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INSPIRING THE NEXT GENERATION

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EVERY CHILD DESERVES A CHAMPION...

MATINA RAZAFIMAHEFA: THE 23-YEAR-OLD WITH A DREAM TO TRAIN AND PUT MILLIONS OF PEOPLE INTO WELL-PAID JOBS

ALSO IN THIS ISSUE

KEISHIA THORPE
WINNER OF THE VARKEY FOUNDATION'S GLOBAL TEACHER PRIZE 2021

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EVERY CHILD DESERVES A CHAMPION

"Every child deserves a champion, an adult who will never give up on them, who understands the power of connection and insists that they become the best they can possibly be," said the late Rita F Pierson, a TED speaker and professional educator who spent her entire life in or around the classroom.

Keishia Thorpe (p 4) is one such champion. An English teacher at International High School Langley Park in the US, Keishia has been awarded the Varkey Foundation Global Teacher Prize 2021 for opening up college education for low-income, first generation American, immigrant and refugee students. Keishia completely redesigned the 12th grade curriculum for the English department and, as a result of her interventions, her English language learners have shown a 40% increase in their reading competencies.

And then there is Matina Razafimahefa (p 40). Born in Madagascar, where 97% of teachers do not have a professional teaching diploma, Matina is determined to train and put millions of people into well-paid jobs. She has set up SAYNA, an online learning and crowdsourcing platform that not only teaches people key IT skills but offers them employment, too. To date, SAYNA has trained and placed over 200 Africans in the global IT marketplace.

The researchers in this issue are also champions. They are passionate about supporting the next generation so that they can be the best they can be. As Dr Joi Spencer (p 44) says, "I see education as a liberating tool. As a mathematics teacher, I want my students to see that all kinds of people can do mathematics and that they can be socially active and love mathematics. Now that I train teachers, my reward is exponential. I can train one mathematics teacher who will go on to inspire thousands of young people. That is incredible!"

At Futurum, we understand the power of connection - connecting young people with academics who are keen to impart their knowledge, and to career paths that will allow them to be the best they can be.

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FOR EXAMPLE:
Animations for **Dr Danielle Densley Tingley** (p 68), **Professor João Porto de Albuquerque** (p 72), and **Dr Ed Gasson** and **Professor Carrie Lear** (p 76) are, or will soon be, available.

CONTENTS

RESEARCH ARTICLES

8 UNDERSTANDING LANGUAGE COMMUNITIES: THE MULTILINGUAL, THE TRANSNATIONAL AND THE TRANSLINGUAL
PROFESSOR STEPHEN HUTCHINGS

16 THE VIEW FROM ABOVE: A DRONE'S PERSPECTIVE ON THE WORLD
DR ELISA SERAFINELLI AND DR LAUREN ALEX O'HAGAN

20 TACKLING MODERN SLAVERY: A SUSTAINABILITY ACCOUNTING PERSPECTIVE PROFESSOR MUHAMMAD AZIZUL ISLAM

24 HOW SUSTAINABLE IS YOUR FOOD? DR CAROLE DALIN

28 DOES SCIENCE HAVE ALL THE ANSWERS? DR SIOBHAN MADERSON

32 EXPERIENCE, GROW AND LEARN TO BE A HORTICULTURALIST
ODILE HUCHETTE

36 HOW CAN COMPUTERS HELP CROPS GROW BETTER?
PROFESSOR TONY PRIDMORE

44 THE STEAM TEAM – ENGAGING STUDENTS THROUGH INTERACTIVE AND IMMERSIVE LEARNING DR ODESMA DALRYMPLE, DR JOI SPENCER AND DR PERLA MYERS

48 HOW MODELLING CAN SHED LIGHT ON MEMORY RETRIEVAL
PROFESSOR OSMAN YAŞAR

52 BUILDING A SMART ENERGY SYSTEM FOR THE PEOPLE OF PETERBOROUGH PETERBOROUGH INTEGRATED RENEWABLES INFRASTRUCTURE (PIRI) PROJECT

60 CAN PLANTS AVERT THE CLIMATE CRISIS? DR ASTLEY HASTINGS

64 COULD WE USE GEOENGINEERING TO COOL EARTH'S CLIMATE?
DR BEN KRAVITZ

68 CAN A CIRCULAR ECONOMY MAKE THE CONSTRUCTION INDUSTRY SUSTAINABLE? DR DANIELLE DENSLEY TINGLEY

72 USING COMMUNITY DATA AND ANALYTICS TO BUILD RESILIENCE TO FLOODING PROFESSOR JOÃO PORTO DE ALBUQUERQUE

76 HOW ICE SHEETS IN THE GEOLOGICAL PAST CAN INFORM US OF SEA LEVEL RISE IN THE FUTURE
DR ED GASSON AND PROFESSOR CARRIE LEAR

80 JAWS: THE IMPORTANCE OF SHARK FOSSILS FOR PALAEONTOLOGY RESEARCH PROFESSOR KENSHU SHIMADA

86 WHAT IF WE UNDERSTOOD THE GENETIC CAUSES OF CANCER?
PROFESSOR IAN PRIOR

90 CAN WE VACCINATE AGAINST THE VIRUSES HIDING IN OUR CELLS?
DR MATTHEW REEVES

94 HOW RESEARCH FIELDS ARE JOINING FORCES TO PROTECT HEALTHCARE SYSTEMS IMPERIAL COLLEGE LONDON AND THE UK HEALTH SECURITY AGENCY

