implement similar programmes, and knowing that all our work here is helping to contribute to that.

WHAT ARE YOUR HOPES FOR THE FUTURE?

My main hope for the future is that the next generation are empowered to take on challenges – we face so many. And if school-leavers have the knowledge that few jobs will have more impact on the health of individuals than being a lactation consultant, breastfeeding medicine specialist or milk bank technician, then my work will be done.

Baby Alby, who received milk from Hearts Milk Bank.

Containers of donor human milk are collected at Hearts Milk Bank.

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HOW CAN SOCIOLOGY HELP ADDRESS A GLOBAL HEALTH CHALLENGE?

DR SANGEETA CHATTOO, FROM **THE UNIVERSITY OF YORK,** IN THE UK, IS ON A QUEST TO BETTER UNDERSTAND ONE OF THE COMPLEX GLOBAL HEALTH CHALLENGES: INHERITED BLOOD DISORDERS (IBD). SHE IS USING SOCIOLOGICAL AND ETHNOGRAPHIC APPROACHES TO HEALTH TO BETTER UNDERSTAND THE LINKS BETWEEN POLICY INTERVENTIONS, HEALTH OUTCOMES AND RACE, ETHNICITY, CASTE, TRIBE AND GENDER ACROSS LOW- AND MIDDLE-INCOME COUNTRIES SUCH AS INDIA AND NEPAL

TALK LIKE A MEDICAL ANTHROPOLOGIST

ETHNOGRAPHY — a research method that uses in-depth qualitative tools to understand and analyse an aspect of social and cultural life, institution or human experience

RECESSIVELY INHERITED DISORDER — a disorder resulting from a person inheriting two mutated genes, one from each parent

SICKLE CELL DISEASE — an inherited blood condition that affects the structure of red blood cells to take a 'sickle' shape, affecting the supply of oxygen in the body

CASTE — a form of social ranking or grouping in some societies often based on factors such as occupation or economic position

THALASSAEMIA — an inherited blood condition that affects the capacity of red blood cells to produce enough haemoglobin

HAEMOGLOBIN — a protein in the red blood cells that gives blood its red colour and transports oxygen around the body

INVISIBLE DISABILITY — a non-visible condition, including neurological, mental or physical, that can challenge or limit an individual's senses, activities or movements

ALLELE — a variant or form of a given gene. A baby inherits two alleles of each gene, one from each parent

ANAEMIA — a condition where a person does not have the right quantity or quality of red blood cells to carry oxygen around the body. It often leads to fatigue and weakness

GENOMICS — the study of all the body's genes (genome), the interaction of these genes with each other and the person's environment

We do not always give much thought to the blood moving around inside our bodies, but our red blood cells are absolutely vital. In fact, the human body manufactures around 17 million red blood cells per second!

Sickle cell and thalassaemia are severe, recessively inherited blood disorders which affect the function of red blood cells. The prevalence of these disorders is higher in low- and middle-income countries where malaria is endemic. India is estimated to have the highest number of carriers of these disorders in the world. However, only a very small percentage of these people receive the care they need.

Dr Sangeeta Chattoo, of the Department of Sociology at the University of York, has studied the practices and policies concerning blood disorders. Her ethnographic research focuses on the lived experiences of sickle cell and thalassaemia patients – especially in poorer families with limited access to healthcare services. People who have sickle cell disease produce unusually shaped red blood cells, which do not live as long as healthy blood cells and can block blood vessels. A person with thalassaemia produces either no or very little haemoglobin, which is used by red blood cells to carry oxygen around the body.

These blood disorders can result in very severe, lifelong health conditions, including anaemia. Sickle cell can be diagnosed at different stages of life, although babies can currently be tested as soon as they are born using a 'heel-prick' test. A 'prenatal' test can identify if a foetus has either of these conditions. If the prenatal test is positive, parents often face the difficult decision of whether to continue or terminate the pregnancy.

RECESSIVELY INHERITED

For a baby to have the disorder, they must inherit two alleles of the gene – one from each parent. When babies inherit only one copy of the gene, they are considered a 'carrier'. Carriers

do not have the disorder but can pass on the gene to their children. This can further complicate the probability of risk.

"If both parents are carriers, there is a 25% risk that the baby may inherit the condition, a 25% chance that it will be healthy and a 50% risk that it will only be a carrier," Sangeeta explains. If both parents have the condition, their children are at a 100% risk of inheriting the disorder. But, if one parent has the condition and the other is only a carrier, the likelihood reduces to 75%. Although all these percentages may seem a little confusing, information about genetic risk can have major implications for individual life choices and procreation.

QUALITATIVE RESEARCH

Ethnographic studies use in-depth research methods to better understand an aspect of social life. An ethnographer tries to gain insight into people's real-life experiences, mapping relationships, conducting interviews and everyday observations. This contrasts with research that uses experimental situations or theoretical hypotheses not derived from fieldwork. Researchers like Sangeeta can combine qualitative and quantitative methods such as demography surveys, census and secondary data for triangulating findings.

Sangeeta wanted to understand the experiences of people in India who are suffering from sickle cell and thalassaemia, as well as the experiences of their families and the non-government organisations (NGOs) that support them. Her team analysed policy documents, interviewed policymakers and healthcare practitioners, and shadowed NGOs. The researchers also interviewed patients and close relatives two to four times over a period of two to three years, to find out about diagnosis, treatments, reproductive decisions, education, employment, and impairment and disability issues.

RESULTS AND RECOMMENDATIONS

Sangeeta's team found that community screening has improved access to diagnosis and information about inherited blood disorders at the sample sites. However, this does not always result in better medical care. Disability assessment tools often ignore invisible disabilities suffered by people with sickle cell and thalassaemia disorders (for example, the psychological and cognitive effects of the disease).

Sangeeta also highlighted several ethical issues. Genomics, the study of the body's genes and their functions, can be used to identify and diagnose blood disorders. However, Sangeeta is sceptical of the promise of genomics and its benefits. "It assumes that the transfer of stem-cell and prenatal technologies will somehow magically improve health outcomes and alleviate the 'burden of disease' in low- and middle-income countries," she states. Genetic technologies are expensive, and they can reinforce existing socio-economic inequalities.

Another ethical issue the research identified is that treatment and intervention often focus heavily on preventing new births by sickle cell and thalassaemia carriers. "This emphasis can reinforce existing negative attitudes and stigma of being a carrier or having a blood disorder in the family," Sangeeta explains. The public health posters and leaflets in circulation often show negative images of children with blood disorders being a burden on families, which increases this stigmatisation.

One of the most complicated issues that Sangeeta's research raised was about the 'framing' of choices for parents accessing state welfare. In several states in India, pregnant women must undergo mandatory carrier screening for sickle cell and thalassaemia. This means that the poorest and most marginalised, less literate women are more likely to be targeted for national development goals, such as population control, as a means of eliminating child mortality and genetic disorders. Focusing on the people rather than policy targets, can have a positive impact on the way society sees and values people with genetic impairments and related disabilities.

Instead of focusing on a poor prognosis at birth, Sangeeta believes that healthcare practitioners should be educated and trained in recognising the variability of sickle cell and thalassaemia disorders and improving access to basic medical care. Her research also calls for a wider discussion about the idea of 'preventing birth defects' in relation to the citizenship laws and legislation protecting the rights of people with disabilities in India.

KEY SUCCESSES

Because of the COVID-19 pandemic, Sangeeta's team faced many challenges due to safety and travel restrictions. However, the team had built relationships of trust with the research participants over several years. The researchers also developed strong partnerships with clinicians and NGOs, which will be essential to improving treatment protocols in the future.

Sangeeta explains that her research has not yet directly influenced policy because of the complex federal healthcare system across India. Instead, working closely with key clinicians and NGOs, 'safe practice care toolkits', written in local languages for patients and parents/family carers, are being developed. These toolkits will help share knowledge and protocols for safe practice to be followed by key clinicians locally, in similar low-resource settings.

Sangeeta's research focuses on a pressing global health issue. Her work is urgent, and her methods capture the complex and sensitive social, cultural and ethical and policy issues and implications. Sangeeta's sociological approach to medicine as a form of knowledge and practice is vital for scientific progress, which also looks after the well-being of vulnerable patients.

DR SANGEETA CHATTOO

Senior Research Fellow,
University of York, UK

FIELDS OF RESEARCH

Medical Sociology,
Medical Anthropology

RESEARCH PROJECT

Understanding the ethical and social implications of treating and preventing inherited blood diseases

FUNDER

Economic and Social Research Council (ESRC)

ABOUT MEDICAL SOCIOLOGY

Sociology is a social science that studies social interactions between humans. This can encompass a variety of subjects ranging from family life to religious structures, to workplace hierarchies. A degree in sociology can lead you to many different careers across various sectors including civil service, health and welfare, culture, education and the charity sector.

Sangeeta uses sociology to understand the societal aspects of medicine and health. This approach is important because it can engage with global health priorities and how these are set, implemented and lived by the people. Sangeeta's research includes socially disadvantaged and marginalised groups who are at the receiving end of healthcare treatments but who may have been neglected in other studies. Medical sociology research must make sure that global health goals are helping a global community, rather than just select, privileged groups.

Sangeeta used ethnographic methods in her research in India. This enabled her to examine socio-structural inequalities such as poverty, gender, caste, race, tribe and ethnicity. She also compares these different types of inequalities and explores how they interact to impact people's health experiences and outcomes. "These analyses can inform public and policy debates by introducing a gradual shift in attitudes, advocacy and professional practices at a local level. Hence, rather than directly trying to policy at the top, we followed an innovative, approach to change," explains Sangeeta.

WHAT ARE THE REWARDS AND CHALLENGES WHEN ENGAGING WITH HEALTHCARE PRACTITIONERS AND POLICYMAKERS?

Working with healthcare practitioners and policymakers involves challenging their (and the researcher's own) assumptions, while also understanding the power dynamics involved. "You have to take a stance on whose voice/case you want to prioritise and how you negotiate the other relations in the field," says Sangeeta, who often works alongside marginalised communities.

WHY WOULD YOU RECOMMEND A CAREER IN SOCIOLOGY TO STUDENTS?

Sociology is a unique way to study the social world we live in. "Sociology teaches you about social life, the world we live in, what brings us together as well as the divisions, differences and disadvantages that set us apart," says Sangeeta. The subject requires many different transferable skills, especially critical reasoning and analytical skills to evaluate evidence, argue your point of view and understand other viewpoints.

Sangeeta uses sociology in the medical field. What field might you bring a sociological approach to?

EXPLORE CAREERS IN SOCIOLOGY

- A career in sociology holds plenty of possibilities, whether you have a general interest in how societies work or an interest in something specific (like health, education, gender, crime, religion or welfare). You can become an ethnographer like Sangeeta or a public policymaker to influence the world around you.
- You can find more information about professions and careers on the British Sociological Association website: **www.britsoc.co.uk**
- Potential earnings will depend on which field sociology takes you into. According to PayScale, a sociologist in the UK will earn between £23,500 and £36,000 a year, while a social worker might earn between £24,000 and £40,000 annually.

PATHWAY FROM SCHOOL TO SOCIOLOGY

- Sangeeta says that studying history, literature, politics, economics, philosophy and anthropology can be useful in pursuing a career related to sociology.
- Sangeeta strongly recommends attending a university open day or a taster session provided by university teachers for schools. Visit the University of York's departmental website to get an idea of the courses they offer at: **www.york.ac.uk/sociology/undergraduate/careers**

HOW DID SANGEETA BECOME A MEDICAL SOCIOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I enjoyed reading (mainly fiction, but also anything I could lay my hands on), music, debates and walking.

WHO OR WHAT INSPIRED YOU TO BECOME A SOCIOLOGIST?

Growing up in a small town in Kashmir, India, I stumbled upon sociology by accident while applying for my undergraduate degree. It was a new subject, and I was excited by the course content since it seemed to cover everything from religion, culture, kinship, politics, education to science. I absolutely loved it and never looked back.

My grandfather, an educationist, was a major influence who inspired me to pursue a PhD. My parents supported me unconditionally when I moved to Delhi for my higher studies. The academic standards were very high. I struggled and nearly failed my first year of my master's degree! I persevered, thanks to some of my brilliant teachers who nurtured a passion for thinking critically.

WHAT INFLUENCED YOUR DECISION TO STUDY THE SOCIAL ISSUES SURROUNDING SICKLE CELL AND THALASSAEMIA IN INDIA AND THE UK?

My long-standing academic partnership with my senior colleague Karl Atkin and our mutual interest in ethnicity/race and health in the UK provided an opportunity to work on a project that explored the experiences of thalassaemia and sickle cell carriers and the screening policies in the UK. It was fascinating to think about how the same condition has such different cultural and historical meanings for different ethnic groups in the UK.

In the process, I asked myself some questions: how different would the history of sickle cell disease have been had it first been 'discovered' in an Indian body rather than a student of Black African heritage in the US? How are genetic risk and illness managed in the poorest communities where access to state healthcare is not guaranteed? What does living with genetic disorders teach us about how we engage with and address differences embodied in notions of genetic mutations, race, ethnicity and disability?

WHAT HAS BEEN THE HIGHLIGHT OF YOUR CAREER SO FAR, AND WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

Getting a grant from the Economic and Social Research Council to work in India has been an absolute privilege. It broadened the scope of my work and provided me with the opportunity to work with an excellent team of colleagues.

My ambition for the next five years is to write a historical biography of sickle cell in India to further explore and document the links between race, ethnicity, tribe and caste, and marginalisation, health and citizenship.

WHAT DO YOU ENJOY DOING IN YOUR SPARE TIME?

Reading, gardening, walking, listening to music and cooking.

SANGEETA'S TOP TIPS

01 Be curious about the social, material and natural spaces around you and how things work.

02 If you have a question, don't be afraid to ask. Curiosity to learn is a gift for life.

03 Success is a measure of perseverance, patience and hard work (with some luck) rather than intelligence or brilliance.

04 If you are motivated to learn a subject or do something that seems difficult, go for it. Stay motivated and you will get there.

05 Remember, we learn more from our failures than our successes.

06 Always aim for slightly more than what you think you can achieve; that motivates you to try just that bit harder.

OTHER ACADEMIC TEAM MEMBERS ON THE IBD PROJECT:

PROFESSOR KARL ATKIN

Professor
Department of Sociology
www.york.ac.uk/sociology/our-staff/academic/karl-atkin/

PROFESSOR VEENA DAS

Krieger-Eisenhower Professor; Interim Director of Graduate Studies
www.anthropology.jhu.edu/directory/veena-das/

PROFESSOR MAYA UNNITHAN

Professor of Social and Medical Anthropology
www.profiles.sussex.ac.uk/p2755-maya-unnithan

HOW CAN WE END THE HEALTH DISPARITY THAT EXISTS IN ASTHMA CARE?

PROFESSOR BRIAN SEYMOUR OF **EDWARD WATERS UNIVERSITY**, JACKSONVILLE, FLORIDA, USA, STUDIES THE IMMUNE SYSTEM'S RESPONSE TO AIRBORNE SUBSTANCES THAT CAN TRIGGER ALLERGIC REACTIONS SUCH AS ASTHMA, THE MECHANISM OF THE DISEASES AND HOW TO PROTECT INDIVIDUALS FROM THEIR HARMFUL IMPACTS. HE IS ALSO INTERESTED IN THE REASONS WHY SOME SOCIO-ECONOMIC GROUPS ARE DISPROPORTIONATELY AFFECTED BY DISEASE, AND HOW TO ACHIEVE BETTER HEALTH OUTCOMES AND HEALTH EQUITY IN VULNERABLE COMMUNITIES

TALK LIKE AN IMMUNOLOGIST

ALLERGY – a damaging immune reaction to a usually innocuous (harmless) and ubiquitous (found everywhere) substance

ASTHMA – narrowing of airways that causes wheezing, often in response to an allergic reaction

IMMUNOLOGY – the study of the immune system and how the body protects itself from infectious diseases

SOCIO-ECONOMIC – based on social and economic factors (such as social class, education or income)

PALYNOLOGY – the study of pollen grains and other spores

PLASMA CELL – a white blood cell, called a B cell, that is capable of producing and secreting antibodies

CYTOKINES – proteins which affect the communication between other cells

T HELPER CELL – a white blood cell that aids the activity of the immune system by releasing cytokines (for example, the cytokine IL4 can cause B cells to release allergic antibodies)

ANIMAL MODEL – an animal used in medical/scientific research

It is highly likely you know someone who suffers from asthma. It is a chronic inflammatory disease affecting more than 300 million people worldwide. In fact, approximately one in every 13 Americans is affected by the condition. Some asthma sufferers have their asthma fully under control and rarely suffer from any related ailments. Some might feel wheezy from time to time or need their inhaler to help their breathing when they take part in exercise. For sufferers with more severe asthma, many aspects of daily life might be a struggle. Asthma is a common-place medical condition, but how much do you know about it? How does asthma affect the body, and how can the disease best be treated? Are some people more likely to suffer from it than others, and to what extent does environment impact asthma rates?

Answering these questions could help millions of people around the world to control and manage this condition. Based at Edward Waters University (EWU), Dr Brian Seymour, a professor of biology with an earned doctorate in immunology, has spent many years studying the body's immune response to asthma to unravel the mechanism of this disease. He is also investigating why certain socio-economic groups are more likely to be afflicted by this disease than others. He is leading valuable community outreach effort to improve health literacy as a strategy to reduce disparities in health care.

A CAREER IN IMMUNOLOGY

Working at a blood bank after graduating from Southern Illinois University with a bachelor 's degree in biology, the future Professor Seymour became fascinated by the way a recipient's body could reject a donor's blood after multiple transfusions, even if they were a match in terms of red blood cell type. This was due to discrepancies in white blood cell type, as was observed from his laboratory test. His work in blood testing led to a position working with kidney donors, testing for compatibility between donor and recipient. The role of the immune system in recognising the body's own cells versus foreign ones sparked Professor Seymour's interest and was the catalyst that motivated him to pursue graduate studies in immunology. Having achieved his master's in clinical science with a major in clinical immunology, he embarked on a career in research studying the immune responses to allergens.

While working at the DNAX Research Institute, Professor Seymour researched the proteins (cytokines) that are released by T helper type 2 (Th2) cells, a type of white blood cell which is

active in the immune system's harmful response to allergens. By blocking cytokine release, the team found it could limit the amounts of antibodies produced by plasma cells (antibody-producing white blood cells) that are elevated during the body's allergic asthma response. Professor Seymour says, "As we were using animal models of lung inflammation, we were, indeed, unravelling the mechanism of allergic asthma."

ANIMAL MODELS

Professor Seymour received funding from the Tobacco-Related Disease Research Program (TRDRP) in California and the DNAX Research Institute to pursue a PhD in Immunology at the University of California, Davis (UCD). There, he studied the effects of second-hand cigarette smoke, also known as environmental tobacco smoke (ETS), on the immune system. Prior to his research, epidemiological studies had suggested that ETS was responsible for increases in cancer and asthma rates. He acknowledges that this was difficult to prove, due to "many environmental pollutants that one is exposed to on a daily basis, such as diesel exhaust particles". He was part of an interdisciplinary team which used animal models (specifically mice) to study the effect of ETS on allergic asthma, without external environmental pollutants. Some mice were kept as control subjects, while others were exposed to ETS. They were all also exposed to allergens that are known to cause allergic asthma. All of the mice were then examined for three parameters that are characteristic of allergic asthma: Th2 cytokines, allergic antibodies and bronchial hyperresponsiveness (wheezing). Professor Seymour explains, "These three parameters were significantly enhanced in the groups exposed to ETS when compared to the control groups that were not exposed to ETS."

This was the first study using mice in a controlled environment to prove that ETS had a harmful effect on allergic asthma. This research, along with similar work from others, led to the ban on smoking in public areas in California.

ENVIRONMENTAL FACTORS

EWU, where Professor Seymour lectures and conducts research, is in an area referred to by public health officials as Health Zone 1 of the six health zones in Duval County, Jacksonville. This area has a high population density and is mostly urban landscape. It is ranked number one for asthma-related hospitalisations (including emergency room visits) and its asthma-related death rate is above the average in Florida. This area is also the least economically advantaged in Duval County; its population is the poorest and least educated. Professor Seymour explains, "Health disparity is not only closely linked to social or economic disadvantage but also to exposure to environmental factors." He believes that economic, social and environmental factors are all interconnected.

ASTHMA IN THE AFRICAN AMERICAN COMMUNITY

With a focus on socio-economic factors, Professor Seymour's team wanted to assess the connection between high levels of allergic asthma in the African American population around Jacksonville, specifically in Health Zone 1. Professor Seymour explains, "In the US, morbidity and mortality from allergic asthma is highest in the African American population." The team collected blood samples from random residents of Health Zone 1 during the pollen season and found that 64% of participants had elevated levels of allergic antibodies. The researchers then studied the concentration of pollen grains in the air in Health Zone 1, using a monitor on the roof of EWU. "We found pollen grains were elevated to levels deemed as severe by the National Allergy Bureau (NAB)," says Professor Seymour. This finding led the team to speculate that high levels of pollen grains may be partly responsible for high rates of allergic symptoms in this area.

DR BRIAN SEYMOUR
Professor of Biology and Research Director of the Center for the Prevention of Health Disparities, Edward Waters University, Jacksonville, Florida, USA

FIELDS OF RESEARCH
Immunology, Palynology

RESEARCH PROJECT
Studying the airborne pollen in Northeast Florida and how it correlates to the high rate of allergic asthma in Health Zone 1, a vulnerable community in urban Jacksonville

FUNDER
US National Science Foundation (NSF)
Grant ID: 2000433

AIMING FOR HEALTH EQUITY

Professor Seymour acknowledges that there is still a long way to go before health equity is attained in the US. He says, "A vulnerable community will have poor health outcomes due to the health disparities that exist in that environment." Issues include access to affordable health care, access to healthy food and lack of public health facilities in particular communities. These factors lead to a situation where, according to Professor Seymour, "ethnic minority groups and the vulnerable populations are disproportionately burdened by many diseases". Researchers like Professor Seymour are working diligently to bring awareness and to provide substantive empirical evidence that policy makers will need to address the health disparity that exists in Health Zone 1.

ABOUT IMMUNOLOGY

WHAT IS IMMUNOLOGY AND WHY CHOOSE IT AS A CAREER?

Immunology is the study of the immune system and how life forms fight infectious diseases. Immunologists can be lab-based (conducting research) and clinical (working directly with patients in a medical setting), studying a wide range of diseases such as allergies, immunodeficiency, neurodegenerative conditions (e.g. Alzheimer's) and cancer. The discipline also covers both academia and industry. Vaccine development is another area of research in immunology. The British researcher Edward Jenner, whose work in the late 18th century led to developing the vaccine against smallpox, is often credited for immunology becoming a science. Vaccination is likely responsible for saving more lives than any other aspect of medicine.

In studying immunology, it is impossible to ignore the importance of public health and the social and environmental factors which have an influence upon different socio-economic groups and their respective health. Professor Seymour states, "Health disparities still exist, and we are far from attaining health equity in the US." To understand immunological problems and achieve health equity, it is important to consider many factors.

Research in immunology may impact upon legislation, to protect people's health. For example, Professor Seymour's work played a role in smoking being banned in public places in California.

REWARDS IN INDUSTRY AND ACADEMIA

Professor Seymour finds positives in both lines of work. He says, "Ultimately, both industry and academia have the goal of making life better for humanity." While industry offers more financial resources for targeted research and development, researchers in this area are more constrained by the demands of the industry in which they are working. Academia gives greater flexibility for researchers to write their own proposals and offers teaching opportunities to work with students from a range of backgrounds, which for Professor Seymour, "is a satisfaction that goes beyond the financial gains".

RESEARCH OPPORTUNITIES

New fields of immunology are constantly being developed. One such field is personalised (or precision) medicine. This involves targeted therapy for a specific problem. For example, a physician can treat a patient for a specific pollen allergy by training a patient's immune system to become unresponsive to the particular pollen. Computational skills will be particularly important in the future.

Professor Seymour explains, "The next generation of immunologists will need to know bioinformatics, while being knowledgeable in the field of immunology in order to unravel big data to understand data trends."

WORKING WITH COMMUNITIES

The Center for the Prevention of Health Disparities is involved with multiple public outreach programmes. Professor Seymour is a board member of the Northeast Florida Health Education Center. This centre, in collaboration with EWU, offers tobacco cessation classes in Health Zone 1 of Duval County, Florida, to assist residents of the community to quit smoking. EWU also organises internships and post-baccalaureate programmes for students. Professor Seymour is also the lead evaluator of a programme to improve health literacy for vulnerable populations, in response to the COVID-19 pandemic. The Center for the Prevention of Health Disparities also offers field trips in ecology, along with health and wellness programmes for students in the community. The centre also runs the only pollen counting station accredited by the NAB in Northeast Florida.

For Professor Seymour, and immunologists like him, work is not confined to the lab!

EXPLORE CAREERS IN IMMUNOLOGY

- You could work for a university or in industry, working on advancing treatments and working towards health equity.
- Find an internship during the summer of your undergraduate degree – most universities will offer an internship programme.
- The American Public Health Association provides information on internships for undergraduate and graduate students: **www.apha.org/Professional-Development/APHA-Internships-and-Fellowships**
- The American Association of Immunologists (AAI) has a careers page on its website: **www.aai.org/Careers**
- The British Immunology Society hosts a wealth of information about careers in the field: **www.immunology.org/careers**
- The UK's National Health Service (NHS) also provides useful information: **www.healthcareers.nhs.uk/explore-roles/doctors/roles-doctors/medicine/immunology**

PATHWAY FROM SCHOOL TO IMMUNOLOGY

- Study chemistry, biology and mathematics at high school.
- At university, study chemistry, microbiology or cell biology.
- With the growing importance of bioinformatics and data, Professor Seymour recommends studying computing and data science when given the opportunity.
- Gain experience with first-hand immunology through an internship or work experience programme.
- Study for a PhD in immunology or become a physician and specialise in allergy, immunology or pulmonology. Information on PhDs in immunology can be found here: **www.online-phd-degrees.com/doctor-phd-immunology**

ASK PROFESSOR SEYMOUR

HOW DID YOUR CHILDHOOD INFLUENCE YOUR CAREER PATH?

As a child growing up in a farming community on the coast of South America in the country of Guyana, I experienced severe episodes of hives, particularly during the harvest season. My grandmother used many home remedies for its treatment. Being an inquisitive child, my curiosity as to why these hives only occurred at a specific time of the year followed me into my college years. I was relieved when I realised that there was an explanation for the problem that had affected me in my childhood. Learning about the role my immune system played in my childhood ailments sparked my interest and motivated me to learn more.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

There are always going to be obstacles in life. We must expect them, confront them and be able to adjust when they occur. However, with perseverance and the ability to learn from our mistakes and the mistakes of others, we can overcome most obstacles. Switching off from work can be easy at times, especially when my family requires attention! Vacations are a must; you need to be able to learn how to relax. Sometimes, it's in those moments that your greatest inspirations are acquired.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

I have worked with Dr Robert L. Coffman, at the DNAX Research Institute, who discovered that there were multiple types of T helper cells by looking at the cytokines the cells secrete during an immune response. We were the first to demonstrate, in an animal model of lung inflammation, that antibodies against IL5 (a cytokine secreted by Th2 cells) will inhibit lung inflammation caused by eosinophils (a type of white blood cell)*. I am gratified to know that studies like this have paved the way for the development of new drugs that treat conditions in patients such as eosinophilic asthma. I am also proud to know that my definitive studies on ETS with Dr Laurel Gershwin of the TRDRP at UCD played a role in changing public policy in California and the world**. I am also proud that I established the only pollen counting station accredited by the NAB in Northeast Florida. It is one of only three such stations in the state. However, my proudest moments will continue to be when I see the undergraduate students whom I have mentored moving on into graduate, pharmacy and medical schools.

**Antibody to interleukin-5 inhibits Helminth-induced eosinophilia in mice. (1989). Coffman, R.L., Seymour, B.W.P. Hudak, S., Jackson, J. and Rennick, D. Science 245: 308-310.*

***Second-hand smoke is an adjuvant for T helper 2 responses in a murine model of allergy (1997). Seymour, B.W.P., Pinkerton, K.E., Friebertshauser, K, Coffman, R.L. and Gershwin, L.J. J. Immunol. 159: 6169-6175.*

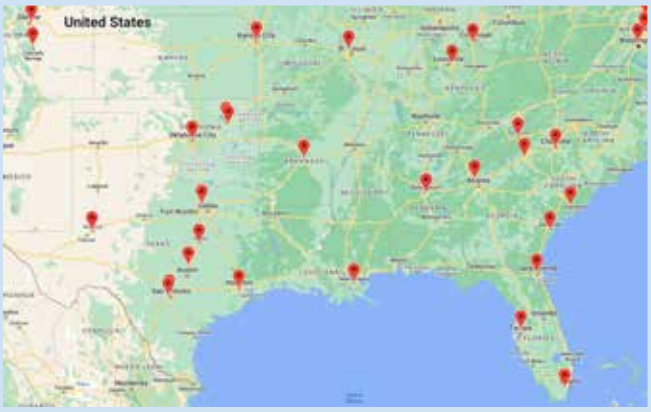
PROFESSOR SEYMOUR'S TOP TIPS

01 Take part in internships during your undergraduate studies to get first-hand experience of many areas of biology and to meet researchers.

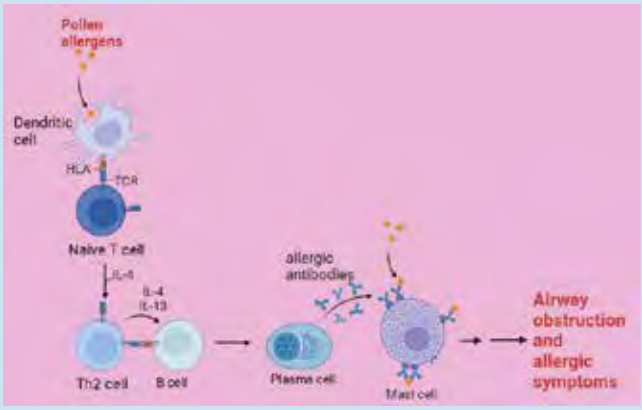
02 Some institutions offer post-baccalaureate programmes, which are paid placements that prepare you for graduate education. If you can, get involved in them.

03 Study computing and data science to future-proof your career.

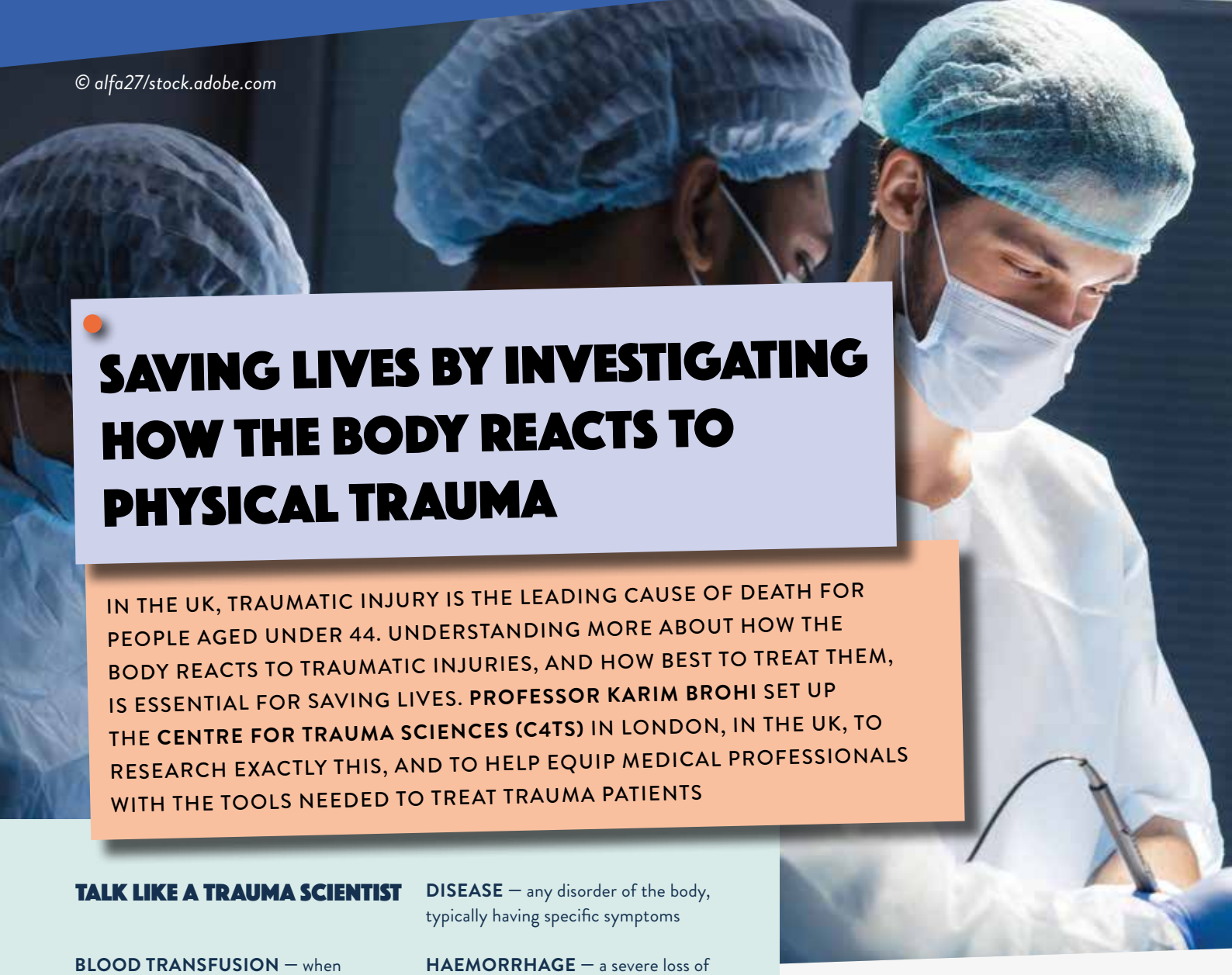
04 Be willing to work hard and be dedicated to science.



Pollen stations accredited by the National Allergy Bureau (NAB) in the US
(posted with permission from the American Academy of Allergy, Asthma & Immunology (AAAAI) – visit AAAAI.org for additional information and updates)



Various immune cells can collaborate with each other to trigger a deleterious immune response in the presence of airborne pollen
(image created with BioRender.com)



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SAVING LIVES BY INVESTIGATING HOW THE BODY REACTS TO PHYSICAL TRAUMA

IN THE UK, TRAUMATIC INJURY IS THE LEADING CAUSE OF DEATH FOR PEOPLE AGED UNDER 44. UNDERSTANDING MORE ABOUT HOW THE BODY REACTS TO TRAUMATIC INJURIES, AND HOW BEST TO TREAT THEM, IS ESSENTIAL FOR SAVING LIVES. **PROFESSOR KARIM BROHI** SET UP THE **CENTRE FOR TRAUMA SCIENCES (C4TS)** IN LONDON, IN THE UK, TO RESEARCH EXACTLY THIS, AND TO HELP EQUIP MEDICAL PROFESSIONALS WITH THE TOOLS NEEDED TO TREAT TRAUMA PATIENTS

TALK LIKE A TRAUMA SCIENTIST

BLOOD TRANSFUSION — when a patient receives replacement blood intravenously

CLINICAL TRIAL — research studies, involving patients, that aim to evaluate the effectiveness of medical interventions, such as new drugs or technologies

CLINICIAN — any a doctor who directly treats patients, rather than undertaking lab research

CRYOPRECIPITATE — a frozen blood product made from blood plasma

DISEASE — any disorder of the body, typically having specific symptoms

HAEMORRHAGE — a severe loss of blood through a ruptured blood vessel

RANDOMISED CONTROLLED TRIAL (RCT) — a clinical trial in which patients are randomly assigned to either a control or intervention arm

TRAUMA — in medicine, a physical injury

TRIAGE — in in medicine, the method by which patients are assessed based on the urgency of treatment, in order to prioritise the most urgent cases and direct patients to the most appropriate medical practitioners

Have you ever watched a TV drama, film or 'fly on the wall' docuseries where a medical emergency takes place? The urgent wheeling of beds through hospital doors, the concise and urgent communication between medical professionals, the wait to see how the patient fares ... We watch these life-or-death scenarios, gripped to our seats, in awe of the professionals dealing with them and willing their hard work to succeed. We can picture such dramatic scenes and imagine paramedics, doctors and nurses referring to trauma and life-changing injuries, but what does trauma mean in medical terms? How does it impact the body? What knowledge, research and expertise are needed to help people survive trauma?

"In medicine, trauma refers to physical injuries to the body and their consequences," says Professor Karim Brohi, a trauma scientist and surgeon. "It's classified as a disease because, like any disease, it has its own specific causes, its own biology, and its own treatment and outcomes." Given that traumatic injuries can vary hugely, it is important that medical professionals know the best way to deal with any trauma case that enters the hospital environment.

Early on in his career, Karim came to realise that the management of trauma patients was flawed. "In the UK, lack of trauma experience and poor organisation of trauma services means that patients are still dying from treatable injuries," he explains. "This has fuelled my ambition to improve these standards." Developing best practice requires a strong evidence base to set standards, and this was what Karim saw was lacking.

In response to this realisation, Karim set up the Centre for Trauma Sciences (C4TS) to improve collective understanding of trauma and how to treat it. The C4TS works across two world-leading organisations, Barts Health NHS Trust and Queen Mary University of London, both of which have a deep commitment to trauma care.

TRAUMA FACTS

- **Traumatic injury** is caused by various forces from outside of the body, which can either be blunt or penetrating (sharp).
- **Blunt trauma** includes falls, road traffic crashes, crush injuries, assaults (eg., punches and kicks) and burns.
- **Penetrating trauma** involves shooting, stabbing or falling onto a sharp object (known as impalement).
- Traumatic injury is the leading cause of death for people aged under 44 in the UK.
- Up to 17,000 people in the UK die from traumatic injury every year.
- For every trauma fatality, between three and four patients survive with a serious or permanent disability.
- Many people who experience a physical trauma also experience psychological and emotional difficulties, which can be long lasting.

PROFESSOR KARIM BROHI

Head of Trauma Sciences research team, Centre for Trauma Sciences, Barts and the London School of Medicine & Dentistry (SMD), Queen Mary University of London, UK

FIELD OF RESEARCH

Trauma Science

RESEARCH PROJECT

Understanding how the body responds to trauma and how to treat it

FUNDERS

National Institute for Health Research (NIHR), Medical Research Council (MRC), European Union (EU), Barts Charity, Rosetrees Trust

WHAT MAKES THE C4TS SPECIAL?

"We are unique in so many ways," says Karim. "I wanted to enable high-quality trauma research that would attract scientists and clinicians to work in this field, and that would show that high-quality research is not only possible in this difficult environment but can save many lives." Researching trauma is not easy. Every case is different, and treatment is usually urgent, meaning that it is far more challenging to set up the typical requirements of good research, such as carefully controlled variables, precise measurements and sufficiently large sample sizes.

The C4TS manages to overcome these challenges. "We have developed an embedded research team that works alongside the clinical trauma teams 24 hours a day, seven days a week, to study patients within minutes of their injuries," says Karim. "We work closely with our patients and clinical colleagues to develop our research programme, and we have a strong commitment to making our research outputs available to everyone."

AREAS OF FOCUS

Principally, the C4TS deals with the immediate aftermath of injury. "At the moment, we are working on developing new treatments to help blood clotting, supporting the heart after trauma, and understanding how the immune system responds to injury," explains Karim. "We are also looking at ways to prevent injury, for instance by reducing violence or cycling accidents." The centre is conscious of the importance of ensuring healthcare is equitable and effective for all in society and is looking into ways to facilitate this.

"Some of our team will be recruiting new patients, some doing follow-up assessments, and some working on their own research projects – in the lab or on computers," says Karim. "The team also participates in a lot of talks and other educational activities." A central component of the centre's work is ensuring that its research findings are taken up in practice and policy, rather than ending their journey in medical journals, so that they bring real, tangible benefits to patients.

SUCCESSES

Thanks to the participation of patients and the ongoing work of researchers, Karim and his team have learned more about how a traumatic injury can affect the blood, particularly in the hours following an injury. The C4TS has now been running for over a decade and has made big strides. "We have discovered a huge amount about how the body responds to critical injury," says Karim. "Sometimes, the body responds appropriately, but other times systems can go awry." These discoveries have led to the development of new treatments and management techniques, both in hospital and at the scene of injury. "For instance, our findings have completely changed how we resuscitate patients," says Karim. "Overall, we have reduced deaths from critical bleeding by over 40% in the last ten years."

Collaboration will be key to future successes. "Trauma is important and complex, so it takes many researchers and clinicians around the world to make progress," says Karim. "We support research networks in London, across the UK and internationally." The team collaborates with trauma units in Europe and the US and conducts clinical trials for products designed to help treat trauma. Karim envisages a future where specialised trauma care is available from the moment of injury to the end of rehabilitation, and research is essential to inform this development. "We want to halve deaths from trauma again in the next ten years," says Karim. "That's our vision and our goal."

RESEARCH IN ACTION

Working in trauma means working with people with a range of injuries and experiences. Trauma can occur from a fall, an accident or from crime. Regardless of how the trauma occurs, medical professionals are passionate about helping trauma victims regain their independence and heal in the best possible way.

From working directly with patients to raising awareness of trauma injuries and trauma sciences with the public, the scope of the research conducted at the Centre for Trauma Sciences is wide and varied. Which aspect of the centre's work interests you the most?

EMBEDDED RESEARCH

The C4TS's approach to trauma care is research-led.

"We have developed a 24/7 embedded research team that works alongside the clinical trauma teams to study patients within minutes of their injuries."

Professor Karim Brohi

CLINICAL TRIALS

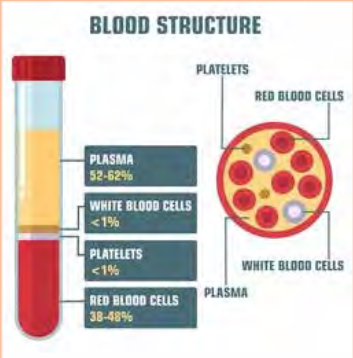
Clinical trials – research studies involving patients – allow the C4TS team to trial and evaluate the effectiveness of the medical interventions its researchers are developing.

"I love working in a role that I feel makes a positive difference to individual people. Whether it's through researching a better healthcare pathway for someone who needs it or trialling a new medical device that may just make a crucial difference for a very poorly trauma patient, I feel like what I do matters, and that's why I do it."

Claire Cochran, Clinical Trials Manager

CLINICAL TRIALS

CRYOSTAT-1 was a feasibility study for a multi-centre, randomised controlled trial (RCT) evaluating the effects of early administration of high-dose cryoprecipitate (a source of fibrinogen that enables the blood to clot) in adults suffering major traumatic haemorrhage (severe blood loss).



CRYOSTAT-2 will report on the effect of early cryoprecipitate (within 90 minutes of admission) compared to standard blood transfusion therapy. CROSTAT-2 will begin in 2023.

For more information, visit:
www.c4ts.qmul.ac.uk/research-programmes/cryostat

CRASH-2 was a clinical trial that looked at how effective an existing drug (tranexamic acid) was at reducing bleeding in patients following a traumatic injury. Results of the CRASH-2 clinical trial found that giving tranexamic acid within 1 hour of traumatic injury significantly reduced the risk of death from bleeding in trauma patients.

Activation of Coagulation and Inflammation in Trauma (ACIT) is the main pathway C4TS uses to enrol trauma patients in research studies. All trauma patients, young and old, who arrive in participating trauma centres are eligible for enrolment.

This allows clinical data and blood samples to be collected from trauma patients to support multiple studies investigating the body's response to blood and transfusion therapy.

ACIT is designed to investigate how the body's inflammation and coagulation (clotting) pathways are activated immediately following major trauma, so researchers can find ways to target and treat them if they go wrong.

For more information, visit:
www.c4ts.qmul.ac.uk/research-programmes/acit

RESEARCH PROJECTS

There are many research questions being investigated in the field of trauma science. For example, researchers at the C4TS have studied how tissue damage can impact the immune system within minutes to hours after injury – a period known as the hyper-acute window. C4TS's research suggests that immune responses during this period may determine whether a patient develops organ failure. Understanding these very early immune responses may help identify treatments to prevent organ failure after trauma.

"My main interests include organ failure and the early immune response to major injury. As well as lecturing, I also help lead a randomised control trial which is examining whether a drug called artesunate can reduce organ failure after trauma. Combining a clinical job with academia and family is a big challenge. I am constantly seeking ways to organise my time, maintain balance and remain healthy. I am privileged to work with inspirational colleagues who share my interests and provide thoughtful mentorship and advice. This helps drive my enthusiasm and motivate me during challenging periods."

Joanna Shepherd, Clinical Lecturer

REHABILITATION & AFTER-CARE

While medical professionals are on the ground seeing patients right after their injury, conducting surgery and providing patient care, researchers are learning new ways to treat patients and improve their chances of rehabilitation and improve their quality of life.

"Having a background in counselling psychology and sociology means that I do not have a traditional medical background. However, my background in the social sciences has provided me with the skills to support patients and their family members with a range of information and guidance if they have been involved in a trauma, through the Aftertrauma.Org website and the AfterTrauma app. If you are not sure which path to take in medicine, just know that there are a range of opportunities for those who have a passion for people and for achieving clinical excellence!"

Dr Jacqueline Rappoport, Lecturer

PUBLIC SAFETY

The C4TS is committed to ensuring the public is aware of the risks that are associated with trauma in a variety of ways. There are public safety events, educational programmes sponsored throughout the country, and videos and free resources available on the C4TS website. The C4TS team is passionate about providing the public with the resources and tools needed to prevent, understand and recover from trauma.

"In the context of trauma, a death is considered avoidable if the injury is treatable, or if the circumstances could have been prevented. Preventative interventions are known as the 'public health approach'. A famous example of injury prevention in trauma is the seatbelt. I'm studying the social determinants of violence, trying to understand if there is an intervention that could prevent a violent incident from happening. Working at the front line of trauma care in the UK, I have a privileged opportunity to work with young people and understand what we can do to help."

Michael Carver, Clinical Research Fellow

MEET KARIM

As a surgeon, I provide care for patients with vascular diseases and traumatic injury. As a scientist, I conduct clinical research and supervise 15 researchers who are investigating different aspects of traumatic disease.

I was interested in pretty much everything while growing up - except learning Latin and piano practice!

I never thought about becoming a scientist. I became a doctor and then a surgeon. Seeing patients dying of traumatic injuries made me want to do better, and to do that I recognised that we needed a better understanding of trauma.

When I realised that management of trauma patients in the UK was poor, I set up **www.aftertrauma.org**, a non-profit online forum that provides educational materials, expert discussions and online support for trauma surgeons worldwide.

My educational career saw me studying medicine and computer science, before becoming a medical practitioner. I became qualified in both anaesthetics and surgery, an unusual combination but an extremely useful set of skills for trauma patient management. I have worked for the Helicopter Emergency Service in London, a trauma hospital in San Francisco, and as a consultant at the Royal London Hospital.

Perseverance. Following-up. Collaborating. Questioning. All these attributes have helped me succeed.

I've found that insurmountable obstacles are rare. Problems usually suggest you need a slightly different path; you need to move faster, or you need to keep going until the obstacle disappears. My tenacity is helped by the fact that, although I persevere, I've never had a problem switching off from my work.

My proudest moments are seeing people who work or study at C4TS go on to get great jobs and do great things.

KARIM'S TOP TIP:

Don't follow in anyone's footsteps. Be interested in something – preferably lots of things – and chase those interests, and see where they take you. You can always regroup and try again!

EXPLORE CAREERS IN TRAUMA SCIENCE

Karim recommends looking for volunteering opportunities in local trauma units, finding opportunities to speak to paramedics, nurses or doctors, and reading widely.

The team recommends the C4TS website (**www.c4ts.qmul.ac.uk**), which includes information about the centre's outreach and engagement activities (**www.c4ts.qmul.ac.uk/education-outreach/outreach-programmes-and-events**) and their MSc programme (**www.c4ts.qmul.ac.uk/education-outreach/msc-trauma-sciences**).

You should also look for nearby trauma research programmes at universities or hospitals, and express interest in getting involved via email.

PATHWAY FROM SCHOOL TO TRAUMA SCIENCE

Karim says there is a wide variety of pathways into trauma science, given the many different specialties in trauma care. He believes it is most important to be interested in and excited by what you are learning.

Entry requirements for a degree in medicine will typically look for A-levels (or equivalent) in biology, chemistry and mathematics.

Many areas of expertise are needed to research trauma and the ever-evolving nature of the field, so you could also explore areas like basic research, physiology, medical interventions, patient care and computational science.

MEET A C4TS TEAM MEMBER – JORDI

DR JORDI LOPEZ TREMOLEDA

Reader, Animal Science and Welfare, and Named Veterinary Surgeon and Welfare Officer

Jordi comes from a veterinary background and a PhD in biomedical sciences, including an extensive breadth of knowledge on preclinical research. His role in the C4TS includes developing experiments to study trauma and treatment techniques in animal models, with the findings going on to inform clinical trials with human patients.

HOW HAS YOUR CAREER PATH LED TO YOU TO THE C4TS?

My career began as a horse veterinarian before progressing into research, initially with horses but then moving to medical research and diagnostic imaging. At the C4TS, I find my veterinary and research expertise are very valuable and can ultimately help improve patient care.

WHAT DO YOUR DO DAY-TO-DAY RESPONSIBILITIES INCLUDE?

I am the designated veterinarian at Queen Mary University of London, which means I'm responsible for the care and welfare of animals used in medical research. At C4TS, I oversee the development and use of experimental models of trauma to help find new treatments.

WHAT ROLE DO ANIMALS PLAY IN TRAUMA RESEARCH?

It's currently impossible to avoid using animals for medical research. It is a legal requirement in the UK for medicines to be tested on animals before use in humans. Trauma is a very complex disease which affects the whole body. Using animals allows us to study the interconnected ways that the body responds to trauma.

WHAT CHALLENGES DOES YOUR WORK POSE FOR YOU?

Animal welfare is a key priority of my work. We must ensure that animal suffering is minimised by protecting their well-being as much as possible. Using animals in research is strictly regulated to ensure it only takes place when absolutely essential.

Animal welfare also directs the quality of research, meaning that high welfare standards can lead to better treatments for human patients. Raising awareness of the importance of animal care in research and supporting a culture of care is very rewarding, as it makes a direct impact on both animals and staff.

Minimising harm can be challenging, and critical compromises are necessary. Unfortunately, some research may cause temporary distress in animals, but is invaluable in discovering new treatments.

WHAT HELPS YOU SUCCEED?

It's important to be a team player. Trauma research is complex so working with colleagues with different areas of expertise is very important. To switch off, I spend time outdoors, swimming or cycling. It's important to recharge and avoid feeling emotionally disconnected from my caring role.

WHAT HAVE BEEN THE PROUDEST ACHIEVEMENTS IN YOUR CAREER, SO FAR?

Earning my doctorate degree was perhaps my proudest moment. I also find teaching students and engaging with audiences very rewarding. Communicating about science and why animal welfare is important is very empowering!

WHICH THREE WORDS SUM UP A TYPICAL WORKING DAY FOR YOU?

Interactive, empathetic and multidisciplinary.

JORDI'S TOP TIP:

Don't be scared of learning new things. Engage with colleagues, be a good team player, promote empathy, and respect others. Diversity is the greatest strength, so take any opportunity to study or work in different places and countries.

WHAT CAN WE LEARN ABOUT MICROBIOMES BY STUDYING WILD MICE?

WITHIN EVERY ONE OF US, THERE LIVES A THRIVING COMMUNITY OF MICROSCOPIC LIFE, KNOWN AS OUR MICROBIOME. LIKE MOST OTHER VERTEBRATES, WE RELY ON OUR MICROBIOMES TO HELP US MAINTAIN KEY BIOLOGICAL PROCESSES, SUCH AS DIGESTION AND IMMUNITY. DESPITE THEIR IMPORTANCE, THERE IS STILL A LOT THAT WE DO NOT KNOW ABOUT MICROBIOMES AND HOW THEY IMPACT THE HEALTH OF THEIR HOSTS. **DR SARAH KNOWLES,** FROM THE **UNIVERSITY OF OXFORD** IN THE UK, AIMS TO CHANGE THIS BY STUDYING THE MICROBIOMES OF WILD MICE

TALK LIKE A MICROBIOME SCIENTIST

MICROBIOME — the microscopic life that lives in or on another organism, including bacteria, archaea and protists

ARCHAEA — single-celled organisms that do not have a nucleus, but are distinct from bacteria

PROTISTS — single-celled organisms that have a nucleus, such as algae

DNA SEQUENCING — the process of determining the order of nucleotides in a strand of DNA. This method can be used to identify which microbes are present in a sample

FAECAL MICROBIOME TRANSPLANT — an experimental technique that allows a microbiome to be transferred from one individual to another

LIVE TRAPPING — a technique used to temporarily capture wild animals designed not to harm them, that allows scientists to sample and measure them

We humans often pride ourselves on our independence and self-reliance. We strive to navigate the trials and tribulations of life as resilient individuals – if we are lucky, receiving help and support from family and friends in times of need. But there is, in fact, something that is always with us, that helps to keep us functioning as we should, even though we rarely think of it – our microbiome! At this very moment, your body is home to roughly 38 trillion cells that do not belong to you, and only 30 trillion cells that do. These 38 trillion 'foreign' cells make up your microbiome – a collection of microscopic organisms that play an important role in keeping you alive and healthy.

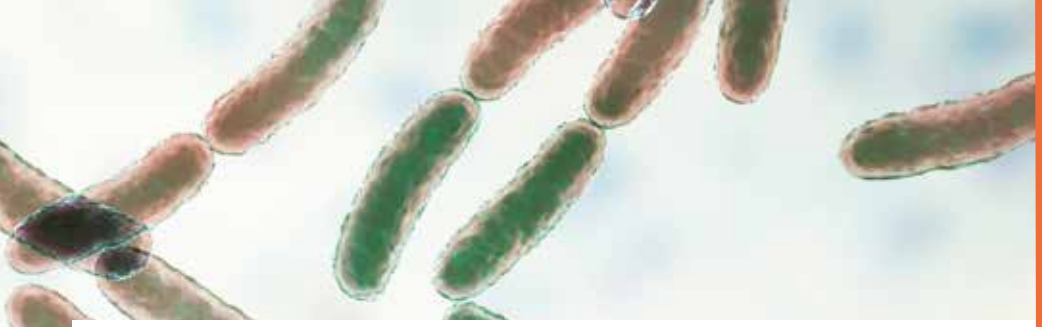
Much of our microbiome is found within our guts. Hundreds of species of bacteria live in our intestines, alongside a menagerie of viruses, fungi, protists and archaea. The microorganisms that make their homes in our intestines perform a range of different roles that help keep us healthy. They help us digest food, some play a role in regulating our immune system, and may even influence our moods by producing serotonin, which has antidepressant properties.

Research into microbiomes has exploded over the last couple of decades. However, most microbiome studies so far have focused on humans or animals in labs.

Dr Sarah Knowles, of the Department of Biology at the University of Oxford, believes that more research should be conducted on wild animals. She says, "My view is that if we want to gain a deep understanding of how microbes affect animals, we need to study microbiomes across as broad a range of animals as possible, and in wild settings, not just in the lab."

WHY IS IT IMPORTANT TO STUDY MICROBIOMES IN WILD ANIMALS?

The ways in which an animal behaves and interacts with its environment can have an impact on its microbiome and how this influences its health. Laboratory settings are, by definition, controlled and artificial. Therefore, any studies conducted under these conditions may have limited relevance to animals in the real world. Lab animals are not exposed to the same microbes that wild animals are, and the ways in which this exposure happens can be very different. In lab studies, animals are also not free to behave as they normally would and are kept secure and well-fed by humans. On the other hand, wild animals are subject to the forces of natural selection and must fend for themselves.



Mice, for example, behave very differently in the wild than they do when confined to laboratories. In the wild, they spend much of their time foraging for food, are constantly on the look-out for danger, and need to find a mate to reproduce. In labs, all their food is provided, they are safe from natural predators and can only reproduce when humans allow.

WHAT MAKES MICE SUCH IDEAL SUBJECTS FOR SARAH'S WORK?

Mice make great test subjects because they are common, easy to find in large numbers and relatively comfortable being handled by humans. A lot of Sarah's work involves marking individual wild mice so that they can be monitored in their natural habitat throughout their lives. Mice rarely travel very far, and they will often return to live traps, which means that Sarah's team can study the same individuals and their microbiomes repeatedly over time. "This is important as their microbiomes are not static but constantly changing, in ways that could alter their effects," she explains.

Another advantage of studying wild mice is that mice have been studied extensively in lab settings. This means that there is already a wealth of literature and research techniques for mice and their microbiomes that Sarah can use to inform her own studies. "This makes the research I do more insightful and powerful than it might be if I focused on a more obscure species," explains Sarah.

WHAT RESEARCH TECHNIQUES DOES SARAH USE?

Sarah's research involves a lot of fieldwork, with teams of two to six researchers setting out into the wild to sample mice. Some fieldwork is conducted locally in Oxford University's research woodland, Wytham Woods, although sometimes the team also travels further afield. One current study is being conducted on the remote island of Skokholm, off the coast of Wales in the UK, where small teams of researchers stay for several weeks at a time. "It involves a lot of early mornings and hard work, but it is also fun and wonderful to be in the great outdoors; there's lots of team spirit and camaraderie on fieldwork," Sarah explains.

Sarah often uses a technique known as 'capture-mark-recapture' when conducting fieldwork. This involves catching mice in live traps, marking them and then releasing them back into the wild so that they can be caught again at a later date. Sarah's team sprays a little sesame oil outside the trap door to attract the mice and, when the mice are captured, the team takes measurements and collects data on characteristics such as their weight, sex and age. The team also collects a faecal sample.

Back in the lab, Sarah's team makes use of molecular biology to analyse the samples. The researchers extract DNA from each faecal sample and sequence it to get a profile of the mouse's entire community of microbes. "That gives us a window into which microbes are present within the gut, and in what numbers," says Sarah. The team then uses statistical tests to analyse this microbiome data alongside information about the mice themselves, to answer questions about what affects the microbiome and how.

WHAT FACTORS CAN AFFECT A MOUSE'S GUT MICROBIOME?

When mice come into contact with each other, they often exchange microbes. Therefore, the social networks they form have a big impact on the composition of their gut microbiome. Sarah and her team study the influence of social contact by tracking mice with passive integrated transponder (PIT) tags. Sarah explains, "These are the same sort of tag some people use to identify their pet cats and dogs, only much smaller." Comparing the patterns of social contact among mice with their microbiome profiles has taught Sarah a lot about how microbes are exchanged in wild settings.

Diet can also influence a mouse's microbiome. Although it is hard to observe what mice eat, as they are nocturnal and like to stay hidden, Sarah's team can analyse the faecal samples to get an idea of what each mouse has been eating. The researchers can then compare each mouse's diet to their microbiome profile to understand how diet shapes this important microbial community.

WHAT FINDINGS HAS SARAH MADE?

"One key thing we've learnt, so far," says Sarah, "is that each wild mouse's microbiome is rather unique – a bit like a fingerprint. The microbiomes are highly responsive to each mouse's external environment. A mouse's microbiome is influenced by the other mice they encounter, including their mother in early life and social contacts, and by what they eat. For example, the microbiome of wild mice changes with the seasons as different food sources become available."

WHAT DOES SARAH PLAN TO DO NEXT?

Sarah aims to understand the significance of natural variation in the microbiome – how it affects physiology and the ability of mice to survive and reproduce. Sarah plans to carry out experiments involving faecal microbiome transplants to see how different microbiomes affect processes such as thermoregulation (how animals regulate their body temperature), weight gain and behaviour.

Understanding the influence that microbiome variation has on wild mice may yield insights into how we humans are affected by our microbial companions. Sarah's work, along with other research in the field of microbiome science, has the potential to influence important sectors such as medicine, agriculture and conservation.

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DR SARAH KNOWLES

Department of Biology,
University of Oxford, UK

FIELDS OF RESEARCH

Biology, Microbiome Science

RESEARCH PROJECT

Studying the gut microbiomes of wild mice to understand how they impact physiology and behaviour

FUNDERS

Natural Environment Research Council (NERC), part of UK Research and Innovation (UKRI), European Research Council (ERC)

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ABOUT MICROBIOME SCIENCE

Like mice, humans have a microbiome that plays an important role in many biological processes. In fact, all vertebrates, like birds and reptiles, rely on the communities of microbes that live within their guts to keep them healthy. Despite their importance, microbiomes can vary dramatically between animals in the same population. The microbiome of an individual can also change significantly depending on factors such as what they eat, which other animals they come into contact with, and as they age.

Microbiome science is dedicated to understanding how and why this variation occurs and what effects it might have on animal health and behaviour. Sarah runs her own lab and is guided by this overarching question to formulate research which she carries out alongside her team.

WHAT ARE THE REWARDS AND CHALLENGES OF LEADING YOUR OWN LAB?

"Running a lab is hugely rewarding in that you have intellectual freedom to pursue questions that spark your curiosity," says Sarah. "You never stop learning, and your job is very dynamic – every new project takes you in new directions, learning new skills and thinking about new problems." Sarah also gets to mentor people who share her passions and interests, which she says is "a huge privilege".

However, running a lab is not without its challenges; Sarah likens it to running a small business. "You have to bring in funding to pay the salaries of people in your group and fund the research. You need to work hard and juggle many different responsibilities around research, teaching and contributing to the wider scientific community. But, for me, it's worth it!"

WHAT MAKES MICROBIOME SCIENCE SUCH AN EXCITING FIELD?

Microbiome science is a young field, and our knowledge about these microbial communities is constantly developing and evolving. The field really took off when new DNA sequencing methods became available, which was around the same time that Sarah finished her PhD.

"Since then, discoveries have been coming thick and fast. So much so that it can be hard to keep up!" says Sarah. New findings are emerging all the time, and microbiome science is unearthing new ways in which microbes influence a wide range of biological processes. "It is also very interdisciplinary, which makes it fun and exciting, and means you get to collaborate with people with diverse skills and perspectives," Sarah explains.

EXPLORE CAREERS IN MICROBIOME SCIENCE

- There is still so much that we do not understand about microbes, so there will be lots of work for the next generation of microbiome scientists. Sarah expects there will also be lots of opportunities in industry as start-ups and big companies look to tackle problems like disease management and food security.
- The Department of Biology at the University of Oxford offers a range of outreach activities (**www.biology.ox.ac.uk/outreach**) including the Curiosity Carnival (**www.ox.ac.uk/curiosity-carnival**) and annual UNIQ spring and summer schools for sixth form students (**www.uniq.ox.ac.uk**).
- The Royal Society for Biology has lots of useful resources for anyone interested in pursuing a career in biology: **www.rsb.org.uk/students**
- Sarah also recommends the British Ecological Society, which has many interesting events, including a summer school for 16–18-year-olds: **www.britishecologicalsociety.org/learning-and-resources/career-development**

PATHWAY FROM SCHOOL TO MICROBIOME SCIENCE

- Sarah recommends studying biology, chemistry and maths at A-level. Other subjects such as physics and psychology can also be useful, depending on what your specific interests are.
- Taking part in summer school programmes, like those mentioned on this page, can help strengthen your university applications.
- University courses in biological subjects range from general (e.g., biology), to specific (e.g., genetics). It is important to take the time to consider your options carefully. Sarah studied biological sciences for her undergraduate degree, and this provided her with a solid and broad foundation from which she was able to specialise.

HOW DID SARAH BECOME A MICROBIOME SCIENTIST?

WHERE DOES YOUR LOVE OF BIOLOGY AND ECOLOGY STEM FROM?

I have always loved the natural world and wanted to know more about it. As a kid, I spent hours trying to identify creatures in rock pools and watching nature documentaries. At secondary school, I developed a particular fascination with infectious organisms and evolutionary biology, having been captivated by Richard Dawkins' book *The Selfish Gene*. From there, I was hooked. My family had some influence too, as my parents are both biologists, albeit in somewhat different fields (pharma and cancer research). Conversations at the dinner table definitely sparked my curiosity.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

When I was younger, I simply loved the subject of biology, so I pursued it at university. Then, during and after my degree, I found that I also loved the actual process of carrying out scientific research, which set me on an academic career path. I've been inspired by many people during my journey through science so far, but my decision to become a scientist evolved gradually, rather than being a lightbulb moment or fervent ambition from a young age.

"I'VE BEEN INSPIRED BY MANY PEOPLE DURING MY JOURNEY THROUGH SCIENCE SO FAR, BUT MY DECISION TO BECOME A SCIENTIST EVOLVED GRADUALLY, RATHER THAN BEING A LIGHTBULB MOMENT OR FERVENT AMBITION FROM A YOUNG AGE."

HOW DO YOU SWITCH OFF FROM YOUR WORK?

Spending time with my kids always puts things into perspective and gives me plenty of giggles to switch off from a day's work. I also love exploring the countryside, and make sure I have proper holidays, without a laptop or emails. These help me top-up my energy, curiosity and creativity.

WHAT ARE YOU AIMS FOR THE FUTURE?

I just want to do good science and contribute discoveries that move the field forward.

SARAH'S TOP TIPS

1. Follow your curiosity and interests.
2. There is no one type of person that can be a biologist, so don't believe you are not good enough, or not from the right background.
3. Seek out and be guided by role models and mentors, but don't be afraid to forge your own path.

HOW CAN SMART CONTACT LENSES MONITOR AND TREAT EYE CONDITIONS?

MORE THAN 3 MILLION PEOPLE LIVE WITH GLAUCOMA IN THE UNITED STATES, AN EYE DISEASE THAT IS THE WORLD'S SECOND LEADING CAUSE OF BLINDNESS. AT **PURDUE UNIVERSITY, DR CHI HWAN LEE** IS USING HIS SKILLS AS A BIOMEDICAL ENGINEER TO DEVELOP SMART CONTACT LENSES THAT CAN BOTH MONITOR THE CONDITION AND DELIVER DRUGS TO COMBAT IT

TALK LIKE A BIOMEDICAL ENGINEER

BIOAVAILABILITY — the fraction of a drug that enters the body and has an active effect

BIOSIGNAL — a signal in living organisms that can be measured e.g., heart rate

CORNEA — the transparent layer forming the front of the eye

GLAUCOMA — an eye condition in which increased pressure within the eyeball can lead to an eventual loss of sight

OCULAR — an adjective describing something concerned with the eye or vision

WEARABLE BIOMEDICAL DEVICE — an electronic device that can be comfortably worn on the body while performing a specific medical function

Imagine wearing contact lenses that could not only monitor your eyes to check for diseases, but could also send reports to your doctor and administer drugs directly into your eyes to improve your condition, all while you are sat in the comfort of your own home. This futuristic-sounding type of healthcare could soon become a reality. Dr Chi Hwan Lee, associate professor of biomedical engineering and mechanical engineering at Purdue University, is developing smart contact lenses that can do just that.

Biomedical engineering lies at the heart of medical technology, where researchers collaborate with healthcare practitioners to develop new and innovative devices that can improve the lives of patients. Chi Hwan's research group is designing wearable biomedical devices that can be attached to a patient's eye or skin to monitor or treat specific health conditions.

WHAT CAN THESE DEVICES MONITOR?

Wearable sensors can be tailored to monitor a range of physical (e.g., pressure and strain), electrophysical (e.g., heart and muscle activities) and electrochemical (e.g., chemicals in blood or sweat) biosignals. For example, sensors attached to the skin under the chin could be used to monitor muscle activity in individuals suffering from swallowing disorders, and contact lenses could monitor ocular pressure in those suffering from glaucoma. As more than 3 million people live with glaucoma in the United States, and it is the second leading cause of blindness worldwide, finding ways to monitor the condition is essential for medical research and patient welfare.

As well as providing continuous monitoring of a patient's condition, another major benefit of Chi Hwan's wearable devices is their ability to record a patient's biosignals while they are at home and then to automatically send a report to their doctor. "This means patients do not need to frequently travel to a clinic, which is particularly helpful for those living in rural areas or with limited mobility," Chi Hwan explains.

DR CHI HWAN LEE

Leslie A. Geddes Associate Professor of Biomedical Engineering and Mechanical Engineering, Purdue University, West Lafayette, Indiana, USA

FIELD OF RESEARCH

Biomedical Engineering

RESEARCH PROJECT

Developing wearable biomedical devices for the skin and eye

FUNDERS

National Institutes of Health (NIH), National Science Foundation (NSF), Department of Defence (DOD), Eli Lilly and Company, Purdue University

WHAT ARE THE CHALLENGES OF CREATING WEARABLE BIOMEDICAL DEVICES?

"The human skin and eye are soft, curvilinear and sensitive to pain," explains Chi Hwan. "Therefore, wearable biomedical devices must have mechanical softness, flexibility, stretchability and breathability, without side effects such as discomfort, pain or tissue damage."

A major challenge for designing smart contact lenses is that the fabrication of wireless sensors typically requires high temperatures and corrosive chemicals, which is why electronic circuits are normally built on hard materials. However, these rigid materials are unsuitable for use in the human eye, so Chi Hwan and his team had to develop novel techniques for creating soft and stretchable sensors that could be placed on various commercial brands of soft contact lenses.

They developed a 'peeling technique', whereby the electronic components are constructed on conventional fabrication substrates that can withstand high temperatures and corrosive chemicals but can then be thinly peeled off and transferred elsewhere. This means the sensors can exist on flexible, stretchable, transparent or biodegradable substrates, including soft contact lenses.

WHAT CAN SMART CONTACT LENSES DO?

Chi Hwan's team has developed a soft, ultrathin, wireless sensor to measure ocular pressure, which can be attached to commercial soft contact lenses. "This allows continuous 24-hour monitoring of ocular pressure for glaucoma patients, even during sleep," he explains.

As well as monitoring eye conditions, smart contact lenses can also treat them, by injecting drugs directly into the eye. "Ocular drug delivery remains a grand challenge due to the complex structure of the eye," says Chi Hwan.

Eyedrops and ointments that are traditionally used to administer ocular drugs have a very low bioavailability. Less than 5% of eyedrop medication reaches its target, as our eyes are designed to prevent foreign substances from entering. "This means larger or more frequent doses are required," says Chi Hwan, "which burdens the patient and increases the risk of side effects such as blurred vision and discomfort."

In response to this, Chi Hwan has developed tear-soluble contact lenses equipped with biodegradable nanoneedles that can inject drugs directly into the required location. "When a patient inserts the contact lens, the nanoneedles penetrate the cornea in a minimally-invasive manner and then undergo gradual degradation over the course of several months while providing sustained, painless delivery of ocular drugs," he explains. "The contact lens itself dissolves in tear fluid within a few minutes." These drug delivery contact lenses will be useful for treating chronic ocular diseases, such as glaucoma, as they will provide painless, long-term, sustained drug delivery to the patient's eye.

WHAT OTHER DEVICES IS THE TEAM CREATING?

Chi Hwan and the team are also designing other wearable biomedical devices. They are integrating electronics (such as heart rate sensors) into fabric textiles, creating fabrics that can monitor health conditions while also retaining their original wearability and breathability. A key condition of these electronic textiles is that they can be worn multiple times and can survive for multiple laundry cycles.

These electronic textiles have recently been applied in a wearable biomedical device for horses. The team created a horse blanket containing multiple sensors that continuously monitor the horse's heart rate, muscle activity and breathing rate. This allows the horse owner to monitor the horse's health over long periods of time, whether they are galloping through a field or asleep in their stable.

WHAT NEXT?

"My next steps will be to bring the research outcomes out of university and into clinical practice so many people can benefit from using our technologies," says Chi Hwan. He hopes that, after extensive clinical trials, his wearable biomedical devices will become commercially available, enhancing and advancing the care of patients with a wide range of health conditions.

ABOUT BIOMEDICAL ENGINEERING

Biomedical engineering is a field that spans many disciplines, combining engineering, biology, medicine and healthcare. Biomedical engineers aim to solve health problems by developing new technologies for clinical use. "As a biomedical engineer, I enjoy spending every moment solving real-world problems by emphasising the importance of team science and interdisciplinary research," says Chi Hwan.

HOW INTERDISCIPLINARY IS THE FIELD?

"Problems regarding human health and disease cannot be tackled by one discipline alone," says Chi Hwan. "I work with collaborators in numerous fields: biomedical, mechanical and materials engineering; speech, language and hearing science; animal science; vision science; medicine… We also actively interact with clinicians, patients and caregivers to identify all aspects of the current challenges in clinical settings. These collaborations are extremely important as their feedback helps us to create patient-centred designs."

Collaborations within and outside academia are vital for ensuring that any technology developed by biomedical engineers will meet the needs of the end-user. "I believe that the success of future biomedical engineers, and all scientists, requires an understanding of interdisciplinary collaborations," says Chi Hwan.

WHAT DO BIOMEDICAL ENGINEERS DESIGN?

In the past, biomedical engineers have given us pacemakers, bionic limbs, hearing aids and MRI scanners. Current topics of research include 3D printing human organs for transplants and designing nano-robots that can enter the bloodstream and release drugs directly into cancerous cells. What new inventions will biomedical engineers develop in the future as technology advances?

EXPLORE CAREERS IN BIOMEDICAL ENGINEERING

- Purdue University's Weldon School of Biomedical Engineering (**engineering.purdue edu/BME**) runs a summer internship programme. Underrepresented students from local high schools can participate in paid opportunities to develop their interests in science, technology, engineering and mathematics (STEM).
- Many research groups in the school also offer internship programmes for high school and undergraduate students, including Chi Hwan's lab (**engineering.purdue.edu/StickTronics**). Participating in such an internship will allow you to experience the work of biomedical engineers while contributing to research projects that are tackling problems facing human health. Contact biomedical engineers at universities near you to see if they offer similar opportunities.
- Purdue University hosts STEM outreach programmes designed for young female students, including the 'Introduce a Girl to Engineering Day' (**IGED; www.purdue.edu/wiep/FutureStudents/IGED.html**) and 'Girls in Engineering, Math, and Science' (**GEMS; gems.education.purdue.edu**) events.
- The Biomedical Engineering Society is the professional society for biomedical engineers: **www.bmes.org**
- Prospects provides information about the type of work you could do as a biomedical engineer: **www.prospects.ac.uk/job-profiles/biomedical-engineer**

PATHWAY FROM SCHOOL TO BIOMEDICAL ENGINEERING

- "Students who have a strong passion for applying the problem-solving techniques of engineering to medicine, and those who love to collaborate with others in different disciplines, will fit perfectly into pursuing a career in biomedical engineering," says Chi Hwan.
- At school, study maths, physics, biology and chemistry.
- Some universities will offer degrees in biomedical engineering. Other related degrees that could lead to a career in the field include biomedical science, electrical or electronic engineering, mechanical or industrial engineering, or physics.
- Chi Hwan recommends taking courses in linear algebra, multivariate calculus, chemistry, statistics, dynamics, electricity, magnetism, physics and programming while at university.

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HOW DID CHI HWAN BECOME A BIOMEDICAL ENGINEER?

I grew up in Incheon, one of the largest industrial complexes in South Korea, where my interest in manufacturing began from watching factories. This circumstance in my childhood naturally drove me towards the manufacturing industry, and I imagined myself working as a manufacturing consultant. This was the primary reason that I chose to study both industrial engineering and mechanical engineering for my dual degrees at Ajou University in South Korea and Illinois Tech in the US.

To strengthen my expertise in the manufacturing field, I then pursued a master's and PhD in mechanical engineering at Stanford University, USA. I focused on the development of a 'solar sticker' through the innovation of nanomanufacturing technology.

At that point, I never imagined that I would go into the biomedical field. However, I had an interview at Purdue University where I had the chance to meet several researchers from different disciplines, including biomedical, mechanical, electrical and materials engineering.

Talking with them, I realised my research on manufacturing solar stickers could be expanded to manufacturing sensor stickers, which could be particularly useful for many biomedical applications.

I found the highly interdisciplinary, collaborative environment in Purdue very attractive. It enabled me to naturally switch a gear in my profession and begin focusing on wearable biomedical devices. I now have a very interdisciplinary background to my career, with dual degrees in industrial engineering and mechanical engineering, post-doctoral training in materials engineering and research in biomedical engineering.

This interdisciplinary background has allowed me to foster a lot of internal and external collaborations with world-leading scientists and engineers, enabling us to tackle the complicated real-world problems associated with human health and diseases.

My ambitions lie in translating some of these research initiatives into tangible forms which will eventually benefit millions of users in need across the world.

CHI HWAN'S TOP TIPS

01 Do not limit yourself to the one specific area that you are currently interested in.

02 Do not be afraid to try something new and do not be afraid to fail.

HOW DO ENZYMES SPEED UP CHEMICAL REACTIONS?

ENZYMES ARE THE CATALYSTS OF LIFE. THEY ACCELERATE CHEMICAL REACTIONS INSIDE CELLS TO INCREDIBLE SPEEDS. ENZYMES ARE SO EXTRAORDINARY THAT WE EXTRACT THEM FROM ORGANISMS, LIKE BACTERIA, AND USE THEM FOR COUNTLESS PROCESSES, FROM CLEANING OUR CLOTHES AND MAKING CHEESE, TO BLOOD CLOT DISSOLUTION AND IMPROVING ANTIBIOTICS. **PROFESSOR JUDITH KLINMAN** AT THE **UNIVERSITY OF CALIFORNIA**, BERKELEY, USA, AND HER LABORATORY TEAM, THE KLINMAN GROUP, ARE FOCUSED ON EXAMINING HOW ENZYMES GENERATE THESE ENORMOUS RATE ACCELERATIONS

TALK LIKE A BIOCHEMIST AND MOLECULAR BIOLOGIST

ACTIVE SITE — the area of an enzyme where a substrate molecule can attach.

AMINO ACIDS — the building blocks which make up a protein molecule

CATALYSIS — a process of modifying the rate of a chemical reaction by adding a substance, called a catalyst, that is not consumed during the reaction

C-H CLEAVAGE REACTION — a reaction in which a carbon-hydrogen bond is broken and the hydrogen replaced with nitrogen, carbon or oxygen

COFACTORS — non-protein molecules that some enzymes require to function. These can be inorganic, such as a zinc ion, or organic, such as vitamins. Without cofactors, these enzymes would remain inactive

ENZYMES — most enzymes are a type of protein, which speed up (catalyse) biochemical reactions in plants, animals and microorganisms without being changed by the reaction

HYDROGEN TUNNELLING — the transfer of a hydrogen particle from a donor to an acceptor, where the hydrogen moves through a barrier rather than over the barrier

HEAVY METALS — are a group of metals that have high atomic weights or numbers and high densities, such as silver, zinc, copper, iron, lead, gold, platinum, mercury, cadmium and arsenic

ISOTOPIC — characteristic of two or more atoms that have the same atomic number (position in the periodic table) but different mass numbers

KINETIC (DEUTERIUM) ISOTOPE EFFECT (KIE) — an experiment in which an atom is replaced by its isotope and the reaction rate observed. Deuterium is an isotope of hydrogen, which is used in KIE experiments

PROTEINS — composed of chains of amino acids. Proteins have different three-dimensional shapes, which determine their function. There are four main categories of proteins in your body: structural, enzymes, hormones and antibodies

QUINO-COFACTOR — quinones that are generated from native amino acids within a folded enzyme's active site and are essential for the enzymes' catalysed reactions

REACTION RATE — the speed at which a chemical reaction occurs in relation to the concentration of the reactants

SPECIFICITY — the range within which a catalyst is active

SUBSTRATE — a substance on which enzymes act

THERMAL CONDUITS — materials that allow the transference of thermal energy/heat

Enzymes greatly enhance the rate of biochemical reactions in cells. Without them, we would not be able to exist. They are essential to life and also have extensive commercial uses, from making beer and cheese to the development of new drugs. Professor Judith Klinman is a Distinguished Professor of the Graduate School at the University of California, Berkeley. Focusing her research in biochemistry and molecular biology, she explores the factors that enable the astonishingly fast catalytic rates of enzymes.

ENZYMES AND HOW WE USE THEM

Thousands of chemical reactions happen in every cell in your body, every second, for your cells and body to function. Cells can die if these reactions occur too slowly, so they produce enzymes to increase the speed of these reactions at body temperature. They do this by binding their substrates, catalysing their chemical reactions and, finally, releasing the products. "Enzymes are the catalysts of life," Judith explains. "They undertake all the chemical reactions inside the cell and do this really quickly: as much as 10^{30} times faster than the same reaction in the absence of the enzyme. That number, 10^{30} [times], is in the range of the number of stars in the universe!"

The catalytic properties of enzymes make them useful in a variety of industrial processes. Enzymes for commercial use are produced from the fermentation of specially selected strains of microorganisms or extracted from plant or animal sources. They can be used to catalyse a wide range of processes, from the

PROFESSOR JUDITH KLINMAN

Distinguished Professor, Graduate School, University of California, Berkeley, USA

FIELDS OF RESEARCH

Biochemistry, Biophysics, Chemistry, Molecular Biology, Enzymology

RESEARCH PROJECT

Exploring the factors that enable enzymes' remarkably fast catalytic rates

FUNDERS

The US National Institutes of Health (NIH) and the National Science Foundation (NSF)

modification of antibiotics to washing powders and cleaning agents; the possibilities are almost endless. "There are many people trying to create catalysts that are as good as the ones that have evolved over the billions of years of life on planet Earth," Judith says. There is increasing demand for industrial processes that follow the principles of 'green chemistry,' where chemical products and processes that reduce or eliminate the use of hazardous substances are designed. Enzymes work under mild conditions of solvent, temperature and pressure, and can be used to undertake processes with less toxic effects on our environment.

THE KLINMAN GROUP

Despite more than half a century of detailed studies, there is still no satisfactory physical model for the enormous rate of accelerations generated by enzymes. "Our long-range goal has been to explore and examine the factors that enable the remarkably fast catalytic rates that enzymes have," says Judith. The Klinman Group, Judith's laboratory, has introduced and used many different kinds of approaches over the years to tackle this. One of the first approaches was the use of stable and radioactive isotopes that had begun to make it possible to follow the course of biological reactions and to identify reaction intermediates.The work of the Klinman Group is highly interdisciplinary, including physical, inorganic and organic chemistry, biochemistry, biophysics and molecular biology. "Our collaborations have been largely focused on the areas of X-ray crystallography, nuclear magnetic resonance (NMR) spectroscopy, electron spin resonance (EPR) and electron-nuclear double resonance (ENDOR) spectroscopy and resonance Raman spectroscopy and theory," explains Judith.

RESEARCH FINDINGS

Judith and her team discovered a new class of cofactors derived from the native amino acids of proteins, leading to novel quinone-based structures. "One of the really fascinating aspects of this work is the recognition that a single enzyme active site can first synthesize its new cofactor and then use it for the catalytic turnover of substrates," says Judith.

Their work has also led to a unique opportunity to understand the contribution of protein dynamics to the specificity and reaction rates of enzyme catalysis. "In science, it is always important to be alert to observations that don't comply with what we have assumed to be correct, and that is what happened while we were studying a number of different redox enzymes," Judith explains. "Basically, the dominant mode for breaking a C-H bond involves moving over the top of a reaction barrier, while the data we were collecting showed that the transferred atom was moving "through the barrier."

She notes that "This phenomenon of 'tunneling' has been shown to be highly prevalent in biologically catalyzed C-H cleavage reactions. Hydrogen tunneling follows from the wave-particle duality of particles, with the wavelength of a particle being inversely related to its mass. To illustrate the point, I like to tell students that if they went on a (very serious) diet, they might get thin enough to be able to go out through the front door without ever getting up from the sofa!"

In the last few years, Judith and her team have uncovered a role for site-specific thermal conduits within each protein. These provide pathways for heat transfer from the solvent to the active site that act in synergy with the highly evolved properties of the active site.

The Klinman Group has further focused their research on reactions that are oxygen-dependent and played key roles as life transformed from initial anaerobic conditions to our current, O_2-rich atmosphere. The team spent many years developing isotopic probes to study the mechanisms of oxygen activation by enzymes and to show how enzymes may prevent their own oxidation in this process. Several of the systems studied depend on the ions of heavy metals such as copper and iron.

ABOUT BIOCHEMISTRY AND MOLECULAR BIOLOGY

Molecular biology deals with the structure, properties and function of the basic molecular components of cells, from bacteria to plants and mammals. This greatly overlaps with biochemistry, which explores the chemical processes within and related to living organisms, focusing on processes at a molecular level. These fields affect many areas of science including biotechnology, medicine and agriculture.

Research is helping to address global issues such as disease, food security and biotechnology.

WOMEN IN BIOSCIENCES

Presently, women are well represented in the molecular biosciences sector, but this was not always the case. Judith was the first female professor in any of the physical sciences at the University of California, Berkeley; the first tenured female professor in the chemistry department there and the first female chair of the chemistry department. "There really is an enormous difference between when I arrived on the Berkeley campus and now," she explains. "Once women are readily accepted into programmes and see what is available to them, they just take off!"

EXPLORE CAREERS IN BIOCHEMISTRY AND MOLECULAR BIOLOGY

- Explore different paths and degree options for becoming a biochemist in the UK: **nationalcareers.service.gov.uk/job-profiles/biochemist**
- According to Career Explorer, the average salary for a biochemist in the US is $102,300: **www.careerexplorer.com/careers/biochemist/salary/#how-much**
- Biochemists can have careers in hospitals, universities, agriculture, food institutes, education, cosmetics, forensic crime research, and drug discovery and development.
- To get news and views on issues relevant to the molecular bioscience community, visit **thebiochemistblog.com**
- The Biomolecular Society promotes the advancement of biochemistry and molecular biology and has information on career paths, work experience, internships and more: **www.biochemistry.org**
- The Department of Chemistry at the University of California, Berkeley, has several outreach programmes: **eduinfo.cchem.berkeley.edu/education-outreach.shtml**

PATHWAY FROM SCHOOL TO BIOCHEMISTRY AND MOLECULAR BIOLOGY

- Judith recommends having a solid background in biology, chemistry, physics and mathematics. Humanities are also important.
- Lab experience is very useful while at school and is essential in university where you can find a placement, internship or a year in an industry scheme.
- In the UK, you need A-Levels in sciences and maths to pursue an undergraduate degree in biochemistry or molecular biology. The exact A-Level requirements will depend on the course and university. For example, the BSc Biochemistry with Molecular Biology and Biotechnology at the University of Bristol, in the UK, requires three As at A-level, including chemistry and another core science or mathematics subject.
- Many people also advance to study for a postgraduate degree in the field.

HOW DID JUDITH BECOME A BIOCHEMIST AND MOLECULAR BIOLOGIST?

Judith has a degree in chemistry and a PhD in physical organic chemistry, both from the University of Pennsylvania. She founded the Klinman Group and has received more than 21 honours and awards over the past three decades, including the National Medal of Science presented by former US President Barack Obama.

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

From an early age, I was really interested in ballet. However, I realized at some point that I was not all that talented, though I still loved it! Growing up, I also loved the ocean and quiet, long walks on the beach, and I still have a strong affinity for nature. My mum directed me to books and art, while my stepdad was a resource once I got interested in science. It was two fantastic teachers from school who taught my physics and chemistry courses who ultimately inspired me to become a scientist.

"I BELIEVE THAT THE HUMANITIES AND SCIENCE ARE NOT SO FAR APART, AND BOTH SERVE THE NEED IN EACH OF US TO BE CREATIVE."

HOW INTERDISCIPLINARY IS SCIENCE TODAY?

I think that once a scientist attempts to solve a major problem, the different disciplines come together easily. Science has become an increasingly interdisciplinary activity and, consequently, more collaborative. This has likely been accelerated by the introduction of the internet and much greater ease of communication. I believe that the humanities and science are not so far apart, and both serve the need in each of us to be creative.

WHAT INSPIRED THE CREATION OF THE KLINMAN GROUP?

I started out as a postdoctoral researcher and then a staff scientist at a research laboratory called 'The Institute for Cancer Research'. As I began to learn the research tools in enzymology and read the literature, I became fascinated with the general field of enzyme catalysis. I was puzzled by the dominant theory for how enzymes give rise to their enormous rate accelerations, and this has guided much of my research efforts since towards a new view of the physical origins of enzyme catalysis.

WHAT HAVE BEEN THE EUREKA MOMENTS IN YOUR RESEARCH CAREER?

I am very proud of the achievements of the Klinman Group. One of our eureka moments was certainly when we figured out the first protein-derived, quino-cofactor structure. Finding enormous and unprecedented kinetic isotope effects that had never been validated before for reactions in condensed phase near room temperature was another eureka moment. Most recently, the uncovering of site-specific thermal conduits in enzymes that enable productive, long-range activation of distal enzyme active sites has changed our formalisms and created new avenues for research.

WHAT ARE YOUR AIMS FOR THE FUTURE?

I have just turned 81 years old and was planning on closing my laboratory before now. However, a number of new directions have emerged regarding (i) the role of solvent in initiating protein catalysis, (ii) the structural bases of protein thermal networks and whether these can be applied to new directions for catalyst design and regulation, (iii) whether we can find a satisfactory physical description for the transient initiation of extremely fast, long range and site-specific protein restructuring and, finally, (iv) whether it will be possible to observe the very rare events that actually lead to barrier crossings in enzyme processes. Clearly, these are big questions, for the next generation of young scientists. Still, we can't resist trying to make some progress during the next few years!

HOW DO YOU TAKE TIME OFF FROM WORK?

I like to explore new books and authors, take long walks and hikes (especially by the ocean), work in the garden, hang out with my life partner and family and friends, and (since the COVID pandemic) 'veg out' in the evening with the latest series on TV. I also maintain a long-standing meditation practice that adds important balance to my life.

JUDITH'S TOP TIPS

01 Find an area where you are both strong academically and very interested – this is a dynamite combination!

02 Work with your teachers to learn how best to read the literature and to be especially attuned to finding something that interests you.

HOW CAN WE MAKE FUTURE PLACES HEALTHIER SPACES?

PROFESSOR RICHARD HARPER, BASED AT **LANCASTER UNIVERSITY** IN THE UK, IS THE PRINCIPAL INVESTIGATOR OF A PROJECT CALLED **THE FUTURE PLACES CENTRE**. THIS PROJECT IS INVESTIGATING HOW COMPUTING, THE INTERNET OF THINGS AND DATA SCIENCE CAN GENERATE INFORMATION THAT PEOPLE CAN USE TO MAKE THEIR FUTURE PLACES HEALTHIER

GLOSSARY

DATA SCIENCE – encompasses preparing data for analysis, including cleansing, aggregating and manipulating the data to perform advanced data analysis

INTERNET OF THINGS – the billions of physical devices around the world that are now connected to the internet, all collecting and sharing data

SMART HOMES – a home equipped with computer-controlled lighting, heating and other domestic appliances that can be controlled remotely by smartphone or computer

ARTIFICIAL INTELLIGENCE – the ability of a computer or a robot to do tasks that are usually done by humans because they require some kind of intelligent judgements

MACHINE LEARNING – an application of artificial intelligence (AI) that provides systems the ability to automatically learn and improve from experience without being explicitly programmed

AGROECOLOGY – the application of ecological concepts and principles in farming. It is also a political movement that aims to improve the way food is grown and consumed globally

Advances in computer technology have accelerated at such a fast pace in recent years that it is no exaggeration to say that they have fundamentally changed our lives. They have done so partly because they have made computer technology so small and inexpensive. It was not so long ago that computers could be the size of a room, but most of us now carry computers around in our pocket (in the form of a smartphone). It was also the case that only large companies could afford computers but now most of us own one, if not more.

The computer technologies we use in our daily lives have become so ubiquitous and pervasive that it is difficult to imagine life without them – from how we perform tasks at school, to how we manage our homes through smart applications and voice-controlled personal assistants like Alexa. The impact of technology, computing and the Internet of Things (IoT) is evident throughout our personal lives.

Such dramatic changes provide an opportunity to (re)imagine how our lives and the spaces in which we live might be enhanced. Computer technologies can help us better understand how we use places and how that use affects our health. Computing can also let us develop more sustainable living practices. It is with these ideas in mind that Professor Richard Harper, based at Lancaster University, has helped to establish the Future Places Centre (FPC) – a research project that is exploring how people can shape their future spaces for healthier, more sustainable living.

Research at the FPC is divided into three broad themes: Natural Environment, Built Environment and Living. These themes have

PROFESSOR RICHARD HARPER

School of Computing and Communications, Lancaster University, UK

FIELD OF RESEARCH

Computer Science

RESEARCH PROJECT

Establishing the Future Places Centre (FPC) to explore how pervasive technologies, the IoT and new data science tools enable people to reimagine what their future spaces might be

FUNDERS

UK Research and Innovation (UKRI), EPSRC Digital Economy Theme

global relevance, but the project will be based in (and developed with) the communities and businesses within the northwest of England – particularly Morecambe Bay. Richard and the team believe that the FPC will show how places can be improved and how those places will be in the future for the people who live in them.

THE SETTING

The North West consists of a fascinating mixture of the exquisitely beautiful and the natural, alongside the changing built landscape of towns, villages and cities. "The relationship between these built environments and the natural environment is changing as people begin to realise that nature can become a part of their daily lives in ways that it didn't use to be," says Richard. "At the same time, new technologies are allowing society to engage with nature in liberating ways. For example, wind is now being re-discovered as a resource for free energy, allowing people to do what they want but also reminding them they can do that in harmony with nature's ebbs and flows."

MAKING PLACES HEALTHIER AND SMARTER

"Healthy places are complex phenomena entailing both healthy bodies and healthy minds – achieving one doesn't always coincide with achieving the other, but, when it does, it can lead to radical improvements on all dimensions," explains Richard. "With technologies embedded in our places, we can learn more about how we are using those places and whether we can optimise that use for different, and perhaps better, ends."

Part of the Built Environment theme involves working in different ways on various types of building projects, from collaborating with young communities about the spaces they might use for their activities to creating better ways of maintaining and monitoring busy communications and transport networks. IoT and data science will also be used to facilitate the development of smart homes which will improve energy, waste and travel management.

PROMOTING HEALTHY LIVING

IoT tools, including wearable technologies, are already in use and enable individuals to self-monitor continuously. "People can monitor their physiological state and social practices, and judge the connection between where they are and their levels of contentment," says Richard. "It is not always easy to define contentment and what constitutes a healthy relationship between a person and a place, but data and evidence can help us to judge the best way forwards."

SHAPING THE FUTURE

The initial aim is to shape and influence public places, but these future places may also be where people work or socialise. These places will provide new reasons to perceive and shape spaces, which will have a small impact, at first, but the hope is that people and businesses will be encouraged to embrace, adopt and adapt the principles behind these future places. As people and businesses gather and measure more data from these future places, they will be better equipped to continue to improve the spaces. Through data, places can be made to respond to change. There are, of course, many types of change, and one example of the changes we might envision is provided by the Eden Project North, which, when completed, will demonstrate what future places might look like.

Ultimately, the FPC will help to show how technology can shape various aspects of our lives in different ways – particularly those surrounding the places we inhabit and how our relationship with spaces can have positive impact on our health and well-being. Although the aims of the project are ambitious, we are rapidly advancing into the future, and life as we know it is always changing. The Future Places Centre is trying to ensure the changes are positive.

MEET THE TEAM

JAN HOLLINSHEAD

SENIOR RESEARCH ASSOCIATE, SCHOOL OF COMPUTING AND COMMUNICATIONS, LANCASTER UNIVERSITY, UK

As a computer scientist, Jan explores the relationship between data, people and the places they live in, and the way data impacts decision making, guides change and shapes the future.

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I loved the outdoors – camping, hiking and climbing. Indoors, I would be found with my nose in a book, or doing puzzles and problem solving – which was really useful for things like getting a campfire going with wet wood or finding your way back to civilisation after getting lost in the hills!

WHO OR WHAT INSPIRED YOU TO BECOME A COMPUTER SCIENTIST?

My father (an engineer) and my brother (a computer architect). Mostly though, I just tried a bunch of things and this one stuck.

HOW HAS YOUR CAREER LED YOU TO THIS CURRENT RESEARCH?

After several years travelling and doing voluntary work, I completed a degree in outdoor studies and got a job in the outdoor leisure industry working with a start-up company. I took on a variety of roles and continued learning anything I could about things that interested me. All of this gave me the skills required for research that looks at many different facets that influence people's health and well-being and how it can be used to benefit the communities around Morecambe Bay for the future.

WHAT DOES A TYPICAL DAY LOOK LIKE FOR YOU ON THIS PROJECT?

There is no such thing as a 'typical' day – and that's why I love it. If I'm working on a project, I can be deploying the tech, working with software developers or curating content. Alternatively, I could be reading past and current research on health and well-being in 'blue' (coastal or inland water) and 'green' spaces (parks or gardens), analysing datasets on populations, or writing about the wins and losses of trying to understand the world through data.

WHAT PROFESSIONAL CHALLENGES DOES THIS PROJECT POSE FOR YOU?

I have written many business reports, but I'm not experienced in writing academic reports for journals or for peer review. It's about finding a way to combine reviewing what others have written and how they relate to our new ideas and theories.

WHAT DO YOU FIND REWARDING ABOUT RESEARCH IN YOUR FIELD?

Finding ways to help people create a healthy relationship with technology, talking with like-minded people and the way collaboration helps my idea nuggets grow into something bigger and better. Ultimately, the research is about trying to make a difference to real people and real communities in my local area.

WHAT HAVE BEEN YOUR PROUDEST CAREER ACHIEVEMENTS?

I don't really do 'proudest achievements' – I'm inordinately pleased with every project that works and I enjoy making things happen for other people – staff I've mentored, trained or just encouraged. There is always something around the corner to understand, or make work, and that will always be something I'm proud of.

EXPLORE CAREERS IN COMPUTER SCIENCE

- Computer Science UK provides a wealth of learning resources via a suite of useful websites: **www.computerscienceuk.com**
- Computer science often leads to combining work with further study in the future through Knowledge Transfer Partnerships, which this website explains more about: **www.ktp-uk.org**
- According to Check Salary, the average salary for a computer scientist in the UK is £42,000, although this will largely depend on your role and experience: **www.checkasalary.co.uk/salary/computer-science-england**

JAN'S TOP TIP

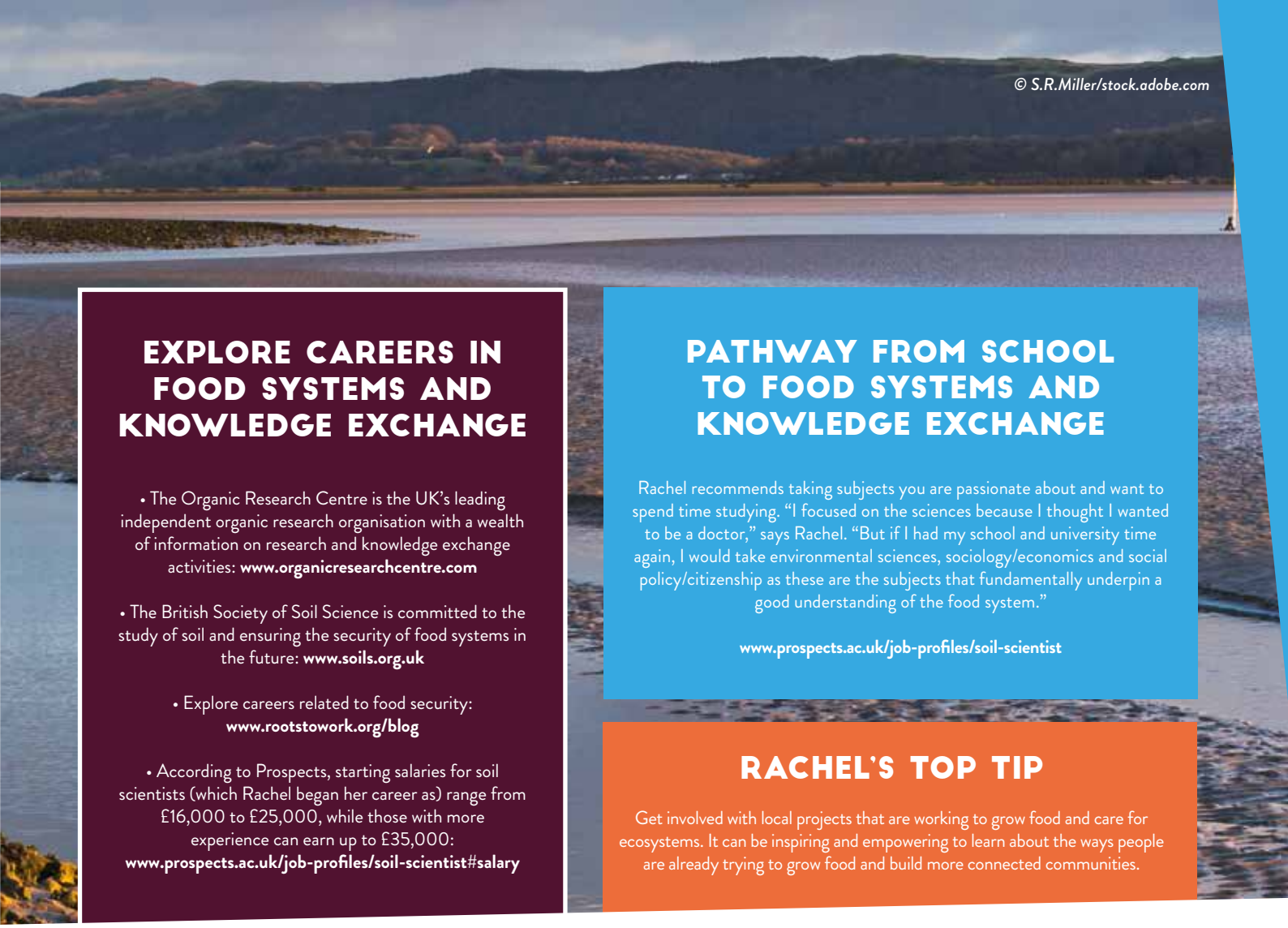
Have an enquiring mind – ask why. Try to understand how it all fits together, how it works, and the rest of it will fall into place. Those lightbulb moments are amazing!

PATHWAY FROM SCHOOL TO COMPUTER SCIENCE

Alongside subjects such as maths and computing, Jan believes the key is to learn how you learn. "Find out what subjects you are passionate about and then run with those," she says. "Computing touches all aspects of society and education, so there is a huge crossover with many different subjects."

You may choose to continue your studies at postgraduate level, studying a computer science subject in greater detail through an MSc or PhD.

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



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EXPLORE CAREERS IN FOOD SYSTEMS AND KNOWLEDGE EXCHANGE

• The Organic Research Centre is the UK's leading independent organic research organisation with a wealth of information on research and knowledge exchange activities: **www.organicresearchcentre.com**

• The British Society of Soil Science is committed to the study of soil and ensuring the security of food systems in the future: **www.soils.org.uk**

• Explore careers related to food security: **www.rootstowork.org/blog**

• According to Prospects, starting salaries for soil scientists (which Rachel began her career as) range from £16,000 to £25,000, while those with more experience can earn up to £35,000: **www.prospects.ac.uk/job-profiles/soil-scientist#salary**

PATHWAY FROM SCHOOL TO FOOD SYSTEMS AND KNOWLEDGE EXCHANGE

Rachel recommends taking subjects you are passionate about and want to spend time studying. "I focused on the sciences because I thought I wanted to be a doctor," says Rachel. "But if I had my school and university time again, I would take environmental sciences, sociology/economics and social policy/citizenship as these are the subjects that fundamentally underpin a good understanding of the food system."

www.prospects.ac.uk/job-profiles/soil-scientist

RACHEL'S TOP TIP

Get involved with local projects that are working to grow food and care for ecosystems. It can be inspiring and empowering to learn about the ways people are already trying to grow food and build more connected communities.

DR RACHEL MARSHALL

SENIOR RESEARCH ASSOCIATE, KNOWLEDGE EXCHANGE FELLOW, LANCASTER ENVIRONMENT CENTRE, LANCASTER UNIVERSITY, UK

Healthy living and how we interact with the natural environment are intrinsically linked to the food we eat. An expert in food systems, Rachel is working with the Future Places Centre to form the link between digital technologies and local communities, food groups and farmers.

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

Nature, the sea and food – so it makes sense that I've ended up focusing on agroecology and food! I loved science at school and any nature projects we had to do. Initially, I focused on physics and chemistry at university but realised I didn't feel that excited about chemical bonds and abstract theories. I switched to some environmental chemistry modules and loved putting my chemistry and physics knowledge into practice learning about acid mine drainage and pollution management.

WHO OR WHAT INSPIRED YOU TO BECOME A RESEARCHER?

I've always enjoyed asking questions and trying to understand why things work the way they do. I wanted to do a job that would have a positive impact but also let me feed my inquisitive mind. I grew up at a time when climate change was starting to be seen as a real and growing threat, so I was drawn to working on projects that were linked to climate research. I started with a PhD in monitoring the impact of climate change on sensitive ecosystems and moved to co-developing solutions and approaches to reducing our impact on the climate.

HOW HAS YOUR CAREER LED YOU TO YOUR CURRENT RESEARCH?

I started my career as a soil scientist studying the way farming practices and climate change affect the organisms in our soil. I became increasingly concerned about the wider issues in our food system, which is when I began working in a food systems knowledge-exchange role. My work focused on working with farmers and organisations that are looking to shift how we produce food to approaches that work with (and within) our natural ecosystems (a fundamental part of agroecology).

WHAT DOES A TYPICAL DAY LOOK LIKE FOR YOU ON THIS PROJECT?

The nature of my work is very varied, so every day is different. I'm often in meetings and workshops talking to researchers and practitioners and learning more about emerging questions and challenges. I give talks to a wide variety of audiences – sometimes I'm in a field in the Lake District talking to farmers and, at other times, I'll be talking to policy makers, researchers and food system activists.

WHAT PROFESSIONAL CHALLENGES DOES THIS PROJECT POSE FOR YOU?

One key challenge is that I have moved away from the academic position of being an impartial observer of a situation and, instead, I am actively working with others to create a different food system. People may be concerned that there is a danger in academics becoming activists, however, there are increasingly more scientists, particularly those who work on climate change, who feel they can no longer not take action.

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CAN MUSIC BE A TOOL FOR SOCIAL TRANSFORMATION?

SOCIAL MUSIC PROGRAMMES AROUND THE WORLD ARE ENCOURAGING COMMUNITIES TO SING AND PLAY THEIR WAY FROM CONFLICT TO PEACE. THE ARTS OF INCLUSION (TAI), A NETWORK FOUNDED BY **PROFESSOR OSCAR ODENA** AT THE **UNIVERSITY OF GLASGOW**, UK, IS STUDYING THE RESULTS TO FIND OUT IF MUSIC REALLY DOES HAVE HEALING POWERS

Life in Kinshasa is hard. Families in the Democratic Republic of Congo's (DRC's) capital often have no choice but to make ends meet by selling things on the hot, dusty streets. With opportunities few and far between, some people resort to violence and theft.

But there is another side to the world's largest French-speaking city. Amongst the clamour of 17 million people going about their daily lives, there is the sound of drums beating out vibrant rhythms from across the DRC's varied musical traditions. For some, drumming has become a new way of life, allowing them to escape old habits of violence. As one man who swapped being a gang member for being a band member told The Arts of Inclusion network member Professor Lukas Pairon, "When I play music, even when I do not eat or drink, I will forget all of that. When I am in front of my instrument, everything else does not count anymore… The only thing that matters then is the pleasure of performing music. If I would not have my musical activity, I might have abandoned my struggle in life a long time ago."

This is just one example of many people from around the world for whom music could have a life-changing impact. Social music projects aim to heal the wounds of war, give individuals new purpose, and bridge divisions between rival groups by getting people singing, dancing and playing instruments. The question is, do these social music projects really work?

Although we hear many stories about the "healing power" of music, there is a lot we do not yet know about social music projects. This is why Professor Oscar Odena, an interdisciplinary researcher at the University of Glasgow in Scotland, decided to create a global network of people studying social music projects from Colombia in South America to the DRC in Africa.

WHAT IS THE ARTS OF INCLUSION NETWORK?

By 2019, Oscar had already spent a lot of time researching social music projects. His focus had been in Northern Ireland, in the UK, where conflict between Protestant and Catholic communities led to a deeply divided society. He noticed that there were limits to the power of music to resolve these divisions – people needed time to pass after a conflict before music could bring them together again. He was left wondering how his results would compare to social music projects in different parts of the world.

The Arts of Inclusion (TAI) was built to compare and contrast social music projects on a global scale. Being bilingual in Spanish and English helped Oscar to reach out to researchers in Mexico, Colombia, Spain, England, Northern Ireland and Scotland, while Brazil and the DRC are also on the list of countries covered by TAI. By comparing projects with varying histories and cultures, Oscar hopes the network will help us understand what makes for a successful project that improves people's lives and brings communities together. Although TAI has focused mainly on music so far, in the future the network members also want to investigate other performing arts, such as drama.

WHY DO WE NEED TO RESEARCH SOCIAL MUSIC PROJECTS?

It might seem obvious that music can bring people together. If you sing with other

PROFESSOR OSCAR ODENA

Professor of Education, School of Education and School of Interdisciplinary Studies, University of Glasgow, UK

FIELD OF RESEARCH

Arts and Social Science

RESEARCH PROJECT

The Arts of Inclusion (TAI) – researching how music and creativity can be used as a tool for social inclusion and conflict resolution

FUNDERS

UK Arts and Humanities Research Council (AHRC), Global Challenges Research Fund, Royal Society of Edinburgh (RSE), Scottish Funding Council (SFC)

people in church, at school assemblies or at gigs, you will know that special feeling of connection when your voices combine. It can be easy to forget that music can also be a way of keeping people apart. Think of the chants sung by fans of two rival football teams: in this case the music is used to express fans' differences.

Oscar says, "There is a risk of romanticising social music practices and thinking they always work." When he was studying projects in Northern Ireland, he saw how music was sometimes used to emphasise the divide between Catholics and Protestants, making the tensions greater rather than leading to peace. Furthermore, stories about the effect of music on individuals (such as the one this article started with) can be powerful, but this does not necessarily mean the effects on society as a whole have been significant. To be sure of this requires thorough research that takes a wide range of experiences into account.

Research will help to uncover the best way of designing a social music project so that it has the maximum benefit, and find out if there are situations where it does not work. This will mean less time spent on ineffective projects, and more people finding their way out of violence or conflict through music.

WHAT HAS TAI DISCOVERED SO FAR?

Oscar, having studied music, education and psychology, has encouraged TAI network members to use a wide variety of approaches in their research into music programmes. His collaborators include people with backgrounds ranging from social work, music, philosophy and political science, many of whom you will meet in this article. Their first big project together has been producing a new book titled *Music and Social Inclusion: International Research and Practice in Complex Settings*, published by Routledge in 2023.

Each chapter of the book is written by a different researcher and discusses one or more projects, from the small scale like Espace Masolo, an arts centre in Kinshasa for children who ran away from their families, up to nationwide programmes in Colombia and Mexico. As he edited these chapters, Oscar noticed some patterns in the results.

The research by TAI shows that music does not guarantee peace, but it can certainly play its part through its powerful effect on individuals. Getting involved with music helps us figure out who we are and where we belong, which in turn helps us to form good relationships with those around us. In addition, playing music is generally a positive experience, helping people who have been through conflict to express themselves and enjoy life again.

Although he aims to be objective with his research, Oscar feels that music really does have its benefits. "It may not change people's social circumstances immediately," he says, "but it can change the way they see themselves, which can bring increased well-being and potentially lead to positive changes."

MEET SOME OF THE TAI NETWORK MEMBERS

Sound Postcards

Dr Andrea Rodríguez-Sánchez is a social worker and member of the Peace Program at the National University of Colombia. She has been unravelling the stories of displaced people through the sounds they remember from different parts of their lives.

WHY ARE PEOPLE BEING DISPLACED IN COLOMBIA?

There has been armed conflict in Colombia for over 60 years. Faced with fighting over territory and resources, much of the country's population has been forced to move to safer areas. By 2013, over 5 million people had left their homes due to threats and violence, the majority of whom are women, children and people of indigenous or African descent (minority ethnic groups in Colombia).

Andrea says, "Civil society has always found itself in the middle of the economic and political interests at play in our country. It is a very sad situation, especially for the new generations who have to continue living or seeing these unjust situations."

Andrea lives in Bogotá, the capital city of Colombia and a destination for many displaced people. Some of Andrea's fieldwork was conducted here, as well as in three other Colombian cities (Cali, Tierralta and Florencia). The fieldwork involved meeting and interviewing people who had been displaced and were now taking part in a social music programme.

WHAT IS MUSIC FOR RECONCILIATION?

Colombia has a number of nationwide social music programmes, including Batuta National Foundation's Music for Reconciliation, which is aimed at victims of the conflict. One of the goals of Music for Reconciliation is to help displaced people feel part of their new communities and find a sense of belonging there.

Although Music for Reconciliation is government funded, Andrea says it "survives largely thanks to the work and initiative of the people who are involved". She hopes that her research will highlight just how important music programmes are for transforming people's lives and peacebuilding, providing strong evidence for better funding into the future.

WHY USE SOUND POSTCARDS?

Andrea asked the displaced people she met to tell her about the sounds they remember from before their displacement, after being displaced, and from being involved in the Music for Reconciliation programme. This technique, called sound postcards, allows her to get a vivid snapshot of certain moments in people's lives, often revealing how they felt at the time. Take, for example, the sound postcards of a 16-year-old boy called Pedro:

BEFORE DISPLACEMENT – The birds, cows, dogs, my grandma cooking the soup and the lads playing football. You can hear that nice and clear from the mountain.

AFTER DISPLACEMENT – The cars, they sound their horns so much they'll end up damaging them.

MUSIC FOR RECONCILIATION – The laughter, singing, the music - Pink Panther

You can access more sound postcards here: **musicsocialfabric.wixsite.com/sound-postcards/copy-of-stream-buy**

MEET ANDREA

When I was younger, I loved medicine and architecture. I drew a lot of diagrams on the computer. I wasn't clear about what I wanted to be, but I knew that these two worlds attracted me.

I really like to help people improve their lives, so I'm very happy researching how music can contribute to a better quality of life for people, especially those who have experienced violence.

Since I was a child, music has been a great joy. Whenever I can, I sing or play an instrument. For me, music is a space for authentic and simple expression. After studying it, I chose not to dedicate myself to music professionally and, perhaps, this has allowed me to have a lot of freedom; I experience music as a kind companion that is always there.

> **"For me, music is a space for authentic and simple expression."**

I see music as a gentle way of bringing us closer to each other, particularly in Colombia. After so many years of violence, there is a great mistrust that weakens our social fabric in a significant way. I see from my experience and studies that collective music, realised under carefully designed conditions, can contribute to social reconstruction.

Batuta concert © Andrea Rodríguez-Sánchez

"There is evidence that the arts can work to promote peace, although there are often claims made about the arts and social transformation that aren't borne out."

Rappers for Peace

Dr Andrew Green is Associate Professor at the University of Warsaw, Poland, with an interest in social music programmes in Mexico. He has been finding out if rap battles can be used to promote peace as well as competition.

IS HIP-HOP A UNIVERSAL LANGUAGE?

You might have heard the idea that music is a universal language, but this is not really true. Different cultures have very different ways of making music, which – just like languages – take time to understand. This is a common pitfall for social music projects: if they impose a certain type of music, participants might feel their own musical traditions are being ignored.

For some, hip-hop is a potential solution to this problem of 'global' versus 'local'. Hip-hop is played and produced in almost every corner of the globe and is easily adapted to different places – partly through lyrics, and partly through sampling. In Mexico City, there is a thriving and varied hip-hop scene, and rap battles are big business. Andrew has been investigating the relationship in the city between rap and violence.

WHAT IS HIP-HOP TRANSFORMACIÓN?

Mexico City has a crime problem, partly because many people – especially young men – are involved with drug trafficking gangs that use violence to assert their power. Hip-Hop Transformación is a project that aims to improve this situation through music competitions.

Participants in Hip-Hop Transformación are required to write rap lyrics that promote peace, and attend workshops about violence. In the workshops, they watch videos, reflect on their own backgrounds, and meet academics and rappers to learn about conflict and alternative ways of life. They then compete to win prizes including studio time and money.

HOW SUCCESSFUL HAS HIP-HOP TRANSFORMACIÓN BEEN?

Andrew says the main thing he has found is "just how complicated it is to try and effect change". One of Hip-Hop Transformación's recent competitions (called Rappers for Peace) asked rappers not to write lyrics that could incite violence, drugs or discrimination, but these things are often part of people's daily lives in Mexico. This meant the rap lyrics had two sides to them: the positive messages delivered in the programme's workshops and the references to the reality of living in conflict.

Hip-Hop Transformación has drawn attention from and inspired some participants to pursue a career in hip-hop. Andrew wonders, however, whether "the people who won the competitions might have been more likely to follow this path to begin with".

MEET ANDREW

I always listened to music and got more into making music as I got older. Being able to make a living through doing research with people who make music is wonderful.

I spent four months in Mexico just after finishing school and fell in love with the country. I was there as a volunteer and spent a lot of time giving children music lessons in an informal settlement – what some might disrespectfully call a "shanty town" – on the outskirts of Mexico City.

I listen to and write music for enjoyment, but also listen out for ways that music can open up different senses of social and political possibility. I listen to music to concentrate when I'm working, too.

There is evidence that the arts can work to promote peace, although there are often claims made about the arts and social transformation that aren't borne out, as in the case of El Sistema in Venezuela. El Sistema is a publicly financed music-education programme founded in 1975 by musician and activist José Antonio Abreu. Among other things, El Sistema claims to provide Venezuela's most vulnerable children a way out of their impoverished lives, but research by Professor Geoff Baker, an academic in the Department of Music at Royal Holloway, University of London, UK, called into question many of its claims: **www.theguardian.com/music/2014/nov/11/geoff-baker-el-sistema-model-of-tyranny**

It's important to have effective, grounded research on arts programmes. I'm attracted to the idea that responses to social problems can be inherently meaningful, fun and life-affirming, as well as providing solutions to social problems. This is what socially engaged arts programmes promise, if they're carried out well.


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The Gap Between Rhetoric and Reality

Dr Gillian Howell is a research fellow in the Faculty of Fine Arts and Music at the University of Melbourne, Australia. She is interested in the difference between how social music programmes report their success, and how well they really achieve their aims.

WHY DO SOCIAL MUSIC PROJECTS NOT ALWAYS GO TO PLAN?

In 1997, Gillian was in the back of a United Nations minibus heading to Vukovar in Croatia, a town physically and socially destroyed by multiple recent wars. Her mission was to play in a concert, to bring an evening of musical entertainment and connection to the inhabitants who had been through so much trauma. When Gillian and her colleagues arrived, however, they found their audience were almost all international aid workers, instead of from the local community.

For Gillian, the experience was a personal example of social music not going to plan, despite everyone's best intentions. By their very nature, these projects target places where communication and trust are difficult to establish, and there are many competing sources of power. This makes for unpredictable project spaces where things rarely go as expected.

WHY DO REPORTS TEND TO FOCUS ON THE POSITIVES?

When she returned home from Vukovar, Gillian was reluctant to see the trip as a failure. After all, she and her fellow musicians had done what they had promised and felt it could have been a worthy contribution. So, when she told people about it, she focused the story more on what the musicians had set out to achieve, rather than what had actually happened.

Focusing on the positive side is a natural thing to do when things do not fit a neat storyline, but there is also pressure from others to paint a rosy picture of social music projects. Funders, for example, look for success stories when allocating money, meaning that admitting failures could lead to fewer opportunities in the future.

WHAT DOES IT TAKE FOR A PROJECT TO BE SUCCESSFUL?

Gillian points to a few reasons why music can be an effective tool for social projects, such as the fact it creates relationships between musicians, and that can be used to express complicated emotions. "Art can be used to represent an idea without making it explicit," she says. "This can help you to explore or express difficult ideas that you may not have words for."

Gillian's research has shown, however, that the success of a music project is mostly about everything that surrounds the music activity. For example, a project needs a well-structured teaching plan; a community that is welcoming external input; a long-term plan; and engagement from lots of committed people.

MEET GILLIAN

We live in an age where the group of people who get to be music-makers and consider themselves musical is getting smaller and smaller. The rest, a much larger group, many of whom call themselves "unmusical" or "tone deaf", are the consumers of music. It is my life's mission to challenge this narrative whenever I can!

After all, human beings are built for music. Our bodies are filled with pulse, rhythm and musical potential. They give us feel-good rewards like dopamine when we engage with music. Our voices have the capacity to be huge – on our own and together with others. I would like to see teachers and students challenging the idea that music is only valuable if it is perfect and ready for consumption.

Music is so much more than something to be consumed. It is one of the ways we make sense of the world, and a way that we connect with others and build community. To do that, we need to truly celebrate all musical sounds. We need to love the sound of music learning and embrace the full journey from beginner to expert. And we need to take deep breaths, fill our lungs, and transform it into glorious, unapologetic sound.

"After all, human beings are built for music. Our bodies are filled with pulse, rhythm and musical potential."

Boarding the UN minibus that took the musicians to Vukovar in January 1996. © Gillian Howell

A Journey Through the Senses

Professor Gloria Zapata-Restrepo is the UNESCO Chair in Arts, Education and Culture of Peace at Juan N. Corpas University Foundation, Colombia. She has been finding out how the programme Expedición Sensorial is revitalising traditional Colombian culture in places affected by conflict.

WHY DID THE MONTES DE MARÍA FALL SILENT?

Near the northern coast of Colombia, there is a remote mountainous region called the Montes de María. Its history has been marred with violence since the arrival of European colonisers in the 16th century, bringing with them weapons and diseases that nearly wiped out the Indigenous population. They also brought slaves from Africa to a nearby port, some of whom managed to escape into the mountains.

Despite this, the Montes de María developed its rich cultural traditions, until drug-related conflict brought more tragedy to the region. Since 1995, more than half of the population were displaced, and in a campaign of terror between 2000 and 2002, the names of many towns became infamous around Colombia for the massacres that took place there. Growing up in a world of fear, the young people did not learn to sing and dance.

WHAT IS EXPEDICIÓN SENSORIAL?

The Colombian Ministry of Culture set out to try and rebuild the culture of the Montes de María through a programme called Expedición Sensorial, which Gloria describes as "a journey through the senses, or an exploration of diverse cultural and arts practices". Since it began in 2016, over 5,000 people across the region have taken part.

The aim of the programme is to help people reflect on the conflict and create new, peaceful bonds in communities. It does so by bringing young and old together to learn traditional dances or instruments such as the kuisi – a type of flute that is made from a hollowed-out cactus stem and sounds something like an alto recorder. In each village, the programme is delivered by a local teacher.

IS IT DANGEROUS TO BE A TEACHER FOR EXPEDICIÓN SENSORIAL?

Although a peace deal was signed in 2016,

> **"For me it's not about forming great artists, but forming great people."**

Gloria says there is still a risk of violence in the Montes de María, and social leaders are often targeted. One teacher said they once received threats: "Letters arrived to three colleagues at the schools where they worked, saying that if they were seen again in the area, then they would be killed".

The teachers do it, though, because they see the benefit of their work. They feel that the music itself is not the end goal, but that the process of learning music helps improve people's lives. One teacher explained, "For me it's not about forming great artists, but forming great people." Another teacher said, "Our focus wasn't to train people to become professional musicians, but to heal the wounds that they received during the armed conflict."

MEET GLORIA

When I was younger, I wanted to be an artist and a scientist. My relatives and friends helped inspire me to study arts and education, but given the need for social changes in Colombia, I also felt it was crucial for me to work in peace studies.

Music is essential and is life itself. I believe arts and culture always give possibilities for change. Every little cultural or arts activity could make the difference for an individual or a community.

> **"Every little cultural or arts activity could make the difference for an individual or a community."**

A group photo of the first TAI workshop in 2019. Gloria is pictured on the far right. © Oscar Odena

Dance classes at Tecnocentro Cultural Somos Pacífico – Distrito de Agua Blanca in Cali. © Gloria Zapata-Restrepo

© Riccardo Niels Mayer/stock.adobe.com

A World of Sound

Professor Lukas Pairon is the founding director of Social Impact of Making Music (SIMM), an international research platform based in Belgium. He has been studying social music projects in Kinshasa, Democratic Republic of the Congo.

WHO ARE THE 'WITCH CHILDREN' OF KINSHASA?

One of the social music projects Lukas studied was Espace Masolo – a centre for young people who ran away from their families as children. They left to live on the streets after being accused by their families of being 'witch children'. This happens when parents believe evil spirits have entered the child and cause bad things to happen such as poverty and illness.

At Espace Masolo, the young people are looked after and given the chance to learn wind instruments, percussion, sewing and theatre. Many are also helped to reunite with their families. The aim is for the participants in Espace Masolo to build confidence through their art and learn they are not 'witch children' but valued members of society.

WHY WAS LUKAS SCEPTICAL OF SOCIAL MUSIC AT FIRST?

"If music could bring peace, peace would be everywhere" says Lukas. When he set out on his research in Kinshasa, he felt that it was far too simplistic to suggest music on its own can resolve conflict. Claims about the "magical power" of music to "save lost souls" were all too romanticised, he thought, and not well founded in evidence. This prompted him to spend many months living in Kinshasa to try and understand the role music was playing there in social and community work.

CAN MUSIC MAKE US MORE OPTIMISTIC?

Lukas stands by the fact that music on its own cannot solve complex issues of poverty and violence, but he has found that it can transform the way people think. In Kinshasa, joining a project such as Espace Masolo will not create new job opportunities, for example, and its participants are unlikely to make much money as musicians. It can, however, lead people to a more positive outlook on their situation.

The young people Lukas talked to told him that learning music took them into a whole new "world of sound", in which they experienced freedom. This freedom was in contrast to the harsh barriers they faced in day-to-day life due to poverty, but it made them more resolute to make the most of what they had. Lukas has coined this capacity 'positive fatalism'.

As he describes it, "positive fatalism is the capacity to embrace the reality you are living in, including its limitations, allowing you to focus your talents and means on developing projects which are possible within that reality."

MEET LUKAS

I did not have a clear idea about what I wanted to be when I was younger, but I wanted to study and be involved in the world of music. I was interested in educational science, being active working with small children in the local youth movement.

I wanted to study different human sciences. In secondary school I learnt about the philosopher Martin Buber and this inspired me to learn philosophy.

SIMM is an international network of scholars developing research on the role music may play in social and community work. The aim of this field of research is to come to a better understanding of social music programmes, so that practitioners can learn from the research findings and improve their practice. Although I am cautious not to overstate it, I do think that music and art can play a role in inclusion and peace education.

> **"Although I am cautious not to overstate it, I do think that music and art can play a role in inclusion and peace education."**

Image of Lukas © Music Fund

A Little Ray of Hope

Professor Patricia A. González-Moreno researches music and music education at the Autonomous University of Chihuahua, Mexico. She is the President Elect of the International Society for Music Education for the biennium 2022-2024. Patricia has been analysing the role of music in supporting children and their families in the state of Chihuahua.

WHY IS MUSIC EDUCATION IMPORTANT IN CHIHUAHUA?

While the word Chihuahua might make you think of a very small dog, the state of Chihuahua is the largest in Mexico, covering an area greater than the UK. Unfortunately, it is also one of the most violent, with high crime rates fuelled by illicit drug imports into the USA.

In this region, dominated by rival gangs and cartels, the rest of society needs to work hard to make sure everybody has a good start to life. That is why there are multiple cultural programmes in the state helping to deliver music education to young people. Their aim is to provide a safe space for socialising and provide an alternative to risky behaviours out on the streets.

One example is Umbral, Construyendo Comunidad, A.C. which Patricia has studied in detail. Children are invited to join symphonic bands, choirs and traditional music groups such as mariachi bands. Parents are allowed to join too, or often work to support the programme, helping to build a sense of shared community purpose. Patricia has also been studying the Núcleo Comunitario de Aprendizaje Musical (NUCAM) programme in Quinta Carolina. Here, too, parents can take part by joining the adult choir or guitar ensemble.

HOW DOES MUSIC PROVIDE HOPE TO YOUNG PEOPLE?

For some young people, joining a music group was one of the few ways they felt safe and secure. Patricia interviewed teachers and found they were very aware that some of the students needed emotional support. One Umbral teacher said, "The programme became a little ray of hope to these young people who are sometimes lost in complicated situations of drug addiction, violence, depression, family issues or sexual violence; they come to our orchestral programmes seeking emotional support as much as anything."

> **"The programme leaders, coordinators and music teachers are all aware of how important it is to build cultures of peace."**

Patricia thinks that because the programmes provide a safe space, they help children to understand who they are and what they are good at, as well as making them more aware of their role in society. She acknowledges that music programmes will not stop the violence but says they "contribute to the participants' well-being and their communities by reinforcing social skills and cooperative behaviours".

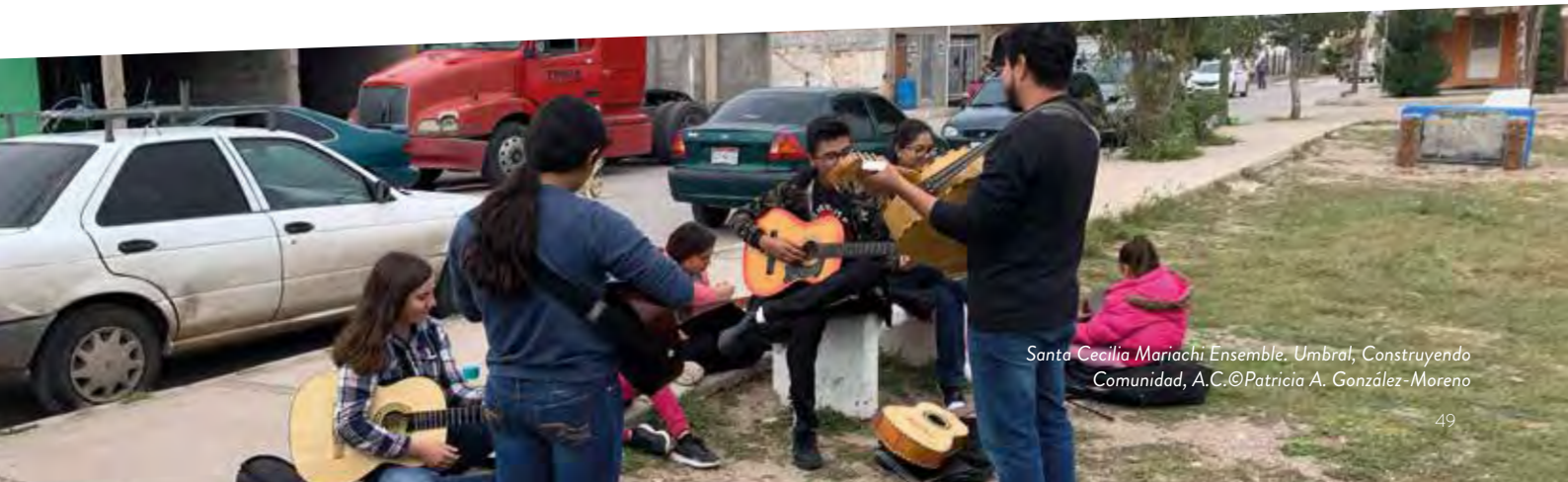
Based on her observations, Patricia feels both Umbral and NUCAM are worthwhile social music projects. "The programme leaders, coordinators and music teachers are all aware of how important it is to build cultures of peace," she says. Over 250 children were enrolled in Umbral 2020, for example, but as Patricia says, "it is difficult to evaluate how successful a programme is simply in terms of participation when those efforts can have a larger social impact that is difficult to measure".

MEET PATRICIA

As a kid, I loved music, however I was not sure what I wanted to be. In primary school, I occasionally had music lessons, and as a teenager I took voice lessons. It was after studying computer sciences for two years that I changed my major, convinced that I wanted to follow my interest and passion for music.

Like any other music student, I wanted to be a professional musician, but along the way I acknowledged how important music teachers are. I felt passionate about music teaching and decided to apply for a PhD in the United States. I was fortunate to be accepted at the University of Illinois where I had guidance from Professor Gary McPherson. He was a great mentor and role model, and he inspired me to become a researcher in music education.

My goal is to make music learning available to others by teaching those pursuing a music career, and through teaching future music teachers and researchers. Music should be available to those who have less opportunities. Music and the arts are a human right, not a privilege for just a few. For this reason, I want to express my deep appreciation for the work that everyone involved in these programmes does to make this possible for the kids they work with, their families and local communities.



Santa Cecilia Mariachi Ensemble. Umbral, Construyendo Comunidad, A.C.©Patricia A. González-Moreno

City tour for Stories of Sanctuary
© Julian Harrop

Stories of Sanctuary

Dr Sam Slatcher is Director of Citizen Songwriters in the UK. He has been working with a project in the northeast of England that aims to bring diverse communities together through songwriting.

WHAT IS PARTICIPATORY SONGWRITING?

Sam was a facilitator for 'Stories of Sanctuary' in the city of Durham, UK. The project was designed to forge connections between refugees and more settled residents, in a part of the country where tensions over immigration are high. It did this by helping the community to write songs together.

The idea of participatory songwriting, as it is known, is to make sure everyone's voice and perspective is included in the song. Sam says, "It works best when everyone has a chance to input their ideas and is involved in the shaping of the song." He thinks it is a good tool for community building because it allows people to connect emotionally, something that is difficult to do by talking.

In one workshop, a refugee called Kareem shared the story of how he fled his home in Damascus, Syria. He was 16 years old and travelled alone. He recalls the sight of his shadow against the moonlight hitting an empty road and feeling very alone. After listening to the story, the group started to form the lyrics of a song, with Sam suggesting chords on his guitar to fit the mood. They wrote:

"Shadow, where are we going tonight?
As you grow, and outrun those searching lights
Somewhere alone in the Serbian snow
All I know, yellow line on the road
Oh Shadow, it's only you and I around."

Although the song was based on Kareem's personal story, the other participants felt they all contributed. Eliza, another participant, said, "The song was very organic, with many pieces coming together. It emerged out of people reacting to his story, plus the melody and the singing."

WHAT CAN WE LEARN FROM STORIES OF SANCTUARY?

Sam says that Stories of Sanctuary was a success because a lot of work was put into encouraging people to take part, understanding the needs of the local community, and taking a creative approach to the songwriting itself. He hopes that his contribution to TAI highlights how he, as a facilitator, "found an opportunity to use music to encourage conversation, points of empathy, connections between people, cultures and ideas".

Participatory songwriting could become more popular in the future. Sam says that it is an attractive approach to social music because it can have a big impact on the communities that take part, and helps to break down the perception that music making is only for professionals.

MEET SAM

"Music stirs our emotions, prompts us to act, helps us laugh and cry and, ultimately, helps us connect with and understand each other."

I wanted to be an airline pilot when I was younger so I could explore the world. How different my life looks now! With her passion for the world, social causes and the environment, my geography teacher at school inspired me to study geography.

I set up Citizen Songwriters in 2018, and we have worked closely with 12 local communities across the UK. We have contracted freelance musicians, worked in partnership with local authorities, recorded community group projects and performed in public more than 20 times. For a small organisation with one full time and one part-time staff member, I think we punch above our weight!

As well as paying the bills, music is my first love. I always carry my guitar around with me in the same way dog owners take their dog for a walk. It is my form of meditation when I walk and play guitar on the move.

Music stirs our emotions, prompts us to act, helps us laugh and cry and, ultimately, helps us connect with and understand each other. As I write, I hear on the radio they are hoping to release John Lennon's "Give Peace A Chance" with the video including 100s of communities singing the song across the world standing in solidarity with Ukraine. I think that says it all!

Music For All

Professor Sergio Figueiredo is a former associate professor at State University of Santa Catarina, Brazil. He has been asking if music education for all can help to create well-rounded citizens.

WHAT IS MUSIC EDUCATION LIKE IN SANTA CATARINA?

The Brazilian state of Santa Catarina has a strong economy and little poverty compared to other parts of the country, but there are still some areas that do not have the same opportunities as others. While music is part of the national curriculum, it is not well-funded and many schools only have one teacher to cover all types of art. Stepping in to fill this gap are social music projects. Sergio has been studying two in particular: Porta do Sol and Bairro da Juventude, which he says "offer opportunities for musical and social development to children and teenagers in vulnerable situations".

ARE GOOD ARTISTS GOOD CITIZENS?

The aim of the Porta do Sol project was to combine music education with general citizenship. Alongside musical activities, the young people involved were encouraged to interact socially, respect each other's differences, and work as a team. Bairro da Juventude also teaches musical cooperation, by running choirs and instrumental groups. "Music is an aggregating activity, which brings people together and awakens a sense of coexistence, respect and collective work," says Sergio.

HAS SOCIAL MUSIC IN SANTA CATARINA ACHIEVED ITS AIMS?

Sergio has spoken to teachers on the social music programmes who have seen transformations in the children they worked with. To begin with, many children struggled to get on with their peers and behaved inappropriately, but they became calmer and more responsible over time. Some former students of Porta do Sol have even gone on to have careers in music.

Sergio feels both Porta do Sol and Bairro da Juventude have shown the importance of music. Instead of complaining about the failure of the state to provide it, they got on and did the job successfully, helping – even if in a small way - to form a "fairer and more humane society".

MEET SERGIO

"I increasingly believe that social music programmes are having positive results, contributing to the quality of life in society in general."

I decided very early on that I would like to be a musician. I studied piano and cello for many years and then dedicated myself to choir conducting. I wanted to be a musician, but to earn money, I started teaching in music schools.

I found it interesting to follow the students' musical development. This led me to research laws and public policy about music education. I believe all those who go through school should have opportunities for musical training, and I hope my research can help to provide that.

Music has been part of my life for many years. Even as a university professor and researcher, I regularly conducted choirs. For me, making music reiterates the importance of this activity. I believe that music has provided experiences that allow me to understand different aspects of being human. Music enriches my life and I always want to share what I have learned.

I think the arts offer important avenues for inclusion and peace education. I am quite convinced that the presence of the arts in social programmes can bring benefits, both for those who receive artistic teachings and for those who teach. And, certainly, the impact is greater when shared with society in concerts, shows, exhibitions or music courses, for example. I increasingly believe that social music programmes are having positive results, contributing to the quality of life in society in general.

Visit the TAI website to uncover the stories of other TAI members, including Alberto Cabedo-Mas, Daniel Mateos-Moreno, Deanna Yerichuk, Geoff Baker, Hector Vázquez, Jenny Scharf, Leeanne O'Hara, Liam O'Hare, María Elisa Pinto, Mo Hume, Oscar Valiente, Ruben Carrillo, Santiago Niño, Shelly Coyne and Valeria Gascón: **www.tai.international**

Participatory songwriting, Stories of Sanctuary

© Barrio da Juventude

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WHAT EXACTLY IS THE 'HEAVINESS' IN HEAVY METAL MUSIC?

DR JAN HERBST AND **DR MARK MYNETT**, BASED AT THE **UNIVERSITY OF HUDDERSFIELD**, ARE COLLABORATING ON A PROJECT THAT IS INVESTIGATING HEAVINESS IN HEAVY METAL PRODUCTION. THE FINDINGS WILL BENEFIT ALL THOSE INTERESTED IN MUSIC PRODUCTION AND METAL MUSIC

Many people – fans of heavy metal music or otherwise – understand the sounds that constitute a genre of music, but what is 'heavy' in metal. Can you define it? Dr Jan Herbst and Dr Mark Mynett, both based at the University of Huddersfield, have embarked on a project titled 'Heaviness in Metal Music Production'. They aim to find out what heaviness is in audio-recorded form.

"So far, Mark and I are more or less the only scholars who have studied musical heaviness," explains Jan. "Mark has written his PhD on producing contemporary metal music and published his findings in a practical manual (*Metal Music Manual*)." Ultimately, Jan and Mark want to expand on this work and develop a theoretical model of what constitutes heaviness in contemporary metal music production with all variables and constraints, then offer that model to practising producers and self-producing artists.

WHY HAS METAL MUSIC BEEN ON A QUEST FOR GREATER HEAVINESS OVER THE PAST FEW DECADES?

In 1970, Black Sabbath, an English rock band, released their self-titled debut, which is said to have started the metal genre and was therefore the beginning of the quest for greater heaviness. Its importance can hardly be overstated. Perceived heaviness – which is metal music's defining feature – can arguably be seen as the source of the listener's pleasure.

"This artistic pursuit for greater heaviness and extremity was paralleled and supported by record production, which had to find creative and technical solutions to ever-greater complexity and demands for sonic quality and aggression," explains Jan.

However, we must also consider the myriad – and highly personal – ways that any form of music can affect an individual. While some people might find solace in metal music, seeing it as a form of rebellion, there are those who will find it pleasing and enjoyable for entirely different reasons.

IS HEAVY METAL THE ONLY SUBGENRE WITHIN METAL MUSIC?

There are some subgenres of metal that are accepted by most metal fans, such as thrash, symphonic, gothic, death, black and doom metal, as well as a host of 'core' genres like metalcore or deathcore. But then there are 'subgenres' that are more of an interpretation of the main genres, like folk metal or Viking metal. In addition, progressive metal tends to describe the complexity of the music, rather than the subgenre. It is worth considering that, sometimes, the function of a subgenre is to be a badge of identity, where people align themselves with a particular subgenre for social and emotional reasons – in those instances, it is in the group's interest to create their own defined subgenre.

HOW ARE JAN AND MARK CONDUCTING THEIR RESEARCH?

The team is looking at how seven leading metal producers – who specialise in different subgenres – define heaviness. From there, Jan and Mark will focus on how these producers process and control the aspects of heaviness during the mixing of a song composed and recorded for the research project. The project will analyse the differences in the producers' understanding of heaviness, their individual approaches and how the characteristics of the

DR JAN HERBST

Principal Investigator, School of Arts and Humanities, University of Huddersfield, UK

DR MARK MYNETT

Co-Investigator, School of Computing and Engineering, University of Huddersfield, UK

FIELDS OF RESEARCH

Musicology, Music Technology

RESEARCH PROJECT

Examining how leading metal producers define and create 'heaviness' in music and their productions
www.himmp.net

FUNDER

Arts and Humanities Research Council (AHRC), grant number AH/T010991/1

In 1970, Black Sabbath released their self-titled debut, which is said to have started the metal genre.
© 'Billboard' 1970

material they work with shape and influence the decisions they make when mixing.

WHY IS IT IMPORTANT TO STUDY HEAVINESS IN METAL MUSIC PRODUCTION?

Jan and Mark are interested in heavy metal, heaviness and metal music production from a personal, professional and academic perspective. Mark balances his time as a lecturer and professional metal music producer, while Jan is interested in filling in the knowledge gaps about the musical nature of metal – especially in its recorded form. "In the last few years, music production has become available and affordable to many interested producers and musicians. What has declined, though, are opportunities to learn music production from masters through assistantships like in the old, analogue days," says Jan. "Instead, aspiring producers and musicians are faced with many free and commercial tutorial materials in print and online, which are great resources but also overwhelming, not only because of the volume but also because the quality is not always guaranteed. Studying how to produce heaviness will help provide useful information for producers and musicians, which will benefit the genre and individuals involved."

WHAT IS THE ULTIMATE AIM OF JAN AND MARK'S RESEARCH?

The aims of the research are quite straightforward. In Mark's words, "We want to understand how heaviness is manipulated by producers in the field." However, there are other benefits, including that this project is so unique and original that it cannot help but make a positive contribution to the wider academic field. Then there is the knowledge discovered, gathered and shared that will help producers and self-producing artists from a range of different abilities and experiences. "The knowledge we will gain from this project is free and based on the professional experience of leading metal producers," explains Jan. "In addition, it is filtered and evaluated by objective scholars with an understanding of – and passion for – the craft."

ABOUT MUSIC TECHNOLOGY AND MUSICOLOGY

It is rare to find a person who has not been affected by music in some way. Whether it is sitting at home, listening to your latest musical purchase, or watching a film with a brilliant soundtrack, music is a beautiful art in its own right. It is also adept at enhancing other arts.

There are those who take a passing interest in music, while others dedicate most of their spare time to it. And then, of course, there are those like Mark and Jan who dedicate their personal and professional lives to music. Musicology means 'the study of music' and Jan and Mark's most recent project seeks to drive forward our understanding of heavy metal and what exactly constitutes 'heaviness', but the pursuit of deeper understanding of a subgenre within music has far wider cultural and social impacts than the subject at hand.

WHY IS IT IMPORTANT TO STUDY MUSICOLOGY AND MUSIC TECHNOLOGY?

In its current forms, music would not be possible without technology – concerts need amplification, while music recording requires a studio of some sort. Of course, as time goes on and technology develops, things that were once exorbitantly expensive become cheaper and more readily available to the masses. In the 1960s, to record music, it was necessary to go into a studio. Now, an album can be produced in a bedroom. Irrespective of where the recording takes place, knowledge and ability are still a prerequisite.

"While music technology resources become more affordable and powerful, the demands on quality increase as well. If an artist wishes to progress beyond a local fan base, professional skills are required that they can acquire themselves or obtain through working with professionals – most likely a mixture," says Jan. "Studying music and music technology provides these professional skills, be it as a practising musician or a music technologist, who has a broad skillset from recording to production and post-production for recorded music and audio-visual media."

WOULD JAN AND MARK RECOMMEND A CAREER IN MUSICOLOGY OR MUSIC TECHNOLOGY?

Yes! Of course, they are bound to say that given it is their main passion, so it is reasonable to present a well-rounded description of what you can expect if you choose to dedicate your professional life to this career. First, if you want a 9-to-5 job with a lot of structure, you should perhaps look for a career in a different area. However, if you want a job that affords you plenty of freedom and diversity, then music technology or musicology might be the perfect field for you. "Music technology is a really wide field, and graduates pursue very different lines of work. Some become freelance musicians or music producers, or work for a company. Some become original artists or compose and produce music for TV, film or games, others work in broadcasting, and yet others develop instruments and software applications. Music and arts is one of the UK's biggest economies, larger than the car manufacturing industry," explains Jan. "This means there is a lot of work, and it comes in all forms, from the freelancing artist type to the scientifically minded technician, and this breadth is represented in the course offer at most universities."

EXPLORE CAREERS IN MUSICOLOGY AND MUSIC TECHNOLOGY

- The International Association for the Study of Popular Music is the perfect starting place for those interested in pursuing a research career in popular music: **www.iaspm.net**
- Jan and Mark recommend visiting the International Society for Metal Music Studies website: **metalstudies.org**
- For those more interested in music technology, the Art of Record Production network (**www.artofrecordproduction.com/aorpjoom/**) is a brilliant resource, as well as the Audio Engineering Society: **aes2.org**
- According to **CareersinMusic.com**, music producers and musicologists earn approximately £38,500 per year, although salaries for music producers can range from £28,000 to £56,000, and £7,300 to £196,400 for musicologists. "Then, of course, there are worldwide recognised 'superstar' producers, who, with producer album royalties factored in, can quite easily earn over a million pounds a year," says Mark.

PATHWAY FROM SCHOOL TO MUSICOLOGY AND MUSIC TECHNOLOGY

There are many different routes into music. As Jan says: "There are examples of artists and industry professionals without a degree but getting structured and proven education is a fast track to acquiring the required skills and vastly increases the chances of being successful."

Many graduate programmes in musicology and music technology are available at universities – it is all about choosing the one that best fits with your requirements.

www.careersinmusic.com/musicologist/

www.careersinmusic.com/music-producer/

www.prospects.ac.uk/jobs-and-work-experience/job-sectors/creative-arts-and-design/careers-in-music

MEET MUSICOLOGIST DR JAN HERBST

For a long time, I thought I would become a software engineer because I quite enjoyed video games. I dabbled in coding, but it didn't excite the passion I was expecting. At 18, I had a pivotal moment where I suddenly realised that my future was in music. It was a spontaneous thought, but I didn't question it or weigh up pros and cons. I intensified my practice routine on the guitar, asked my professional guitar instructor for guidance and, eventually, enrolled on a performance course.

Making research my main career relieves me of the pressure of keeping up my guitar performance skills! I'm joking – but I do find research a stimulating activity. I won't lie: reading texts to find out what is already known, conducting original studies and writing them up is hard work, but when you see the results, you realise it is always worth it.

Metal music studies is a very young field of research and is advanced mainly by emerging researchers, who are also fans of the music. Of course, there are some problems with researching music you love, but few would argue that this does not benefit from insider knowledge. When it comes to music technology within metal music studies, you are looking at a handful of scholars. In other words, there are plenty of opportunities to make an impact and drive the field forward. Technological research in metal music is commonly conducted by practitioners and usually has the potential to inform and improve professional practice.

Although I tend to listen mainly to rock and metal, I like to play a variety of styles on the guitar, especially funk and other rhythmically complex genres. This is similar in my production practice. Rock and metal are my preferred genres to produce, but I am fascinated by the individual approaches to songwriting, arrangement and production in popular music more widely.

My biography is full of changes; I have had different jobs and acquired multiple degrees. The unifying element has always been music. Sometimes I concentrated on performance, sometimes on musicology and other times on technology. In hindsight, these different paths that I have taken all led me to where I am now, and each change has brought me closer to what I ideally want to do. Ultimately, there are no regrets and I realise education is never in vain.

MEET MUSIC TECHNOLOGIST DR MARK MYNETT

I went to my first gig when I was 12. Thin Lizzy, an Irish hard rock band, was playing and five weeks later, on my 13th birthday, I got a guitar.

I studied for a BSc in popular music production while working as a self-employed record producer. This stemmed from my interest in music production and the degree definitely opened up opportunities.

I also have a PhD in engineering, producing and mixing contemporary metal music. The depth of study required for this greatly facilitates my work as a lecturer.

Managing my time can be very difficult! I lecture at the University of Huddersfield, produce music, work as a front of house engineer for live music festivals and write articles for various music technology publications.

When I was younger, I wish I had known the importance of living in the present. I am aware of the irony in this statement, but far better to live in the present than the past or future.

JAN AND MARK'S TOP TIPS

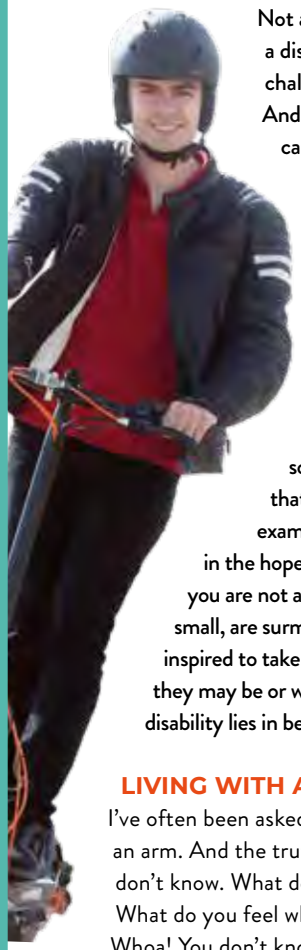
01 Persevere. As with any field of interest, once you step back and get some perspective, you will be astonished at what you have created or discovered. It does not matter what field – all are satisfying in their own right.

02 Don't worry too much about the specific title or focus of your future education. Find a domain that you like and explore it extensively from all areas. As the saying goes, if you do a job you love, you never work a day in your life.

03 Some people hold the view that humanities and liberal arts degrees are not as valid as degrees in STEM, medicine or law. However, liberal arts degrees contribute to a shared meaning and the well-being of humanity in a different way. All pathways are equally valid.

PIECE BY PIECE: A HEARTFELT MEMOIR OF A BOY WHO BUILT HIS PROSTHETIC ARM FROM LEGO

IN NOVEMBER 2020, WE FEATURED **DAVID AGUILAR AMPHOUX** IN 'HOW TO BUILD A STEAM GENERATION', ISSUE 6 OF FUTURUM. TWO YEARS LATER, DAVID HAS WRITTEN A MEMOIR ALONGSIDE HIS FATHER FERRAN ABOUT HIS JOURNEY TO BECOMING A ROLE MODEL FOR MILLIONS WORLDWIDE



Not all of us will know what it is like to live with a disability, but all of us will have experienced challenges that seem insurmountable at the time. And while we are dealing with those challenges, it can feel as if no one is around to help – as if we must face our battles alone. David's memoir, co-written with his father Ferran, centres on his experiences of living with a disability and his incredible journey, from building a prosthetic arm from LEGO at the tender age of nine, to becoming an influencer with a degree in bioengineering.

In addition to this, *Piece by Piece* exposes some of those overwhelming life experiences that affect us all: bullying, heartbreak, grief, failing exams. Here, we publish extracts from this memoir in the hope that, just as David has, you will discover that you are not alone and that all challenges, however big or small, are surmountable. We also hope that, like us, you will be inspired to take risks and follow your dreams, no matter what they may be or what anyone else thinks. As David says, "The true disability lies in believing you can't achieve anything."

LIVING WITH A DISABILITY

I've often been asked what it feels like when you're missing half an arm. And the truth is, even now at twenty years old, I still don't know. What do you feel if you're missing a finger? [...] What do you feel when you're missing the eleventh finger? Whoa! You don't know what that feels like, right? I count to five you count to ten. I am not missing anything. Neither are you.

And if you are a part of that small group of us who don't reach ten, like me, then you're not missing anything, either. Really. At first you don't see it, because your entire life you've heard the word without or been told you're "missing" something. Well, I'm here to tell you: You're not missing anything; in fact, you have a surplus.

A surplus of opportunities.

BULLYING

"Hey, David," Jordi greeted me when I arrived. I've already told you he's been on my case from the beginning. I was surprised he'd say hello, he was usually a jerk to me. "Can you lend me a hand with the math homework?" he asked, stretching out his right hand.

As you can see, it took 0.7 seconds for him to act like usual – that is to say, like a complete and total bonehead.

[...]

"Oh, sorry!" Some giggles could be heard from our classmates. "I guess I have the upper hand on this one." And the chuckles broke out.

It's hard to believe that people still get on your case or sell you short, even if you do great things. Jordi was in my class when I'd build the first prosthesis; he knew what I was capable of. [...] But what I want to explain now is: I barely cared at all about his opinion. One of the biggest lessons you need to learn in life is that reaching your goals, whatever they are, is what's important – but you need to do it yourself.

Photo caption: David on a scooter @ Ferran Aguilar

“THE TRUE DISABILITY LIES IN BELIEVING YOU CAN’T ACHIEVE ANYTHING.”

David with his father, Ferran. © Jose Sanchez, Foto Estudi La Seu

The making of Mr Hand Solo, a documentary. © Ferran Aguilar

National Geographic Spain featuring David. © Pau Fabregat

HEARTBREAK

She wrote a lot of things. That yes, she had a good time with me, but ‘it’ (my arm, or lack of arm) gave her the “creeps”. That her friends “laughed at her” (no, Marta, they laughed at me; maybe now you understand that better), and she just “couldn’t”. That she felt bad. That we were friends. That she hoped I forgave her.

Without knowing how, I managed to say goodbye and archive the chat without blocking her.

Returning home, I felt like the stupidest creature on the face of the earth.

GRIEF

Tears slid down my cheeks like silent, unceasing waterfalls. They sprang from a well of pain, that, sealed off until then, now seemed to find its way out. I had cried on only three occasions in my life up till then, and my abuela’s funeral was, without a doubt, the worst of all.

[...]

With all the overwhelming love and support that had reached me since I’d gone viral, I couldn’t help but remember with every day, and even every hour, my abuela Basilia. More than a year had passed since she’d left us, and although I missed her affectionate caresses, embraces, kisses and words (her voice diluted in my memory like the steam off a hot chocolate – sweet until the end, bitter when it’s over), her love remained around us like a warm blanket.

FAILING EXAMS

It was then that my grades started to plummet until they settled lower than five in all my classes. Even physics and math. Even Catalan, Castilian, history. The heat arrived with increasing violence, but I still wore long sleeves and tucked the right cuff into my pocket. My teachers called my parents, and my parents spoke to me. I tried, studied and struggled to concentrate, but my head rejected anything that tried to enter it. There was no room left. The wound from Marta’s betrayal kept bleeding. The well of grief my abuela had left behind seemed impossible to drain. In the end, I had put on short sleeves because the heat won, and I had to repeat five subjects.

[...]

Repeating a year was an unexpected tributary that opened before us, and while it seemed better to avoid it, I wasn’t so sure it would be something bad. Maybe it was the path I needed to take. Perhaps in the end, the tributary was in reality the main watercourse, and it would lead me to the sea I was hoping to reach. Sometimes the unexpected holds the biggest solutions in life, and to achieve them, we just need to let ourselves follow the current.

Extracted from *Piece by Piece* by David and Ferran Aguilar (**Amazon Crossing, £8.99**).

READ DAVID’S PREVIOUS ARTICLE HERE:

futurumcareers.com/if-lego-can-take-me-down-a-path-of-success-imagine-what-steam-could-do-for-you

"WITH THE RESOURCES THAT ARE AVAILABLE ONLINE, THERE'S NOTHING STOPPING ANYONE FROM LEARNING ELECTRONICS, MECHANICS, PROGRAMMING, ENTREPRENEURSHIP, OR HOW TO BUILD PROTOTYPES."

OPEN BIONICS DEVELOPS MEDICAL DEVICES THAT ENHANCE THE HUMAN BODY, AND ITS FIRST PRODUCT IS THE HERO ARM FOR PEOPLE LIVING WITH A BELOW-ELBOW LIMB DIFFERENCE. **JOEL GIBBARD**, CEO AND CO-FOUNDER, EXPLAINS HOW HE STARTED CREATING BIONIC ARMS WITH A 3D PRINTER

WHO OR WHAT INSPIRED YOU TO STUDY ROBOTICS?

As a child, my favourite toy was LEGO Technic. I'd spend hours engrossed in building various contraptions. This was definitely an early inspiration for me. I also had inspiration from my father, who used to tinker with electronics and radio-controlled robots. He used relays, transistors and a lot of analogue electronics, before semiconductors and integrated circuits really existed, to teach me the principles of electronics and logic. The first Iron Man movie was released in 2008, just as I was about to start university, which brought robotics to the mainstream and made it more accessible.

WHAT DID YOU DO IN YOUR FIRST ROLE AS APPLICATIONS ENGINEER AT NATIONAL INSTRUMENTS?

This role primarily involved providing technical support and training to customers who were using National Instruments equipment in test and measurement applications. It was a great introduction to working in a large engineering organisation, with plenty of opportunities to problem solve while getting an understanding of how a larger company works. Ultimately, I found that the role didn't afford me enough opportunity to explore new ideas or projects, and this was one of the realisations that led me to think about a different career path.

Hero Arms come in all different sizes. © Open Bionics 2022

WHAT LED YOU TO FOUNDING THE OPEN HAND PROJECT?

During my university degree, I saw the potential of 3D printing as a transformative technology for prosthetics, and assumed it would be adopted quite quickly. However, after following the 3D printing and prosthetics industries for some time, I noticed that nothing was being done to bring the two together, so I decided I would have a go at doing this myself.

The price of most new technologies goes down quite rapidly after their initial launch, but I noticed this wasn't happening for bionic hands, the first of which was launched in 2008. I felt this was preventing bionic hands from becoming accessible and that contributing to this accessibility would be a noble pursuit.

HOW DO YOU CONVINCE PEOPLE TO FUND A PROJECT LIKE THIS?

I bought one of the first commercially available 3D printers and started making prototypes. Raising money is extremely difficult, and you have to deal with a lot of rejection. You have to have a lot of self-belief, put yourself out there and not be afraid to ask for help. I was very fortunate to have a lot of support from my friends and family, and it was easy for people to understand the potential behind the idea and its impact.

HOW DID YOU MEET YOUR OPEN BIONICS CO-FOUNDER, SAMANTHA PAYNE?

We initially met while I was doing the Open Hand Project crowdfunding campaign in 2013. Samantha was working as a freelance journalist in Bristol, UK, and a mutual friend suggested she write an article about the Open Hand Project. At the time, she was reporting on technology start-ups in the city and was running a project developing a wearable technology prototype to support victims of domestic abuse. After experiencing the passion and excitement from the start-up founders she was interviewing, she wanted to do something similar, and the idea of working on a project that had social impact appealed to her.

Open Bionics was initially founded so we could start entering more start-up competitions and raise money. It gradually came to a point where we could start hiring a team and develop a product.

HOW IS THE HERO ARM REVOLUTIONISING THE PROSTHETICS INDUSTRY?

The Hero Arm was designed with a 'user first' mindset. This has led to some fundamental differences compared with most products in the industry, which have been designed to suit the needs of reimbursement systems, insurance schemes, doctors and clinicians. Other companies are making components, such as bionic hands, batteries, cables and sensors, which they sell to a prosthetist who will then build them into a prosthesis.

Our Hero Arm is fully integrated, and the result is that it is a truly bionic arm. It is lightweight, and we can customise the way the user's arm looks. The lightweight, removable covers make the Hero Arm design even more distinctive. For prosthesis users, it represents a new mindset, enabling people to celebrate their limb differences, gain confidence and wear their prosthesis with pride.

WHAT IS YOUR VISION FOR THE FUTURE OF OPEN BIONICS?

I'd be very happy if Open Bionics can make a lasting improvement to the accessibility of advanced prosthetic and orthotic limbs. I envisage the development of new products that offer touch feedback, better control and more degrees of motion to people with limb loss. These features should be made available to anyone who needs them, free of charge. That means making sure healthcare systems fund them, that they are easy to fit on patients, and that they are simple to use.

ABOUT JOEL

Joel studied robotics at the University of Plymouth in the UK. On graduating, he became an applications engineer at National Instruments before moving on to found the Open Hand Project, the aim of which was to make prosthetic hands more accessible to amputees. The project was funded through a crowdfunding campaign, which successfully raised £44k. Together, with co-founder Samantha Payne, he set up Open Bionics in 2014. In 2020, Joel was recognised with an MBE in the Queen's Birthday Honours List for services to International Trade and Engineering Technology.

LOOKING BACK, WHAT DO YOU WISH YOU HAD KNOWN WHEN YOU WERE YOUNGER?

The fastest way to learn new things is by talking to people. If you are an introvert, it feels easier to try and research around a subject and learn about it yourself, but you can learn much faster and more effectively by finding experts and learning directly from them.

WHAT ARE YOUR TOP TIPS FOR YOUNG PEOPLE HOPING TO A) BECOME A BIONICS ENGINEER AND/OR B) START THEIR OWN BUSINESS?

My main piece of advice would be to just start doing it. With the resources that are available online, there's nothing stopping anyone from learning electronics, mechanics, programming, entrepreneurship, or how to build prototypes. It's possible to have a 'side hustle' while studying at university or in full-time employment. You don't have to have super innovative resources to teach you how to run a small business, either. The lessons you learn along the way will be extremely important and you'll get better and better the more you try.

If you want to become a bionics engineer or start your own business, start doing bionics engineering or start your own business! Do it today. It's that simple.

CONNECT WITH JOEL AND OPEN BIONICS

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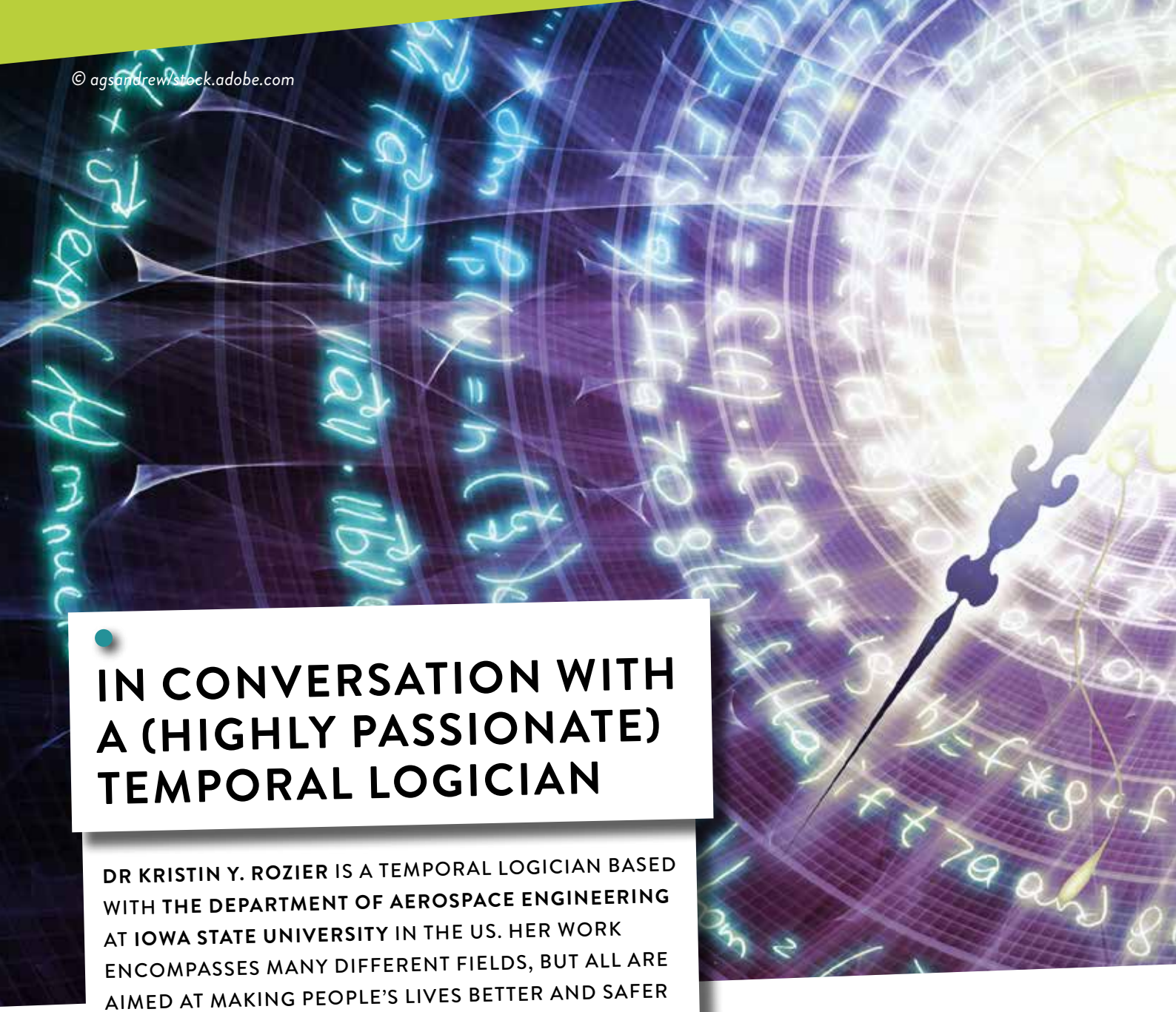

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IN CONVERSATION WITH A (HIGHLY PASSIONATE) TEMPORAL LOGICIAN

DR KRISTIN Y. ROZIER IS A TEMPORAL LOGICIAN BASED WITH **THE DEPARTMENT OF AEROSPACE ENGINEERING** AT **IOWA STATE UNIVERSITY** IN THE US. HER WORK ENCOMPASSES MANY DIFFERENT FIELDS, BUT ALL ARE AIMED AT MAKING PEOPLE'S LIVES BETTER AND SAFER

If you have 100 socks in a drawer, 50 of which are red and 50 black, how many will you have to pull out to guarantee you have a pair? We will give you a second to think about it… Okay, time is up. Let us work through this logically. You pull out one sock and it is red. Now, the next sock could be red, making two socks to make a pair. However, you could pick out a black sock, meaning you do not have a pair. Regardless, the next sock you pick will be either a red or a black sock, which would guarantee you have a pair. The answer is three.

That gives us a simple logic puzzle we can all understand, but somebody who understands logic to a far greater degree is Dr Kristin Y. Rozier, associate professor within the Department of Aerospace Engineering at Iowa State University in the US. A recipient of the Initiative-Inspiration-Impact Award from Women in Aerospace, Kristin's main passion (and foundation to her approach to life) is temporal logic; Kristin absolutely LOVES solving puzzles in order to make life better and safer for people.

WHY DOES KRISTIN DESCRIBE HERSELF AS A TEMPORAL LOGICIAN?

Kristin's research spans a wide range of applications and theoretical domains, but the one thing they all have in common is temporal logic – that is, an unambiguous, mathematically precise way of describing and reasoning about systems that change over time. By adopting this approach, Kristin is able to solve meaningful problems in aerospace engineering, robotics, cybersecurity, theoretical computer science, mathematics, virtual reality, and more. "Think about solving an air traffic control problem, where you have to direct all of the planes to a configuration where they are safely separated from each other but still progressing toward their final destinations," says Kristin. "You can come up with a solution (a configuration for all of the planes) but then they move! The planes keep flying! You have to come up with a series of solutions for the continuously changing airspace."

Temporal logic provides a way of capturing critical details about puzzles so researchers can devise solutions and prove that they accomplish a project's aim, such as keeping all the passengers safe in the air traffic control scenario.

FASCINATING FORMAL METHODS

Formal methods are mathematically rigorous techniques for the specification, design, validation, and verification of cyber-physical systems (systems that are made of hardware, software, or a combination of the two). They are vital to Kristin's work as they enable her to prove both the presence of behaviours she wants a system to exhibit and the absence of behaviours she does not (such as something that would make a system unsafe). "Many people think you verify a system by testing; you give the system some

DR KRISTIN Y. ROZIER

Associate Professor, Department of Aerospace Engineering, Iowa State University, USA

FIELD OF RESEARCH

Temporal Logic and Formal Methods

RESEARCH PROJECT

Designing algorithms to approach a range of research questions – including those in aerospace engineering, robotics, cybersecurity, theoretical computer science, mathematics, and virtual reality – from a logician's standpoint

input and observe that it does what you wanted in response. This works if you want to verify that – if there's an obstacle on the left, the plane will turn right to avoid it. But what if the behaviour you want to verify is that the automated air traffic control system is incapable of telling two planes to get dangerously close to each other, under any circumstances?" explains Kristin. "Think about it: you cannot test for the absence of a behaviour you don't want your system to have, but you can formally verify that, and you get to solve fun temporal logic puzzles in the process."

Ultimately, Kristin's research involves developing new algorithms to reason about safety-critical systems so that people can use and be around technology that makes their lives better and adheres to certain requirements at the same time.

Undergraduate students Logan Gross and Christopher Johannsen helping Kristin to assemble a COTS (Commercial Off-The-Shelf) UAS (Unmanned Aerial System) as part of a study for the OpenUAS project in her lab. OpenUAS is an undergraduate research project to create an all-open-source, reconfigurable UAS test bed accessible to broad audiences.

WHERE WILL KRISTIN'S RESEARCH LEAD TO IN THE FUTURE?

Or should that be, where does Kristin not see it heading in the future? One of the major challenges of Kristin's work is that as technology becomes more advanced, it is necessary to advance formal methods to keep up. In that regard, her work is never-ending. "Wherever technology interacts with humans, or critically needs to work correctly, my research will be aimed at tackling that challenge. This includes future aircraft, robots, rovers, satellites, spacecraft, medical devices, automated cars, even Internet of Things (IoT) devices like the video doorbells and smart appliances in every-day houses," says Kristin.

"Systems that exhibit high levels of autonomy or learn and adapt to their environments present a new frontier for formal methods that I am very excited to explore."

Kristin's passion for problem solving is inspiring – will you be joining her to explore the logic puzzles of the future?

ABOUT TEMPORAL LOGIC

The key difference between logic and temporal logic is the quality of time (hence temporal). While logic is a precise and unambiguous means of describing a system, temporal logic describes systems that change over time. Many of the most challenging puzzles in life have this property – they are reactive systems that respond to their environments and therefore change over time.

Kristin firmly believes that puzzles have real-life analogues; when you complete a puzzle (like sudoku or matrix logic) or a level on a game, you will reach a screen that congratulates you for winning. Imagine, instead, that the clues you use to solve these puzzles were sensor data from a spacecraft and solving the puzzle means you can know that something is going wrong with the mission, even though you cannot directly see the fault. Instead of a 'congratulations' screen, your reward would be contributing to a scientific breakthrough that makes people's lives better – you would enable the spacecraft to figure out by itself that something is wrong, and save the mission!

HOW DOES TEMPORAL LOGIC ENABLE KRISTIN'S RESEARCH?

Computer scientists have a way of classifying the hardness of problems, with the caveat that every problem in a particular hardness class has a proof that it is equivalent to other problem(s) in the same class. Puzzles and games that we find fun are most often in the class called 'NP-Complete' which is a meaningless acronym designating the class of problems that are challenging, but solvable, with the satisfying characteristic that if we are presented with a solution, it is easy to tell that that solution is correct. "The cool thing is that many of the world's most impactful problems are also in the class NP-Complete or are at least helped by being able to solve problems in this class better," explains Kristin. "If you develop strategies for efficiently solving these kinds of problems, you could apply those strategies to games and puzzles, or you could apply them to real-world problems – it's really the same thing, except that it is so much more rewarding to use the same skills, have fun and have real-world impact!"

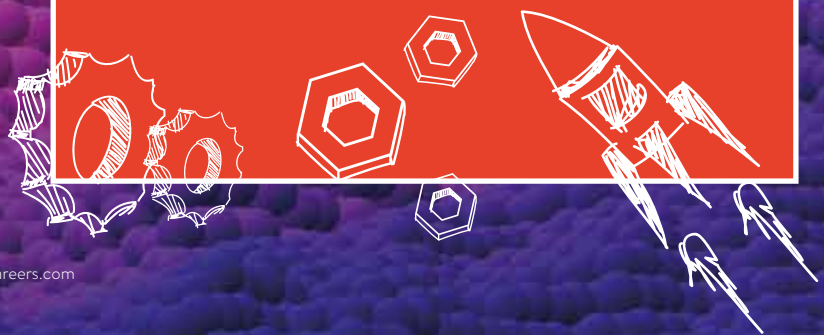
EXPLORE CAREERS IN TEMPORAL LOGIC

- We highly recommend reading through the NASA website – it is a brilliant resource and provides a great way of learning more about specific projects that are currently underway: **www.nasa.gov/**
- The Aerospace Industries Association is a great place to start if you are looking for opportunities in the future: **www.aia-aerospace.org/**
- According to **www.payscale.com**, the average salary for an aerospace systems engineer is $81,000.

PATHWAY FROM SCHOOL TO TEMPORAL LOGIC

Kristin recommends studying logic and problem-solving (both inside and outside academia), which will help you to develop the ability to learn new things with deeper understanding and to practise using your brain in new ways. It is unlikely your school or college will offer specific 'temporal logic' classes, but Kristin says studying computer science, mathematics (especially mathematical logic), algorithms, and philosophy will help nurture the thinking involved in her work. Analysing the connections between events in history is also related.

"Shying away from mathematics and science classes will cut off your future opportunities, so study hard and do well in those classes to ensure you can choose what you want to do in the future," says Kristin. "I suffered terribly during my 12th grade mathematics class (due to the teaching style and others telling me I couldn't do math), but I am glad I persevered, as I earned an A and got accepted to the College of William and Mary, where I was able to study calculus again in a better environment. Ultimately, that set me on the path to the computer science programme that changed my life and set me on my current trajectory."



HOW DID KRISTIN BECOME A TEMPORAL LOGICIAN?

WHAT WERE YOUR INTERESTS AS A CHILD?

I loved logic puzzles! I never thought that would amount to anything – I am so glad I was wrong. When I design an algorithm now, I am solving a huge, complex matrix logic puzzle for every point in time!

I always wanted to travel and meet people, and I wanted to shape policies to make their lives better. I thought I might work for the United Nations, but STEM attracts the brightest minds from all over the planet. I get to collaborate with awesome people from many different countries and learn from their diverse perspectives. I get to present my research findings at international meetings and work with research labs in many different locations, learning about global challenges and publishing work that influences technology worldwide – it's more fun than I ever dreamed as a kid.

I wanted to be a professional ballerina (and I succeeded too – I taught ballet at a dance studio down the street from NASA Langley Research Center while I was a research scientist there). I also taught tap dance!

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

My parents gave me a book on Marie Curie that sparked my imagination. I ended up doing a James Monroe Scholarship project on her as an undergraduate at college, where I traced her life through Poland and France. My parents were both interested in STEM (my father was a technologist and my mother was a nurse), and I have crayon drawings that I made in elementary school of Bell Laboratories because my dad would tell me stories of the fascinating people who got to work there. Initially, I thought I could never have the impact I wanted as a scientist and thought I would have to become a lawyer at the UN or something like that, until I had the epiphany that I could do more as a scientist.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

Seeing the world as a collection of giant puzzles, waiting to be solved! Once I had an education that allowed me to see the parts of the puzzles, the world started to look like a collection of challenges, some of which I might be able to solve. There are so many challenges out there, and the key is to take each one and ask, "Can I advance this one closer to a solution?" Most of the time, the answer is no, but sometimes I have a great idea that works. Even ideas that fail are great learning experiences that make you better at devising future solutions.

WHAT MOTIVATES YOU TO DO THE WORK YOU DO?

I get to push the bounds of human knowledge; I get to advance the state of the art and do things that have never been done before; I get to create new technology that makes life better, safer and more secure; and I get to collaborate with fascinating people who challenge me, from all different backgrounds, from all over the world. When we accomplish a mission together, we get to see something amazing, like a flight of a new aircraft or a spacecraft going where no one has gone before.

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

Failure is a wonderful thing – it teaches you more than success. I tell the students in my lab that failure is an opportunity to learn how to do it right next time and abject failure comes with the bonus of a great story to tell at the next party! I try to get things right, of course, but when I don't, I try to learn as much from that experience as I can. As a woman, I've had a lot of people tell me I can't do this job, which has presented a significant obstacle in my life. I have learned not to listen to them, and I'm still working on finding ways to keep those people from limiting the opportunities available to future scientists.

HOW DO YOU 'SWITCH OFF' FROM THE COMPLEXITIES OF YOUR WORK?

My brain never switches off! Sometimes it works better when I'm spotting a pirouette in ballet class, or climbing a mountain on my bicycle, or staring at a painting in one of my favourite museums.

WHAT AMBITIONS DO YOU STILL WANT TO ACHIEVE?

There are so many places I want to see, experiences I want to have, and people I want to meet. My ambition is to do the best that I can do and explore the opportunities that open up from there.

KRISTIN'S TOP TIPS

01 Mastering logic (mathematical logic, logical deduction, the skills you need to reliably solve matrix logic puzzles or Raymond Smullyan books, or even to have a good guess at the culprit in Agatha Christie novels) will serve you well in all areas of life.

02 Logic underlies all the challenges I tackle and allows me to break down the problems into sub-problems that I can solve. It even prevents me from arguing with other people; if you can logically deduce your point of view, and that of the other person, then there is nothing to argue about!

03 Logic and logical thinking can prevent you from becoming confused or taken advantage of; logic can instil an idea of making decisions based on reality and thought, as opposed to emotions, which will help you reach your goals.

A CRISIS OF CLARITY: CAN DEFINING BIODIVERSITY HELP US PROTECT THE NATURAL WORLD?

FOR CENTURIES, MANY HUMANS HAVE TREATED NATURE AS A COMMODITY, PURGING FORESTS OF TREES AND THE OCEANS OF FISH. AS A RESULT, BIODIVERSITY IN ECOSYSTEMS AROUND THE WORLD IS DECLINING AT AN ALARMING RATE, THREATENING THE BALANCE OF LIFE ON EARTH. BUT WHAT IS BIODIVERSITY, AND HOW CAN WE MEASURE IT? **PROFESSOR CHARLES PENCE** FROM **THE UNIVERSITÉ CATHOLIQUE DE LOUVAIN** IN BELGIUM BELIEVES THAT ANSWERING THIS QUESTION IS OF VITAL IMPORTANCE IF WE ARE TO STOP THE LOOMING BIODIVERSITY CRISIS

TALK LIKE A PHILOSOPHER OF SCIENCE

BIODIVERSITY — the variety of life found within an ecosystem or, more generally, on Earth

SPECIES — the basic unit we use to classify organisms, often defined as similar individuals that are capable of interbreeding

TAXONOMY — the branch of science associated with classifying and organising organisms

INTERDISCIPLINARITY — the collaboration of two or more branches of knowledge

ECOSYSTEM — all the organisms in a place and the environment that they interact with

CONCEPTUAL ENGINEERING — a method philosophers use to try to find and fix places where ideas from science (or everyday life) are confused or unclear

Around the world, biodiversity is decreasing at an alarming rate. In Brazil, vast swathes of the Amazon rainforest are being decimated and transformed into farmland. In the eastern Pacific, rising sea temperatures are causing massive bleaching events on coral reefs, leaving these once vibrant ecosystems barren and lifeless. And in the UK, invasive plant species like rhododendron and Himalayan balsam are crowding out native trees and causing a massive reduction in biodiversity.

This loss of biodiversity has the potential to become one of the biggest threats facing humanity over the coming decades. Biodiversity forms the foundation of all healthy ecosystems on the planet. As more species are threatened by climate change, habitat loss and invasive species, these ecosystems could become irreparably damaged.

We rely on many of these ecosystems for the services that they provide. For example, healthy forests can reduce air pollution, prevent flooding and soil erosion, absorb carbon from the atmosphere and provide humans with places to relax and explore. Without the biodiversity that underlies them, we would not have forests and all that they provide for us.

WHAT IS BIODIVERSITY AND HOW CAN WE MEASURE IT?

These questions, it turns out, are harder to answer than they would first appear. Their answers are shrouded in debate and uncertainty, making it hard for scientists to collaborate on potential solutions to the biodiversity crisis. Professor Charles Pence from the Université catholique de Louvain is leading a research project that aims to clarify these definitions. Without precise definitions, Charles argues, we will struggle to understand the impacts that we are having on biodiversity and how we might be able to protect it.

Biodiversity is commonly defined as the total number and variety of species found within an ecosystem. On paper, this seems like a fairly simple and concise explanation. However, when scientists try to apply it to nature in the real world, things become less clear. Charles explains that one problem with this definition is that "there's also very little agreement about how to define species."

In nature, boundaries between different species, habitats and ecosystems are often blurred. For example, a species is often defined as a group of organisms that can breed and produce fertile offspring. Lions and tigers are not the same species because when they mate, their offspring, known as ligers, are sterile and not able to reproduce.

Although many scientists accept this definition, "others," Charles points out, "may point to different kinds of visible (morphological) characteristics, arguing that species need to have similar traits." Darwin's finches, for example, found on the Galapagos Islands, are often considered to be many different species based on variations in their morphology and behaviour. Despite this, there have been many reports of interbreeding between members of the supposedly distinct species.

WHY IS CLARIFYING THESE DEFINITIONS IMPORTANT?

The debate around how to define a species has a significant effect on how scientists understand and measure biodiversity. "If we take a population and split it into a larger number of species," explains Charles, "those species may immediately be more endangered without any change in the natural world."

The ecosystem that these species are a part of would also appear to have a higher level of biodiversity than it does. This can significantly change how healthy an ecosystem appears and can lead to vulnerable populations being overlooked. "All that just because we changed our opinion about what counts as a species," says Charles.

Clarifying these issues will have benefits not only for the scientific community but also for many other members of society who are trying to protect biodiversity. "We often get wide agreement from business leaders, NGOs, governments and more that biodiversity is something that needs to be saved," says Charles. Uncertainty around the exact definition of biodiversity may make it harder for these groups to collaborate and work together.
Charles asks, "Is this disagreement part of the reason that we've failed to protect biodiversity in the past?" He believes that finding a more concrete and widely accepted definition could help us avoid miscommunication and create a more coherent strategy for protecting biodiversity.

HOW IS THIS PROBLEM STUDIED?

Much of Charles' research is focused on understanding the disagreements that surround the concept of biodiversity. Charles and his team use complex digital tools to analyse huge collections of research articles on biodiversity and taxonomy to identify where, when and by whom different definitions are used. Mapping out these discrepancies and identifying trends in how the different definitions are used will enable Charles and his team to understand where clarification is needed.

Another aspect of Charles' research involves examining science in a historical context. In particular, Charles says that he is "hoping to explore the development of the idea of biodiversity – a word that was only invented in the 1990s! – as a way to understand what non-scientists mean by the term." Understanding how and why the concept of biodiversity was first coined will allow Charles to make sense of how different groups of society use the term.

"In the kind of work that we do, interdisciplinarity is essential," says Charles. His work sees him collaborating with linguists and scholars in the field of digital humanities, researchers of the history and sociology of science and biologists, taxonomists and ecologists that study biodiversity. Charles explains, "Interdisciplinary work is, I think, the only way that we can meet the kinds of grand challenges that we face today!"

Despite the benefits, interdisciplinary work still poses a challenge for Charles. Researchers are very busy people and finding mutually agreed free time can be difficult. This is particularly challenging for Charles as his research may be considered by some to be a "pie in the sky" project. This means that although other researchers may find the problem interesting, they may struggle to see how it will translate into practical outcomes.

PROFESSOR CHARLES PENCE

Faculty of Philosophy, Arts and Letters
Institut supérieur de philosophie
Université catholique de Louvain

FIELD OF RESEARCH

History and Philosophy of Biology

RESEARCH PROJECT

Exploring the debate and uncertainty surrounding the concepts of biodiversity and taxonomy

FUNDERS

FNRS (Fonds de la Recherche Scientifique, Belgium)

This work was supported by the Fonds de la Recherche Scientifique - FNRS under grant no. T.0177.21.

WHAT IS NEXT FOR THE RESEARCH?

Charles believes that the concept of biodiversity was never intended to be restricted to the scientific community. "We invented the word," Charles says, "not only because we had scientific goals that we wanted to pursue, but because we wanted to change the world to better protect the species around us." Many different people from all over the world want to do their bit to protect biodiversity, and Charles and his team are running workshops to bring all of these people together to help them collaborate.

Charles hopes that these workshops, along with his research, will help to resolve many of the disagreements surrounding the definition of biodiversity. "A natural second step is to think about what we might do about it – how can we use this knowledge to make the world a better place," he explains.

ABOUT PHILOSOPHY OF SCIENCE

The philosophy of science is a field of philosophy that contemplates the foundations, methods and purpose of scientific study. "I often like to say that philosophers of science spend their time thinking about questions about science that scientists are too busy doing their jobs to have time to think about!"

Philosophers of science ask questions such as: Can science reveal the ultimate truth? How much evidence is needed to confirm a scientific theory? Does science have any moral obligations? Many of these questions have been subject to debate for centuries, and such debates will likely continue for many years to come. They are important questions to contemplate as emergent philosophical insights can provide unique perspectives on the scientific process.

Charles focuses on the philosophy of one specific branch of science: biology. The philosophy of biology contemplates questions surrounding evolution, genetics, life and, more recently, humanity's impact on the natural world. Charles' investigations around the concepts of biodiversity and taxonomy may help to heal humanity's relationship with the natural world.

WHAT'S THE DIFFERENCE BETWEEN A SCIENTIST AND A PHILOSOPHER OF SCIENCE?

Scientists spend a lot of their time out in the field collecting data or in labs doing experiments to answer questions about the world around us. Philosophers of science, however, are asking questions about what scientists are doing, and why they are doing it. "What makes our work rewarding," says Charles, "is that we have that ability to step back and think clearly about what's going on in the sciences, without having the pressure to do more experiments or get published in high-profile science journals."

WHAT OPPORTUNITIES WILL BE OPEN TO THE NEXT GENERATION OF PHILOSOPHERS OF SCIENCE?

One of the biggest challenges that philosophers face is translating their observations and insights into practical outcomes. "We don't just want to do philosophy for the sake of doing philosophy," says Charles. "We want to do it to try to better understand real problems and improve the state of the world."

Communicating their insights to real-world decision-makers, like politicians and businesses, is not always easy for philosophers. "But it's exactly what we need to try to do in the years to come if we hope for our research to have any real impact," says Charles. As the biodiversity crisis deteriorates over the coming decades, this will become an increasingly important challenge for Charles' successors to overcome.

PATHWAY FROM SCHOOL TO THE PHILOSOPHY OF SCIENCE

- Studying history and philosophy alongside science subjects is important. Charles points out that, if history and philosophy are not available to students, studying language and literature is also beneficial.
- When studying science subjects, think about your work from the perspective of a philosopher, as well as a scientist. "Think about your study of science not just from the perspective of learning facts and figures, but asking questions about the scientific process itself," says Charles.
- Ask questions about science when you are studying history and other subjects. Think about how science is related to history and culture, for example. Thinking about science from different perspectives is key. Charles recommends that students motivate themselves to find new ways of thinking about science and to stay curious and ask questions.

EXPLORE CAREERS IN THE PHILOSOPHY OF SCIENCE

- There are some great public philosophy resources on YouTube such as Philosophy Tube (**www.youtube.com/user/thephilosophytube**), Jeff Kaplan (**www.youtube.com/channel/UC_hukbByJP7OZ3Xm2tszacQ**) and Gregory Sadler (**www.youtube.com/channel/UCEtxsMx4qsoitFwjBdLU_gA**).
- The American Philosophical Association (**www.apaonline.org/page/undergrad_resources**) and The British Philosophical Association (**bpa.ac.uk/careers-and-employability**) have some great resources for exploring a career in philosophy.
- The Internet Encyclopedia of Philosophy (**iep.utm.edu**) is a comprehensive and accessible research tool for learning more about philosophy.
- Questions: Philosophy for Young People (**www.questionsjournal.org**) is a peer-reviewed journal made up of articles written by high-school students, as well as scholars and teachers.

HOW DID CHARLES BECOME A PHILOSOPHER OF SCIENCE?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I'd always wanted to be a scientist – I went through phases when I was sure I'd be a palaeontologist, an archaeologist, a physicist or a biologist. I've always been excited by scientific knowledge. What changed was when I realised that the kinds of questions about the sciences that I wanted to ask weren't those that were asked in the sciences themselves – that's when I discovered the philosophy of science!

WHO OR WHAT INSPIRED YOU TO BECOME A PHILOSOPHER?

I was pursuing an undergraduate degree in physics, and steadily becoming disenchanted with what I was working on; spending all my days solving complex calculus problems wasn't what I thought I would be doing when I signed up to be a scientist. At the same time, I met a professor in our philosophy department who was working on the philosophy of physics – studying the nature of quantum mechanics and reality, technically informed and extremely astute but focused on exactly the kinds of big-picture questions that I wanted to study. I was hooked.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A PHILOSOPHER?

I think this work requires a lot of flexibility. Some days, I might spend all day reading historical works from 19th-century biologists. Other days, I may be reading contemporary papers in evolutionary theory or attending scientific conferences. I may also be writing code to run digital analyses or managing our data, servers or computing infrastructure. I love the constant variety, but I think it takes a particular kind of person.

HOW DO YOU DEAL WITH CHALLENGES YOU ENCOUNTER AT WORK?

I'm lucky to have quite an extensive network of colleagues, in a variety of different fields, all around the world. That's my favourite part of academia; if I'm stuck or a student comes to me with a great question that I have no idea how to answer, I know where to go to get help!

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

This year, I've published two books that were long in the making: one on the history of biology, chronicling the development of statistics and chance in evolutionary theory, and another on contemporary philosophical work on the structure of natural selection. I think they're some of my best work, and I'm just thankful that I'm in a position where I get to do this every day.

WHAT DO YOU DO TO UNWIND?

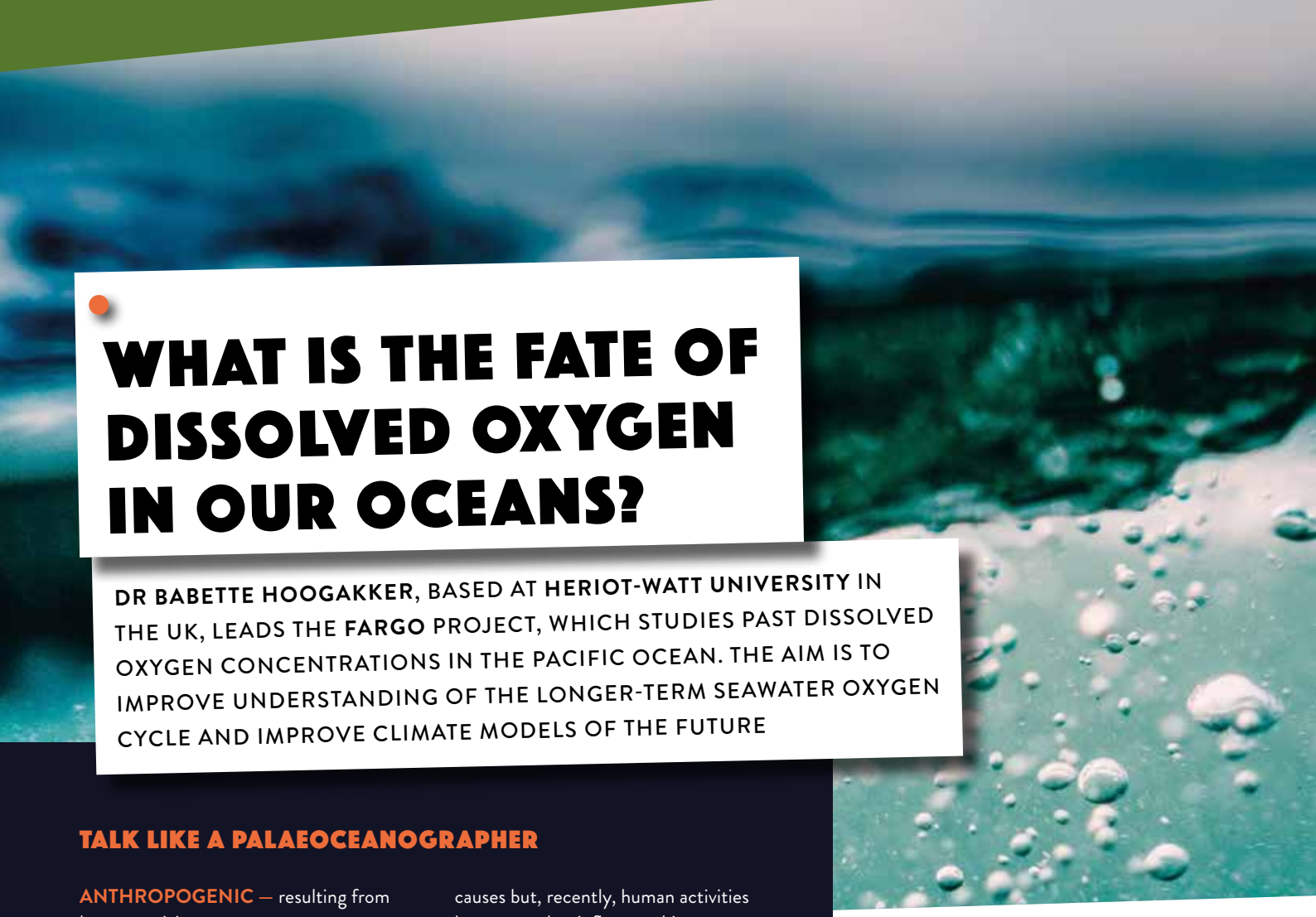
When I'm not working, I'm usually out for a long run, listening to music or playing video games.

CHARLES' TOP TIPS

01 Stay curious and ask lots of questions.

02 Think about science from as many different perspectives as you can.

03 Don't feel that you're being a bad scientist for asking different types of questions.



WHAT IS THE FATE OF DISSOLVED OXYGEN IN OUR OCEANS?

DR BABETTE HOOGAKKER, BASED AT **HERIOT-WATT UNIVERSITY** IN THE UK, LEADS THE **FARGO** PROJECT, WHICH STUDIES PAST DISSOLVED OXYGEN CONCENTRATIONS IN THE PACIFIC OCEAN. THE AIM IS TO IMPROVE UNDERSTANDING OF THE LONGER-TERM SEAWATER OXYGEN CYCLE AND IMPROVE CLIMATE MODELS OF THE FUTURE

TALK LIKE A PALAEOCEANOGRAPHER

ANTHROPOGENIC — resulting from human activity

CLIMATE MODELS — big computer models that use maths, physics and chemistry to characterise how energy and matter (solid, gas or fluid) flow between the hydrosphere (oceans, ice, rivers and lakes), atmosphere and land

FORAMINIFERA — amoeba-like, single-celled organisms that live within a shell. These shells can be preserved in sediment

OCEAN DEOXYGENATION — the reduction of the oxygen concentration of the oceans. This can be due to natural causes but, recently, human activities have started to influence this

OXYGEN MINIMUM ZONES — the places in the world ocean where oxygen concentration in the water column is at its lowest

PROXY — when a variable (e.g., past oxygen concentration) cannot be directly measured, scientists can instead measure a proxy, a different variable (e.g., chemical composition of foraminifera) that allows them to infer the variable of interest

SEDIMENT — matter that settles to the bottom of the seafloor

As the vast majority of living organisms on planet Earth will tell you, oxygen is extremely important. In addition to being the Earth's most abundant element, it is critical to the health of all forms of higher life, including fish and marine organisms. It is, therefore, alarming that oxygen concentrations in seawater have decreased by about 2% over the past 50 years – a process known as ocean deoxygenation.

Ocean deoxygenation threatens the sustainability of marine ecosystems, with the current trend brought about by human-induced global warming and the resultant climate change. For this reason, Dr Babette Hoogakker, based at Heriot-Watt University, is leading a project which studies past dissolved oxygen concentrations in the Pacific Ocean. By developing our understanding of the history of ocean oxygenation, we will be better placed to understand the longer-term oxygen cycle, improve model simulations of future deoxygenation and put solutions in place to remedy this serious issue.

WHAT DOES THE PROJECT INVOLVE?

The seven-year project, entitled 'Fate of ocean oxygenation in a warming world (FARGO)', has been established to understand why – and to what extent – oxygen concentrations dissolved in seawater might change in a warming world. Babette and her team are studying dissolved oxygen concentrations in the Pacific Ocean, currently the world's largest low-oxic water body, through an innovative and dedicated research programme incorporating a novel multi-proxy approach which will inform climate models.

LIMITATIONS OF CURRENT CLIMATE MODELS

The current simulations designed to predict future climates do not all agree. In addition, they fail to adequately describe what we have seen in the past 50 years regarding deoxygenation, suggesting that the models are missing key interactions and factors. "Various hypotheses have been put forward to explain this model-data mismatch. To better understand longer-term oceanic dissolved oxygen concentrations and the key processes that influence this, we'll need to continue with observational programmes, but this will be a relatively slow process,"

explains Babette. "One way to extend the observations is by reconstructing dissolved oxygen levels and drivers in the geological past - this is where FARGO's research comes in!"

TIME INTERVALS

The team is looking at sediments from three key warm time intervals that cover important periods in the Earth's history: warmer climates that occurred 4-15 million years ago; the mid-Pliocene Warm Period (3.3 to 3 million years ago); and Pleistocene warm intervals (interglacials of the last ca. 800,000 years). "The longer-term variability (thousands to millions of years) in oxygen levels is not well-understood," says Babette. "Using deep-sea sediment records, where sediments have accumulated for millions of years, helps form unique resources to reconstruct the environmental conditions of past oceans, and assess seawater oxygen levels and various processes behind any changes."

FORAMINIFERA

Foraminifera are single-celled organisms which play a crucial role in developing understanding of the evolution of life and past environments on Earth. When the team examines seafloor sediments, there are many foraminifera contained within them. "Foraminifera can provide so much information about the environment they used to live in and have provided a wealth of information about past environmental conditions and climate," explains Babette. "Studying foraminifera under the microscope is amazing; they are beautiful to look at. If you could inflate them, they would make brilliant Christmas tree decorations!"

The foraminifera Babette and the team study are made of calcium carbonate, the same compound that forms chalk, limestone and marble. By using various chemical analyses, the team can gather information about the age of the samples and the temperature, nutrient and oxygen concentrations that the foraminifera lived in. This helps the researchers build up a picture of what conditions were like at specific times in the past.

CHALLENGES

One challenge of this project is finding the right sediments that contain the right foraminifera from the right area. "While the sediment cores we use are well dated, for our purposes we are looking at very narrow time-windows and we've had to carry out some extra work to make sure we are getting reconstructions for that particular time period. A lot of the methods to reconstruct dissolved oxygen levels only work well at lower dissolved oxygen levels," says Babette. "We focus our reconstructions on areas in the oceans where oxygen levels are low now, which happens in large swaths of the Eastern Pacific Ocean. Getting samples from this ocean basin means we have a much better chance to get meaningful results compared to the Atlantic Ocean where areas characterised by lower oxygen concentrations are a lot less common today."

DR BABETTE HOOGAKKER

Associate Professor, The Lyell Centre for Earth and Marine Sciences, Heriot-Watt University, Edinburgh, UK

FIELDS OF RESEARCH

Palaeoceanography, Climate Change

RESEARCH PROJECT

Studying past dissolved oxygen concentrations in the Pacific Ocean

FUNDERS

UK Research and Innovation (UKRI), National Environment Research Council (NERC)

This work is supported by UKRI Future Leaders Grant MR/S034293/1

SUCCESSES

Over the past couple of years, Babette and her team have carried out a lot of work on developing and testing methodologies that enable them to estimate dissolved oxygen concentrations of past seawater. The various scientific publications resulting from this work provide satisfying recognition of the team's efforts. The team has also worked to expand its network of researchers and is organising a workshop featuring researchers from all over the world.

IMPACT

In addition to improving understanding of past oxygen concentrations in seawater, the team hopes the insights its research provides will contribute to improving climate models of future oxygen concentrations. "It is very important that we develop a good understanding of this, so that we can better predict what regions are going to be negatively affected by ocean deoxygenation in the future, and why," says Babette. "Such future projections may be used to develop strategies to slow and, possibly, reverse ocean deoxygenation."

ABOUT PALAEOCEANOGRAPHY

Palaeoceanography is the scientific study of the history of the oceans and can involve various elements of research, including analysis of the ocean's sedimentary record, glacial changes and how the Earth's tectonic plates have moved over time. Babette's research is focused on past dissolved oxygen concentrations in the Pacific Ocean, but the field of palaeoceanography could take you all over the world.

WHAT IS REWARDING ABOUT RESEARCH IN THIS FIELD?

For Babette, there are a range of different areas that she finds rewarding. "I love engaging with the public and other scientists, as well as contributing to growing knowledge about our Earth system," she explains. "I was chatting to a quantum informatics scientist recently, commenting on how awesome their research sounded. They said 'well, your work is helping to save our planet', which was very nice to hear!"

For Catherine, the feeling of discovering something that has never been seen before is especially gratifying. "Most discoveries are small but making them is such a wonderful feeling and continues to be a powerful motivation for me," she says. "I find uncovering our place in the natural world as it sits in both space and time to be incredibly rewarding – it is fundamental for tackling the most significant problem of our age, climate change."

PhD student Helge Winkelbauer sieving deep-sea sediments (photo credit: Helge Winkelbauer)

EXPLORE CAREERS IN PALAEOCEANOGRAPHY

- Palaeoceanography is closely related to palaeoclimatology. In the UK, you can join the Paleoclimate Society: **www.paleoclimatesociety.org**
- The Micropalaeontological Society provides information about the application of tiny microfossils for research: **www.tmsoc.org**
- The average salary for an oceanographer is between £14,000 and £60,000 depending on the level of experience and specific job role: **nationalcareers.service.gov.uk/job-profiles/oceanographer**

PATHWAY FROM SCHOOL TO PALAEOCEANOGRAPHY

Babette says that subjects like Earth sciences, maths, computing, physics, chemistry and biology are all useful for various subjects in palaeoceanography. Your pathway will depend on the particular direction you wish to head in, but a solid background in the sciences is important.

You can study for a degree in oceanography or a related subject, like ocean science, geology or environmental science.

Employers are increasingly looking for postgraduate qualifications, like a master's or PhD. They also value experience of working in marine science or oceanography research.

BABETTE AND CATHERINE'S TOP TIPS

01 Believe in yourself. Sometimes it helps to make a long-term plan, but don't be afraid to change directions if it feels like the right thing to do.

02 Seek out people to work with who are supportive and willing to lend you their time.

03 Follow what you are passionate about and let that motivate you to gain the skills you need.

HOW DID BABETTE BECOME A PALAEOCEANOGRAPHER?

Growing up, I was interested in chemistry and animals. At secondary school, I was also interested in economics, mathematics and physics. But, at the end of secondary school, I didn't know if I would enjoy doing any of those subjects at university, so I decided to have a year to think about it, during which I had lots of different jobs. I knew very early on in that year that I wanted to keep my brain engaged and go to university! In the end, I chose a subject that incorporates all the topics I enjoyed at secondary school: physical geography.

I loved going to university. I love learning new things, but it was also nice to interact with people who had similar interests. I really enjoy the outdoors and, as part of my physical geography degree, we visited different places and conducted lots of fieldwork. It was my geology and sedimentology teacher at Utrecht University (J.R. Boersma) who inspired and encouraged me to become a scientist. I realised that I wanted to work in an area of research that helps us understand how our planet works, so I pursued a PhD in marine geology following my degree. Since then, enthusiasm, perseverance, patience and tenacity have made me successful as a scientist.

I am proud to have received two fellowships (NERC and UKRI-FLF) and a Philip Leverhulme Prize, but mostly I am proud of the people who I have had the joy to work with. Two PhD candidates from my group are about to submit their PhD theses, and I feel proud and humbled to have mentored them to this point. My ambitions are to expand my network and research horizons further and continue mentoring awesome young scientists.

MEET CATHERINE

Dr Catherine Davis is an assistant professor of marine, Earth and atmospheric sciences at North Carolina State University in the US and has similar research interests to Babette.

HOW HAS YOUR WORK LED TO YOUR CURRENT RESEARCH ON OXYGEN MINIMUM ZONES (OMZ)?

I came to be interested in oxygen minimum zones through my interest in ocean acidification and carbon cycling in the ocean. The ocean is one of the largest storage sites for carbon and we understand that the uptake of excess anthropogenic carbon in the oceans has profound consequences both for ocean life and in regulating the response of the planet to increasing atmospheric carbon. Where carbon is located in the ocean is strongly influenced by biology – primary producers that take up carbon and release oxygen, and organisms which take up oxygen and release carbon. This means that oxygen distribution in the ocean is basically a mirror image of carbon. Oxygen minimum zones are the fascinating extreme case of where there is little to no oxygen available. This type of extreme environment is fascinating to me.

WHAT DO WE KNOW ABOUT OMZS IN THE PAST?

We know that OMZs probably expanded during periods of rapid warming in the past, although we have a lot to learn about to what extent and the exact mixture of mechanisms that caused this. Many factors contribute to OMZs in a complex way that is frequently difficult to disentangle. Understanding how OMZs have changed in the past will allow us to make better predictions of how they will change in the future.

WHAT ENVIRONMENTAL INFORMATION IS PRESERVED IN THE SHELLS OF OMZ FORAMINIFERA?

The abundance of certain species specially adapted to an OMZ environment can tell us about where OMZs existed in the past. Measurable physical features of shells can indicate how much oxygen was available in the past. As foraminifera calcify using elements taken directly from the water around them, their shells also record the chemistry of the seawater they grew in. That means that the chemistry of shells can also hold clues to the temperature, oxygenation, and/or source of OMZ water.

WHY IS THE EASTERN EQUATORIAL PACIFIC SUCH A SIGNIFICANT LOCATION FOR YOUR RESEARCH?

The Eastern Pacific is the site of the largest OMZ in the modern ocean and is particularly interesting to me for two reasons. Firstly, it is at the confluence of many deep waters that formed from surface waters at locations across the globe and each with unique histories. Secondly, some of these old deep waters rise to the surface in the Eastern Pacific. This means it is one of the places where deep, low oxygen, high carbon waters regularly interact with the surface ocean and the atmosphere.

WHAT DOES A TYPICAL DAY IN THE LAB LOOK LIKE FOR YOU?

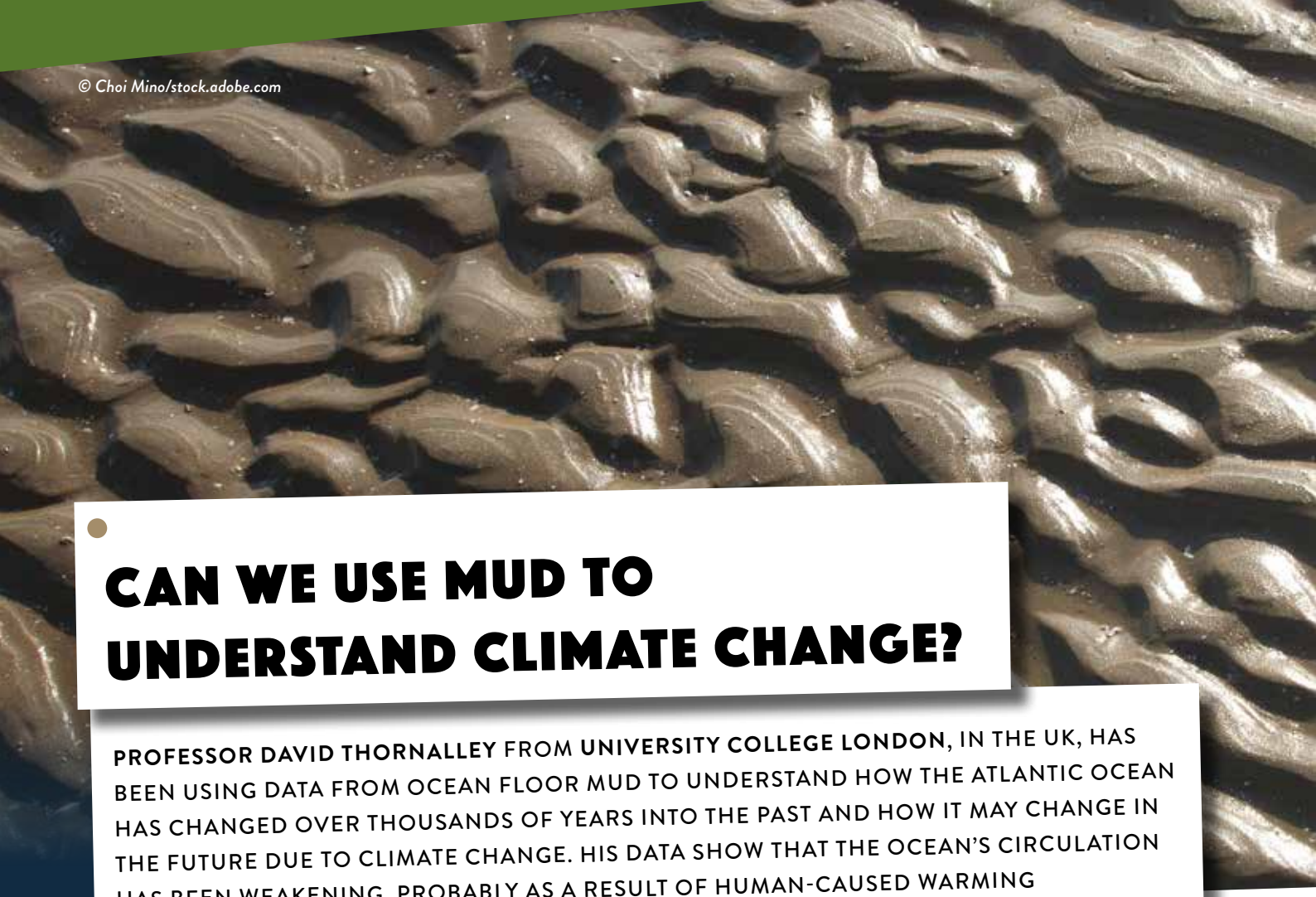
Because foraminifera are so small, I spend a lot of time at a microscope! Some days could also be spent on board a ship, collecting foraminifera or making measurements of ocean conditions, or in a more typical chemistry lab doing chemical preparation or analyses of samples.

WHAT SUCCESSES HAVE YOU HAD, SO FAR?

Some of my favourite moments of success have come in understanding how living foraminifera and other fossil-forming organisms make their living in the ocean. Understanding life histories has been key for developing a better understanding of how individuals living in the past interacted with and recorded their environments.

WHAT ARE THE NEXT STEPS FOR YOUR RESEARCH?

I would like to better understand how foraminifera and other fossil forming organisms respond to change in the recent past, including but not limited to oxygenation. I want to use past records to contextualise our current moment of climate change with other periods of long-term change that we understand primarily through the fossil and other indirect records.



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CAN WE USE MUD TO UNDERSTAND CLIMATE CHANGE?

PROFESSOR DAVID THORNALLEY FROM **UNIVERSITY COLLEGE LONDON**, IN THE UK, HAS BEEN USING DATA FROM OCEAN FLOOR MUD TO UNDERSTAND HOW THE ATLANTIC OCEAN HAS CHANGED OVER THOUSANDS OF YEARS INTO THE PAST AND HOW IT MAY CHANGE IN THE FUTURE DUE TO CLIMATE CHANGE. HIS DATA SHOW THAT THE OCEAN'S CIRCULATION HAS BEEN WEAKENING, PROBABLY AS A RESULT OF HUMAN-CAUSED WARMING

TALK LIKE A CLIMATE SCIENTIST

ATLANTIC MERIDIONAL OVERTURNING CIRCULATION (AMOC) – a system of water travelling from the tropics to the North Atlantic and back again

CLIMATE CHANGE – shifts in temperature and weather over a long time

GLOBAL TEMPERATURE – the average temperature around the world

PRECIPITATION PATTERNS – where and when rain, hail and snow is falling

CLIMATE MODEL – a computer programme that simulates how the Earth's climate system – including the atmosphere and oceans – behaves

MARINE ECOSYSTEMS – ocean habitats and the creatures that live there

CENTENNIAL VARIABILITY – how something has changed over a 100-year or more period

Oceans are a key part of the Earth's climate system, responsible for transporting heat and storing carbon from the atmosphere, and several large ocean current systems contribute to this. The Atlantic Meridional Overturning Circulation (AMOC) is a system of ocean currents in the North Atlantic, with a large influence on climate in the Northern Hemisphere. In his research project, ReconAMOC (Reconstructing the AMOC), Professor David Thornalley of University College London has been studying the AMOC using samples of ocean floor mud to understand how this system has varied in the past and how it may be affected by climate change in the future.

WHY IS THE AMOC SO IMPORTANT?

The AMOC is a system of ocean currents which includes warm water in the tropics flowing into the North Atlantic. The warm climate of the tropics means water evaporates from the ocean and it becomes salty. This salty water travels further north in the North Atlantic, where the climate is colder, and so the salty tropical water now also cools down. The cooler, saltier water sinks, and the dense water then flows southwards, before it eventually rises back to the surface in the Southern Ocean and also the tropical oceans. This creates a conveyer-like system.

Along with the water, large amounts of heat are transported around the Atlantic by the AMOC – David describes the amount as "equivalent to a thousand billion kettles boiling!" This is partly responsible for Europe having a warm climate, as the AMOC transports up to 25% of the Northern Hemisphere's atmospheric and oceanic heat. Furthermore, CO_2 is absorbed into the ocean as cool water sinks – the CO_2 is stored in the deep ocean, so the cycle works to soak up some of the CO_2 in the atmosphere.

WHAT IS AFFECTING THE STRENGTH AND STABILITY OF THE AMOC?

The driving force behind the AMOC's centennial variability is thought to be the continuous formation of salty, cold, dense water in the North Atlantic. If the water becomes too warm – or has become less salty due to melting ice/changing precipitation patterns – the circulation will weaken and could become unstable. Because climate change is causing increased global temperatures, David expects the AMOC to be weakening, and that this will continue.

PROFESSOR DAVID THORNALLEY

Professor of Ocean and Climate Science, University College London, UK

FIELD OF RESEARCH

Ocean and Climate Science

RESEARCH PROJECT

Analysing data from ocean floor mud samples to understand how the Atlantic Meridional Overturning Circulation is changing

FUNDERS

Natural Environment Research Council (NERC), European Union Horizon 2020

Funding was provided by NERC Project ReconAMOC (NE/S009736/1). This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No's 678760 (ATLAS) and 818123 (iAtlantic). This output reflects only the authors' views and the European Union cannot be held responsible for any use that may be made of the information contained therein.

HOW CAN CLIMATE MODELS HELP US?

"Climate models are our best tools for investigating how climate may behave in the future," explains David. "They are thought to be quite robust in simulating certain features of the climate system, such as the global temperature response to greenhouse gas increases." However, many important ocean processes take place on a very small scale, and many older climate models can only simulate large (100 km square) areas. It is also sometimes difficult to improve the models because we do not have as much real-world data to compare them to as we would like. "This can lead to the modelled ocean behaving in ways that may not be the same as the real ocean," says David. "One way around this is to simply try and prescribe larger scale behaviour based on set equations, but we need to know we are doing this in an accurate way." Lots of time and effort is continually being spent trying to improve climate models, and newer models are now much better at resolving – or simulating – processes on smaller areas. As David says, "With improved computer power and scientific understanding, it is an exciting and optimistic time for research."

WHAT NOVEL APPROACH IS RECONAMOC TAKING?

David's project uses marine sediment cores – samples of mud from the ocean floor – to create a dataset representing the North Atlantic over the past 7,000 years. "Our project is ambitious because, in some locations, we are trying to reconstruct the AMOC over a thousand years or more," says David. "This means we are having to undertake thousands of analyses!"

David's team travels by ship to sites around the North Atlantic and lowers metal pipes into the soft mud. When the pipe containing marine sediment is pulled back up, the team can observe the layers in the sample and analyse their contents. Currently, there are no direct observations longer than a few decades, so ReconAMOC is a big step forward. David's team compares the mud from past years to recent conditions, to make sure that the data does a good job of representing the AMOC.

WHAT IS THE PROCESS OF ANALYSING DEEP-SEA MUD?

David says examining the layers in the mud is "like reading the pages in a book", with the process telling the 'narrative' of how the ocean behaved in the past. The analysis can reveal the speed of past water currents, as larger grains in the mud indicates how currents have varied in the past. David's team also looks at the types of shells in the sample – different marine species like to live in different conditions, so by looking at what shells are present, the team can ascertain what marine ecosystems existed in the past.

David's analysis has shown what he describes as the "recent weakening of the AMOC, that is unprecedented in at least 1,600 years". This weakening is probably tied to human-caused climate change because of increasing global temperature. New data suggests the changes David is seeing have not been observed for up to the past 10,000 years.

WHAT SUCCESSES HAS RECONAMOC HAD, SO FAR?

David and his team have been really pleased with how much data they have been able to generate. Their work has been written about in the New York Times in the US and The Guardian newspaper in the UK and has been used to help write Intergovernmental Panel on Climate Change (IPCC) reports and produce policy briefings for governments. All of this is contributing towards people becoming more aware of the AMOC and how climate change is affecting the oceans.

WHAT IS NEXT?

As well as ensuring others know about their current findings, David and his team are determined to further their research and gain even deeper insights. "We want to better understand the precise mechanisms that caused these recent changes," he says. "We want to know how much was due to human-induced warming, versus natural processes. We are also trying to find out how these changes in the AMOC affected life in the ocean, to help ensure we can conserve marine ecosystems and use marine resources in a sustainable way."

The more we understand how the AMOC has varied in the past, the better we can understand the impact that modern day climate change is having on our oceans. Understanding climate change is key for planning and preparing for its impact, and climate scientists like David are at the forefront of this important work.

ABOUT CLIMATE SCIENCE

Climate science is a wide-ranging subject that studies the impact of climate change on all parts of the Earth. This may be focused on the oceans (as David's work is) but can also be focused on the atmosphere, how ice sheets are changing and how human impact is affecting ecosystems.

The oceans are a key part of the climate system. David describes how the world's ocean has taken up about 50% of the historical emissions of carbon dioxide released by humans. It is very important, therefore, to understand how oceans are behaving and changing in response to climate change.

A key aspect of climate science is making sure that the true impact of human-caused warming is understood. David says, "We want to better understand the precise mechanisms causing these recent changes, and how much was due to human-induced warming, versus other natural processes." This is important to make sure the impact that humans are having on the planet is clear and undeniable.

WHAT ARE THE RESPONSIBILITIES OF BEING A PRINCIPAL INVESTIGATOR ON A PROJECT LIKE THIS?

As principal investigator (PI), David helps the team to interpret the new data, coming up with new ideas about how the oceans have behaved. He is responsible for overseeing the technicians who work in the labs and has meetings with his team to make sure everyone is comfortable with what they are doing and keeping on track. His responsibilities also include keeping an eye on budget and timelines, as well as meetings with scientists from other universities working in the same field.

WHAT ARE THE REWARDS?

David enjoys being at the cutting edge of science, finding something unique and unexpected during his research. He says, "It's really cool at that moment in time to be the first (or one of the first people) to know a particular fact, and then thinking about how it changes your view of the world and how it works." Being part of a team is also a rewarding and exciting aspect of his work – being able to work together to contribute towards understanding the climate crisis is hugely important and motivating.

EXPLORE CAREERS IN CLIMATE SCIENCE

- The continuing threat of climate change means that climate scientists are needed now more than ever. You could work for a university or a climate change charity and find yourself taking part in field work all over the world where climate impacts are being felt, from the North Atlantic to Antarctic glaciers to tropical rainforests.
- To keep up to date with climate science news, the Woods Hole Oceanographic Institute has updates about climate and ocean science: **www.whoi.edu**
- The Challenger Society also provides information: **www.challenger-society.org.uk**
- Look for volunteering opportunities with climate change charities in your local area.
- At university, you might find experience through a summer internship, such as with the Natural Environment Research Council (**www.ukri.org/councils/nerc/career-and-skills-development**) or University College London (**www.ucl.ac.uk/prospective-students/summer-school**).

PATHWAY FROM SCHOOL TO CLIMATE SCIENCE

- Study maths and at least one science subject at A-level. These are likely the entry requirements for a climate science or related degree at university.
- David says, "Computer and coding skills are becoming more and more important and offer another way into the field." You can get computing experience at school or through online courses.
- Many universities offer degrees in Earth or ocean sciences. You can also start with a degree in physics, chemistry, biology or maths, and then specialise in climate or ocean sciences for a postgraduate degree.

DAVID'S TOP TIPS

01 Find what you are interested in – work is easier when you are working towards something you are passionate about.

02 Be willing to work hard; there are times when you might have to spend hours doing something quite tedious.

03 Be inquisitive, start reading and then follow up on things you find interesting.

HOW DID DAVID BECOME A CLIMATE SCIENTIST?

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I enjoyed reading science books as a kid and watching David Attenborough documentaries. I loved reading about famous physicists and their discoveries, but I also wanted to work with wildlife and thought about being a zookeeper or observing wildlife in the field for conservation. I guess I always just loved watching the world and trying to find out how things worked.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

I have quite a good memory for things I read, which helps me to remember key ideas and evidence. I was always willing to work hard on simple mundane tasks (lots of swimming sessions get you used to monotony!), which helped me to produce datasets during my earlier research years. I'm driven to find answers – I love when you have new data and you are on the hunt to try and make sense of it, and then when it finally clicks, it is really rewarding and exciting. I think I am open-minded as well, which helps you to reject established ideas if they don't make sense, or to try and think up new ones.

HOW DO YOU SWITCH OFF FROM YOUR WORK?

The commute home on the train, reading a non-science book and having a 5-year-old son to feed and get ready for bed all help!

AS A CLIMATE SCIENTIST, HOW DO YOU REMAIN OPTIMISTIC AND MOTIVATED?

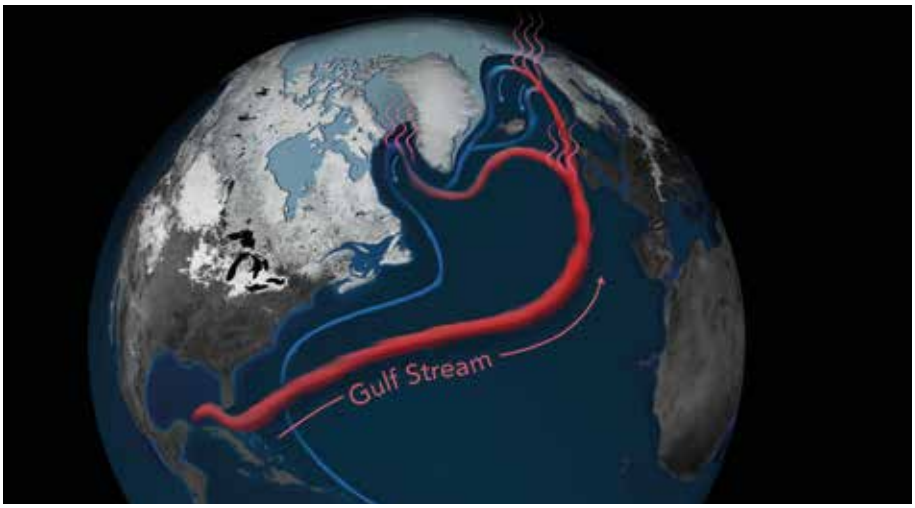
I feel guilty saying it, but my main motivation has always been finding out about the world and solving puzzles; it is just nice that the work I do is also in an area that is important and, hopefully, useful to society. Scientists play a vital role in helping us to know how the world might change, so we can plan and prepare, but lots of different people need to work together – we have the evidence, but the solutions also involve politics and social science.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

I collected some data during my PhD and for months and months (I think maybe a year) I couldn't work out how to interpret it and then, after doing loads of reading, it all finally clicked. That idea went on to be my first paper and I was lucky enough to get it published in Nature.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I hope I can really help my PhD students and others in the team achieve their goals and make some of our students see how cool studying the ocean is. For now, I'd be happy to find time to write up all the exciting results we have been getting from ReconAMOC, since some of the data we have is quite important for understanding how the world has been and is changing.



A partial view of the Atlantic Meridional Overturning Circulation (AMOC), showing the Gulf Stream (photo credit: Natalie Renier/Woods Hole Oceanographic Institution)

David and his PhD students, Jack and Alice, extracting a sediment core just retrieved from the seafloor (photo credit Alice Carter-Champion, University College London)

WINDS OF CHANGE: USING DUST IN ANTARCTIC ICE TO UNDERSTAND PAST CLIMATES

UNDERSTANDING PREHISTORIC CLIMATES IS KEY TO UNDERSTANDING HOW OUR CLIMATE MIGHT CHANGE IN THE FUTURE AND ANTARCTIC ICE CORES PROVIDE FUNDAMENTAL INFORMATION THAT FORMS THE BASIS FOR MUCH OF THIS KNOWLEDGE. **DR BESS KOFFMAN,** FROM **COLBY COLLEGE,** WATERVILLE, MAINE, IN THE US, STUDIES THE DUST TRAPPED IN ANTARCTIC ICE, RESOLVING WHERE IT CAME FROM AND HOW IT GOT THERE

TALK LIKE A GEOLOGIST

CLIMATE – the long-term (typically 30 years) average temperature, pressure, precipitation and other atmospheric conditions of a region

ICE CORE – a long cylinder of ice, extracted from ice sheets or glaciers, which helps scientists learn about past climatic and environmental conditions

ISOTOPE – a form of an element containing the same number of protons but a different number of neutrons. Some isotopes are stable and others are radioactive, meaning they decay through time. Because this decay occurs at a predictable rate, the products of radioactive decay can provide valuable insight into the age of Earth materials and the identity of dust source regions

PALAEOCLIMATE – the climate of the Earth or a certain region at a past point in geologic time

PLANKTON – microscopic organisms found in water that are critical for the functioning of aquatic ecosystems. Phytoplankton are photosynthetic, like plants, whereas zooplankton are tiny animals that eat bacteria, phytoplankton or each other!

The Earth's climate is an exceedingly complex system, where temperatures, water, wind patterns, landmasses, ocean currents and many other factors interact and affect one another. Climatic conditions are fundamentally determined by the Sun, which warms the earth's surface. This warming is uneven, with different areas receiving varying amounts of heat because of the shape and tilt of the Earth. This is the principal reason for different climates and seasons around the world.

A key rule of physics is that heat energy moves from high-energy to low-energy areas. This is what drives winds and ocean currents, which move air and water from warmer areas near the equator towards the cooler poles. However, these patterns have not always existed exactly how we see them presently. "During past climate changes, evidence suggests that the Earth's wind belts changed in strength and location," says Dr Bess Koffman. "By studying past changes using natural archives like ice cores, scientists like myself can learn what causes the Earth's winds to shift. This in turn helps us better understand how wind patterns may change in the future."

FROM DUST TO DUST

Bess is an Assistant Professor of Geology at Colby College, Waterville, Maine, in the US. One of her main projects involves extracting deep ice cores from Antarctica and then analysing the atmospheric dust trapped within them. "Dust gets picked up by winds from dusty places like deserts and mountain valleys," says Bess. "Once in the atmosphere, it can get blown over the ocean and deposited in places such as the surface of the Antarctic ice sheet." Over time, as more snow falls and ice forms, the dust becomes encased within the ice. Because dust that fell earlier will be lower down in the ice sheet, an extracted ice core provides a vertical 'timeline' with clues to what happened on the ice surface at different points in geologic history.

From the dust and other chemicals within ice cores, Bess is aiming to determine how winds have changed over time and what has driven these changes. "It's important to remember that each palaeoclimate record only represents one location," says Bess. "To decode whether our findings represent global or local patterns, we compare multiple ice core records from across Antarctica, as well as Arctic ice cores and other environmental records for the full global picture."

TAKING AN ICE CORE

Ice can be extremely thick in Antarctica (up to nearly 5 km!), so extracting cores requires a significant amount of drilling. "An Antarctic ice core might be 1,500 to 3,000 metres long," says Bess. "Each cylindrical ice core is drilled in short segments and then cut into metre-long 'sticks' that are analysed separately." Because of the wealth of information contained within the ice, many different scientists from various labs will typically work on any individual core to ensure that maximum scientific value is extracted. "The technique I use to study dust is called a continuous melter system, which involves slowly melting each stick from

DR BESS KOFFMAN

Assistant Professor of Geology
Colby College, Waterville, Maine, USA

FIELDS OF RESEARCH

Palaeoclimate Science, Geology

RESEARCH PROJECT

Studying polar ice cores to learn more about past climates, by examining the sources and concentrations of dust through time

FUNDERS

US National Science Foundation (NSF), North Pacific Research Board, American Association of University Women (AAUW)

one end towards the other, and extracting information on dust particle concentration and size within every millimetre using a particle counter," says Bess.

For a several-kilometre-long ice core, this process can take a large team of people several months, but the information extracted is highly valuable. Ice cores are most famous for their usefulness in providing measurements of past carbon dioxide levels in the atmosphere. "By analysing the tiny bubbles of air trapped in ice, we know how carbon dioxide levels have changed over the past 800,000 years," says Bess. "In addition to gases and dust, ice cores contain a variety of other chemicals, making them one of the most powerful environmental archives for learning about past climates."

Although the end results can be very rewarding, Bess acknowledges the day-to-day lab work can be a grind. "Melting and analysing ice cores can be tedious work that is very detail-oriented," she says. "Scientists must pay attention to many different components of the lab system to make sure everything is working. This takes a whole team of people, so communication and careful note-taking are of critical importance."

EUREKA IN ALASKA

Bess' work takes her to both poles, and a recent project in the Arctic culminated in some fascinating findings. "I used isotopes of certain elements in dust from snow in Alaska to investigate sources of dust and pollution," she says. "The data showed that local glacial river valleys were important sources of dust at lower elevations. At higher altitudes, dust principally originated from the deserts of East Asia. The lead pollution in the Alaskan snow mainly came from metal smelting and coal burning in China."

These findings have implications for people and the environment. Lead pollution can be toxic, especially for aquatic animals and growing children. "Over the past century, industrialisation in China has resulted in increased levels of lead pollution," says Bess. "Although China has been working to reduce lead pollution, the data from Alaska shows that the Arctic region continues to be affected by industrial lead emissions, even after the global ban on leaded gasoline."

FROM POLE TO POLE

Bess' specialisations are relevant for many different research applications. "A current project of mine in Alaska is examining how volcanoes and dust sources affect ocean ecosystems by supplying nutrients such as iron to marine phytoplankton or algae," she says. "In the northeast Pacific Ocean, phytoplankton growth is limited by a lack of iron, so an increase in iron deposition from dust or volcanic ash can boost their populations. Because these species form the base of the marine food web, this can have implications for the entire marine ecosystem." Bess' team is analysing the effects of volcanic ash and dust from Alaskan river valleys and Asian deserts on marine phytoplankton growth.

In Antarctica, Bess' team's research on dust sources continues. Bess hopes to use the composition of wind-blown dust to learn how the Antarctic ice cover may have changed in the past. "One potential application of this work is to learn whether the West Antarctic Ice Sheet collapsed during the Earth's last interglacial warm period, about 125,000 years ago," says Bess. "This will provide lessons for our current warm period, as climate change progresses. If this ice sheet did collapse in the last warm period, it may do so again, which would raise sea levels by up to six metres." Such an increase in sea level would have dramatic implications on human populations; so, knowing what to expect and how to respond is critical.

ABOUT GEOLOGY

Geology is a broad discipline, involving the study of how the Earth's systems work at present and worked in the past through a variety of clues from the environment. Bess explains more about what attracted her to the discipline, important skills for aspiring geologists and what to expect in the future.

The Earth is everywhere around us and its systems intimately affect our well-being. As an Earth scientist, I can study the air we breathe, the water we drink and the soil that nourishes our crops. Our world currently represents processes that have been interacting over hundreds of millions of years through the present, including the impacts of humans over the past few centuries. I love being able to study the dynamic interrelations within the biological, chemical and geological systems of the Earth.

Communicating science is fundamental. After robust scientific results have been developed, it is time to publish these findings. Scientists have to use persuasive language to explain why their interpretation makes sense, and this is an important skill for students to practice in their writing. Through evaluating evidence and mapping out arguments, students can practice this important aspect of scientific communication.

The expertise of geologists will be critical for the transition to clean energy. Understanding how to find and safely extract the elements needed for green technologies will play a key role in this shift. There are many geopolitical challenges to overcome as well, so the expertise of scientists will need to be included alongside international relations, economics and communication.

As our climate changes, clean fresh water will become increasingly scarce. Geologists can help society by quantifying different water sources, determining recharge rates and which resources are being overused. Contributing to these societal shifts will be challenging, but the next generation of geologists will be inherently broad thinkers with an important role to play.

EXPLORE CAREERS IN GEOLOGY

- Geology is a broad field, with opportunities for many different specialisations. Geologists work in various sectors, including academia, energy, consulting, resource extraction and natural hazards.
- Bess shares several resources for early career scientists interested in palaeoclimate and cryosphere research. These include the Association of Polar Early Career Scientists (APECS, **www.apecs.is**), Ice Core Young Scientists (ICYS, **pastglobalchanges.org/science/end-aff/icys**) and the Polar Science Early Career Community Office (PSECCO, **psecco.org**).
- Colby College's undergraduate courses are exciting gateways into geological careers. Undergraduates typically will conduct research in a professor's lab including one summer of intensive research as part of their degree. Coursework sometimes involves engaging with younger students, for example, by doing outreach at local high schools. Also, many public talks and seminars happen regularly across campus.

PATHWAY FROM SCHOOL TO GEOLOGY

Bess says that her broad scientific background in geology, chemistry and biology has helped her career, but notes that ice core scientists can come from a range of backgrounds, including maths and physics. For a typical geology degree, good courses to consider taking in high school are maths, chemistry, physics, biology, geology and geography.

Bess notes that writing and other communication skills are critical for science because scientists spend a significant amount of time applying for funding, communicating with other scientists and sharing findings with the public.

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HOW DID BESS BECOME A GEOLOGIST?

WHAT WERE YOUR INTERESTS GROWING UP?

I loved horses as a child and wanted to be a large-animal veterinarian for a long time, even after my undergraduate studies in geology. However, when I learned that vets typically graduate with significant debt whereas PhD scientists get paid to go to graduate school, I decided to pursue scientific research instead.

Other interests included anything outdoors. I loved swimming and being in the water. I would often climb trees, right to the top of huge fir trees near my house. I liked to collect rocks, shells and leaves, which perhaps reflected my early interest in geology.

WHAT INSPIRED YOU TO BECOME A GEOLOGIST?

While I was studying my undergraduate, Professor Richard Alley gave a visiting seminar describing the seminal ice core research done in Greenland in the 1990s, including how much we had learned about past climatic changes and how much more there was left to discover. I was hooked! After graduation, I found a job in Antarctica as a research technician, collecting ocean water samples to learn about the role of micro-organisms in the ocean food web. After this amazing experience, I decided to apply to graduate school to study ice cores.

WHAT ATTRIBUTES HAVE HELPED YOU IN YOUR CAREER?

I am highly organised, have a strong work ethic and practice my communication skills. Working with other people inevitably involves challenging conversations and sometimes conflict resolution, so having strategies for these situations is useful. I worked as a wilderness trip leader before returning to graduate school, which I think helped me develop some of these skills.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Landing my current job is a dream come true. I have awesome colleagues, I get to teach engaged and intelligent students and I have a lab where I can do rewarding work. I am grateful for the opportunities that led me to this point, and especially for the mentorship, guidance and support of my family, professors and schoolteachers.

HOW DO YOU DEAL WITH CHALLENGES AT WORK?

Sometimes tasks pile up and it can feel impossible to get everything done. Although my personal care suffers sometimes, I try to maintain healthy habits and regular sleep schedules. At work, being organised and delegating where appropriate help to keep everything on track, ensuring that I reach my long-term research goals despite all the short-term deadlines.

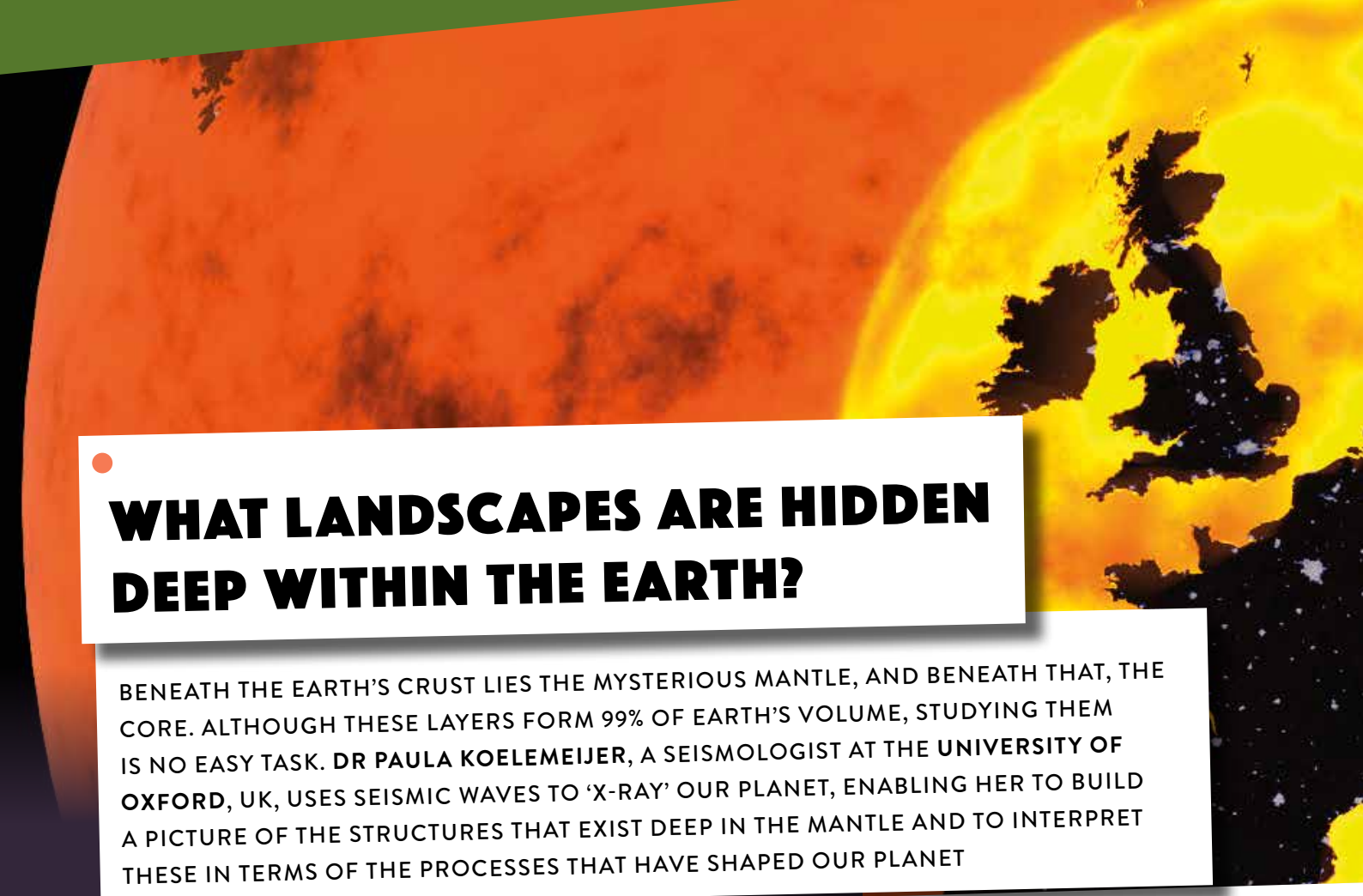
WHAT DO YOU DO WHEN YOU'RE NOT WORKING?

My young son keeps me busy! I also enjoy gardening and have a large vegetable garden and orchard. As well as spending time with my husband and friends, I play traditional New England and French-Canadian folk music on the fiddle. I also love being outdoors, especially in the winter months when I go skiing and ice skating as much as possible.

BESS' TOP TIPS

01 Allow yourself to explore opportunities and see where they lead. It's okay to try something out and find that a particular area of science doesn't appeal to you. A summer job that you find you don't really like can save you from suffering through a PhD in that field. Everything is a learning experience.

02 Talk to people. Reach out to mentors. Email professors. If the people in your sphere know what you're passionate about and what you are aiming for, they can more readily connect you with opportunities.



WHAT LANDSCAPES ARE HIDDEN DEEP WITHIN THE EARTH?

BENEATH THE EARTH'S CRUST LIES THE MYSTERIOUS MANTLE, AND BENEATH THAT, THE CORE. ALTHOUGH THESE LAYERS FORM 99% OF EARTH'S VOLUME, STUDYING THEM IS NO EASY TASK. **DR PAULA KOELEMEIJER**, A SEISMOLOGIST AT THE **UNIVERSITY OF OXFORD**, UK, USES SEISMIC WAVES TO 'X-RAY' OUR PLANET, ENABLING HER TO BUILD A PICTURE OF THE STRUCTURES THAT EXIST DEEP IN THE MANTLE AND TO INTERPRET THESE IN TERMS OF THE PROCESSES THAT HAVE SHAPED OUR PLANET

TALK LIKE A SEISMOLOGIST

CONVECTION — the movement of material due to temperature differences, with lower-density (often hotter) material rising while denser (typically colder) material sinks

CORE — the central portion of the Earth, primarily composed of iron and nickel

CRUST — the thin, outer layer of the Earth on which we live

GEODYNAMO — the generation of the Earth's magnetic field by convection in the outer core

MAGNITUDE — a measure of the strength of an earthquake, with a larger magnitude corresponding to a larger earthquake

MANTLE — the layer between the Earth's crust and core, primarily composed of silicon, magnesium and oxygen

RESONANCE — the frequency at which a system naturally vibrates

SEISMIC WAVES — elastic vibrations that travel through the Earth

SEISMOMETER — the instrument used to record seismic waves

STANDING WAVES — stationary waves which cause a material to vibrate at its resonance frequency

There is a lot going on down below our feet. The radius of the Earth is 6,371 km, yet the crust on which we live only has an average thickness of 30 km. So, what lies below? At 2,900 km beneath the surface, we reach the Earth's core, comprising a solid inner ball of iron and nickel surrounded by a liquid outer iron and nickel core. Between the core and the crust is the solid mantle, which makes up two-thirds of the Earth's mass and is the source of magma that occasionally reaches the surface via volcanic eruptions. These layers are far too deep for us to physically reach, but techniques in the field of seismology allow scientists to build a picture of what is happening down there.

Dr Paula Koelemeijer is one such scientist. As a seismologist at the University of Oxford, she is using seismic waves to image the structures that exist deep within the Earth. "My research focuses on understanding the structures in the mantle," she says, "which are products of the dynamic processes occurring in the Earth since its formation."

These dynamic processes include vigorous convection in the liquid outer core that produces the Earth's magnetic field (in a process known as the geodynamo) and sluggish convection in the mantle. Despite being solid, the mantle is constantly moving over a million-year timescale. Heat from the core causes material in the mantle to rise slowly upwards until it nears the crust, cools and sinks back down, generating convection currents. These currents move the tectonic plates that make up the crust and therefore control the global distribution of earthquakes and volcanoes. "Without these dynamic processes, life on Earth would not have been possible," says Paula. "We can learn about them by studying the structures they produce deep in the Earth."

X-RAYING THE EARTH

Earthquakes produce waves of energy that travel through the Earth, diminishing in strength with distance. The speed at which these waves travel depends on the material through which they are travelling. "Each wave recorded by a seismometer therefore contains information about the material it travelled through," explains Paula. "By recording thousands of waves from hundreds of earthquakes, we can combine all these data to build a 3D model of the velocity structure of the Earth." In this way, seismic waves can be used to 'X-ray' the Earth's interior.

DR PAULA KOELEMEIJER

Department of Earth Sciences, University of Oxford, UK

FIELD OF RESEARCH

Seismology

RESEARCH PROJECT

Using seismic waves to image the landscapes present deep below the Earth's surface

FUNDERS

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THE MUSIC OF THE EARTH

Paula is especially interested in vibrations called 'standing waves', produced by very large earthquakes (greater than magnitude 7.5). In the case of standing waves, the wave itself does not move in space, but instead, the material vibrates with a certain frequency. "Think about plucking a guitar string," says Paula. "We hear a specific pitch or sound as the guitar string vibrates at a particular frequency."

Similarly, after particularly strong earthquakes, the Earth deforms periodically with a resonance frequency, as if it is a bell hit by a hammer. The measured frequency recorded by seismometers depends on the properties of the Earth, just as a guitar's pitch depends on the properties of the plucked string. Plucking a different guitar string will produce a different note, while different materials in the Earth will produce standing waves with different resonance frequencies. Paula can therefore use the observed frequencies of standing waves (which she refers to as the 'music of the Earth') to draw conclusions about the material deep inside the Earth.

One of Earth's standing waves is known as the 'breathing mode', where the whole planet inflates and deflates at the same time. After the magnitude 9.1 Sumatra earthquake in 2004, this inflation was about 0.5 μm. Although this is much thinner than the width of a human hair, it resulted in the Earth's volume changing by roughly 50 km^3 every hour!

HIDDEN LANDSCAPES WITHIN THE EARTH

Differences in the physical and chemical properties of the layers of the Earth result in significant boundaries between them, such as the core-mantle boundary. "These boundaries may have physical topography on them, with kilometre-high mountains and valleys, induced by mantle flow," says Paula. "Similar to the Earth's surface where landscapes are formed by topography together with vegetation and other characteristics, I envisage these boundaries and the seismic structures we find close to them as landscapes within the deep Earth."

In her research, Paula combines travelling and standing seismic waves to make 3D models of the Earth's mantle and to study the landscape of the core. She particularly focuses on two large and intriguing 'blobs' deep in the Earth's mantle, where seismic waves travel more slowly than through the rest of the mantle. "These blobs cover about 25% of the surface of the core, and extend many hundreds of kilometres into the mantle," she says. "If these blobs were on the surface of the Earth, the International Space Station would have to navigate around them!"

There is much debate among scientists about what these structures are. The blobs may be purely thermal features, with higher temperatures in these regions causing seismic waves to travel more slowly through them. Or there may also be chemical differences between the background mantle and the material of the blobs, making them thermochemical structures.

"The properties of these two structures affect several dynamic processes in the mantle, including the way in which material moves," says Paula. If these blobs have a different chemistry, they may act as blankets that prevent the core from cooling down. This would change our understanding of how the Earth has cooled over time.

To solve this mystery, scientists need to know the density of these blobs and the only seismic data that can provide information on density are the Earth's standing waves. Paula continues to study these in detail, with the hope of constraining the properties of the blobs and creating more accurate pictures of the landscapes hidden within the Earth.

ABOUT SEISMOLOGY

Seismologists use seismic waves to understand the world around us. Seismic waves are not only generated by earthquakes, but also arise due to other sources. This section explores some of the more unusual topics that fall within seismology.

MOONQUAKES AND MARSQUAKES

It is not just our planet that experiences seismic events. Thanks to seismometers placed on the Moon during the Apollo missions and on Mars during the InSight mission, seismologists also study moonquakes and marsquakes! "Although the number of seismometers on the Moon and Mars is limited, we have still learnt a great deal about their structure," explains Paula. "Both the Moon and Mars, like the Earth, have an iron core. In the case of Mars, the core is still fluid." Seismologists use these moonquakes and marsquakes to build models of the interiors of planetary bodies, helping scientists to understand planetary evolution.

WILDLIFE MONITORING

Paula has also collaborated with zoologists to investigate a very peculiar seismic source: elephants. "The size of elephants means their movements produce vibrations large enough to pick up on seismometers," she says. "Additionally, their communication rumbles generate low-frequency vibrations that travel through the ground as seismic waves."

A few years ago, Paula was in the field in Kenya to study whether we can determine different elephant behaviours by analysing the seismic signals detected on seismometers. The long-term aim is to inform on poaching threats and catch poachers in the act. "If these seismic signals can be used to monitor elephants remotely, we may notice when the animals are in distress," says Paula. "For instance, if we detect with seismic waves that elephants are running in panic, it is possible they are being poached."

ANTHROPOGENIC NOISE

Seismic waves are also caused by human activities. Paula has a seismometer in her home that, as well as detecting earthquakes in the UK and from across the world, picks up vibrations from cars on the road outside, passing trains and the neighbours' washing machines!
In urban areas, our rhythms of life produce predictable patterns in seismic noise, with commuting hours showing the highest seismic activity, and lulls during the night and at weekends. "In recent years, there has been growing interest in urban seismology and what we can potentially learn about human behaviour," says Paula.

The dominance of commuter movements as a source of anthropogenic seismic activity was highlighted in 2020 as the COVID-19 pandemic took hold. "As national lockdowns were enforced around the world, our human activities almost stopped entirely, as people studied and worked from home. Trains, buses and cars came to a standstill and, consequently, there was a worldwide reduction of 50% in background seismic noise." This presented an opportunity for seismologists to measure the natural seismic activity of urban areas, shedding light on background fault movements near cities.

Paula in the field in Kenya, installing seismometers to record elephant vibrations

EXPLORE CAREERS IN SEISMOLOGY

• Seismologists can apply their skills to a huge range of topics, from determining the internal structure of planets to understanding the hazards caused by earthquakes, and from characterising the subsurface for energy exploration and storage to studying wildlife and human behaviour.

• Find out what a seismologist does and what skills and qualifications they need in this career profile from The Geological Society: **www.geolsoc.org.uk/Geology-Career-Pathways/Careers/Career-Profiles/Seismologist-Profile**

• The British Geological Survey conducts research into earthquakes in the UK (**www.earthquakes.bgs.ac.uk**) and offers work experience opportunities for school students: **www.bgs.ac.uk/about-bgs/working-with-us/work-experience**

• The Incorporated Research Institutions for Seismology (**www.iris.edu/hq**) has a wealth of information about seismology. Explore the Education tab on its website to find lesson plans, videos and fact sheets about seismology, and to discover where earthquakes have occurred around the world in the last month, week or 24 hours.

• The UK's National Careers Service (**nationalcareers.service.gov.uk/job-profiles/seismologist**) and Career Addict (**www.careeraddict.com/become-a-seismologist-in-the-uk**) give an overview of seismology careers, including where seismologists work, salaries and the skill sets needed.

PATHWAY FROM SCHOOL TO SEISMOLOGY

• "Seismology, and geophysics in general, are very quantitative subjects. It is therefore primarily useful to take physics and maths at school," advises Paula. "Geology can provide additional background knowledge but is not essential."

• Computer coding is a key skill for seismologists, so learn programming as soon as possible.

• Most seismologists will have an undergraduate degree in geophysics, physics, geology or Earth science, followed by a master's and/or PhD in geophysics.

HOW DID PAULA BECOME A SEISMOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

According to my mum, when I was little, I picked up rocks and pebbles wherever I went. At school, I loved Greek and Roman mythology and solving puzzles, before becoming more interested in the sciences in secondary school.

DID YOU ALWAYS WANT TO BE A SEISMOLOGIST?

Initially, I wanted to be a volcanologist. This, together with the fact I could combine my interests in physics, maths and chemistry, led me to study a general Earth sciences degree. During my studies, I migrated towards the geophysics side of Earth sciences and became primarily interested in seismology.

WHAT DO YOU MOST ENJOY ABOUT YOUR JOB?

I get to work with lots of interesting people and basically do what I am interested in for a living! Although keeping a healthy work-life balance can be difficult from time to time, I still love it.

WHAT HAS BEEN THE HIGHLIGHT OF YOUR CAREER SO FAR?

In 2021, I was awarded a Philip Leverhulme Prize for research excellence. I felt honoured as well as humbled, as there are so many amazing scientists. Being awarded such a prize is not only heart-warming, but also will enable me to pursue a new research project in urban seismology, which will focus on the natural seismicity and sources of seismic noise in London.

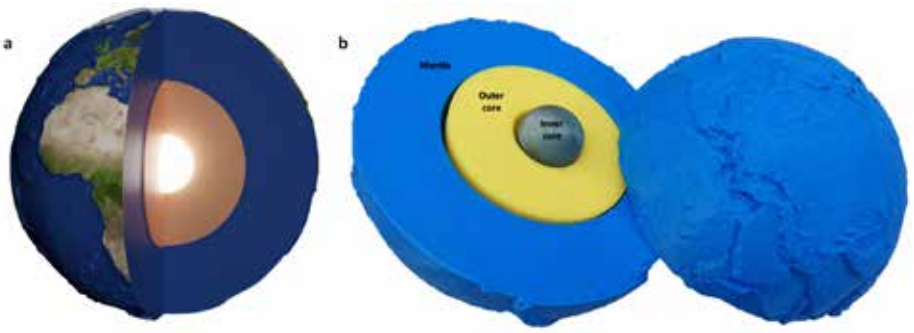
"HAVING TRAINED AS A GEOLOGIST, I MISS BEING IN THE FIELD SO I ALWAYS LOOK FOR OPPORTUNITIES FOR FIELDWORK"

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I hope to be more involved in seismic deployments to study local seismicity and subsurface structures. As a global seismologist, I rarely get to do fieldwork as I mostly analyse data recorded by instruments that are already in place. Having trained as a geologist, I miss being in the field so I always look for opportunities for fieldwork.

WHAT DO YOU ENJOY DOING OUTSIDE OF WORK?

A lot of my 'free' time is taken up by work, as I just enjoy doing research. I also develop 3D printed materials and globes for outreach activities. Besides this, I enjoy hiking, gardening and swimming, as well as spending time with my 2-year-old daughter.



a) The structure of the Earth and b) a 3D printed version developed by Paula

PAULA'S TOP TIPS

01 Don't worry too much about figuring out your entire career path when you are young. I certainly couldn't have predicted where I am now when I was at school.

02 Remember that whatever skills you learn and develop in a particular degree can be applied in many different disciplines and jobs.

03 Pursue a topic that really interests you, rather than one that has a lot of well-paid job prospects. This way, you will be more motivated and will likely enjoy your work more.

EXPLORE THE RESOURCES FROM THE UNIVERSITY OF OXFORD

- The Department of Earth Sciences has a wealth of resources for teachers and students of all ages, including videos, worksheets and classroom experiments: **www.earth.ox.ac.uk/teaching/outreach/resources-for-learners-and-educators-2**
- The department can also arrange school visits and talks: **www.earth.ox.ac.uk/teaching/outreach**
- The department participates in the university's access programme, UNIQ, which allows students from state schools and underrepresented groups to visit the University of Oxford for a residential course, introducing them to academic activities and enabling them to experience college life, as well as providing support during the admission process: **www.uniq.ox.ac.uk**
- Oxford Sparks has videos and podcasts covering a wide range of scientific topics, from chemistry to computer science, maths to medicine: **www.oxfordsparks.ox.ac.uk**

Background image: A day-long recording of seismic signals at a Raspberry Shake instrument in London, UK

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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!

Get top tips from scientists and researchers

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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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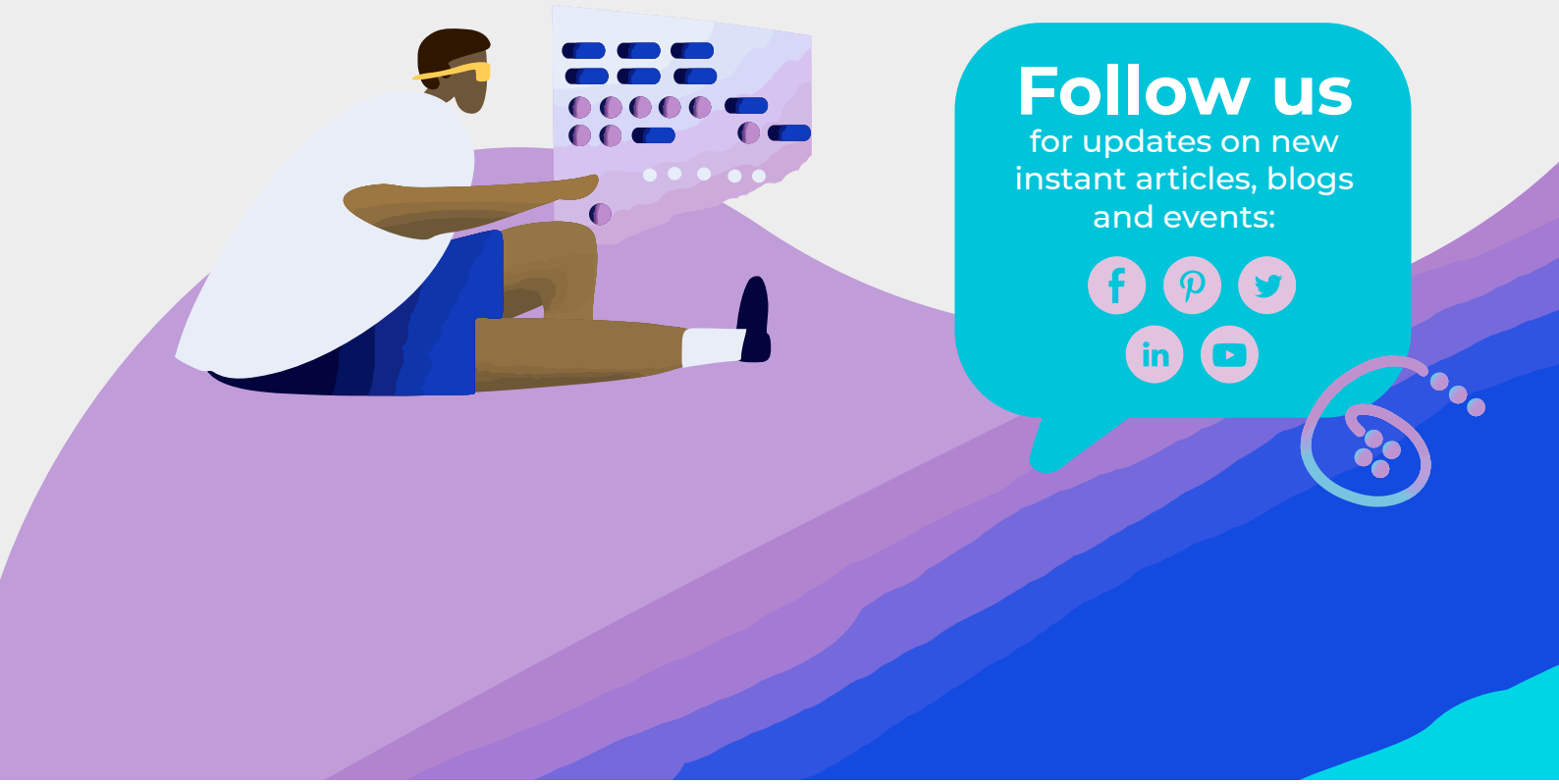

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