92 REACHING OUT TO OVERCOME DIABETIC EYE DISEASE IN THE PHILIPPINES PROFESSOR TUNDE PETO

INTERVIEWS

4 **KEISHIA THORPE**
WINNER OF THE VARKEY FOUNDATION'S GLOBAL TEACHER PRIZE 2021

40 **MATINA RAZAFIMAHEFA**
FOUNDER, SAYNA

84 **PAUL HOLPER AND SIMON TOROK**
FOUNDERS, SCIENTELL

104 **HOW TO USE FUTURUM'S EDUCATION AND CAREER RESOURCES**

KEISHIA THORPE p 4

MATINA RAZAFIMAHEFA p 40

PAUL HOLPER p 84

SIMON TORK p 84

"TEACHERS MUST BE GIVEN A SEAT AT THE TABLE, AS THEY ARE THE ONES WHO UNDERSTAND THE NEEDS OF STUDENTS."

ENGLISH TEACHER **KEISHIA THORPE** HAS WON MANY PRESTIGIOUS AWARDS, INCLUDING THE MEDAL OF EXCELLENCE FROM THE GOVERNOR OF THE STATE OF MARYLAND IN THE US, NATIONAL LIFE CHANGER OF THE YEAR AND THE VARKEY FOUNDATION'S GLOBAL TEACHER PRIZE 2021. SHE TELLS US WHY IT IS IMPORTANT TO SHINE A LIGHT ON THE TEACHING PROFESSION AND THE GREAT WORK TEACHERS AROUND THE WORLD DO

WHO OR WHAT INSPIRED YOU TO BECOME A TEACHER?

As an immigrant from Jamaica, I attended Howard University on a track and field scholarship, initially on a prelaw track, and graduated top of my class. Taking the time to volunteer at local schools and seeing the lack of access to resources students needed for their success, I was inspired to become a teacher, especially as I personally witnessed and experienced just how transformative the power of education could be and how it allowed children from different backgrounds to appreciate they can succeed in society. I wanted to make sure children like me have the power to turn their dreams into reality. I've been teaching for 17 rewarding years, and I still love it because I believe every child deserves a champion, an adult who will never give up on them, who understands the power of connection and insists that they become the best they can possibly be.

HOW WOULD YOU DESCRIBE THE INTERNATIONAL HIGH SCHOOL AT LANGLEY PARK (IHSLP) AND WHY DID YOU CHOOSE TO WORK HERE?

It is a high school redesign model with strategies to prepare English language learners for college and careers through a competencies-based approach and project-based learning. We have students from around 30 countries who speak around 20 languages.

When I received my teaching credentials, I chose to teach at Title I and III schools, to help students who are considered underserved, economically disadvantaged, underrepresented, and at-risk of not completing high school. Because these were students that were counted out, it was challenging to change their mindsets to look to a better future. So, I employed many strategies to build relationships with them and their families. All my students are English language learners, first and second-generation Americans, immigrants or refugees and 95% of them identify as low income. We are also a community school that offers wrap-around services for students and their families.

WHAT LED YOU TO REDESIGN THE 12TH GRADE CURRICULUM FOR THE SCHOOL'S ENGLISH DEPARTMENT?

Many of my students face struggles with language and cultural barriers. The 21st century classroom has a growing need to recognise students' identities and how they interact. So, my approach to this was to design a curriculum from a global perspective, through a Social Emotional Learning (SEL) and social justice lens, to implement culturally

© Varkey Foundation

responsive teaching that can better connect students to what they learn. Education is not a 'one size fits all' situation; therefore, I ensure all my students are represented in my curricula, integrating lessons and texts that represent their cultures and individual ways of learning. This approach has resulted in increased student attendance in class, more engagement and improved grades. It has helped me develop authentic relationships with students and improve communication with parents.

WHAT CHALLENGES DID YOU HAVE TO OVERCOME TO MAKE THIS CURRICULUM CHANGE?

With the language barriers of students who, in the pandemic, had little or no socialisation with their peers and major learning loss due to extended school closure, I had to get innovative. I had to find ways to ensure my English language learner students had social and academic interaction with native speakers to help with their comprehensibility and language acquisition. This is not only a chance to learn English; students also have an opportunity to share their language, develop social and cultural awareness, form relationships, and build their self-confidence with the English language.

CAN YOU GIVE SOME EXAMPLES OF CURRICULUM CHANGES THAT HAVE LED TO A 40% INCREASE IN YOUR STUDENTS' READING ABILITIES?

At first, I had to consider my student's language proficiency levels and make sure I am differentiating to make the content accessible. Then, I had to rethink my approach to amplify students' voices and take them on a learning journey, aligning what I am teaching to students' culture and current events in society. Connection has been a challenge here since the pandemic, but I tried to stay creative. I had to take a few media arts classes so I could engage students in the content and help navigate their learning. I used Google Classroom as my main platform to teach students and for them to collaborate with their peers.

Focus and momentum is another challenge. To make learning new and interesting, I used many interactive online sources such as WeVideos, Flipgrid and many others. I also brought in two innovations that yielded positive outcomes for my students: a new Language Exchange Program, which I developed by partnering with schools in the Bahamas and taking the social justice approach with my curriculum redesign.

In the course, we explore students' own identities amidst racial tensions, their stories, civic responsibilities, and the role of men and women in society. We analyse how literature teaches us about just and unjust societies. We research the identity and struggles of other minority groups, and focus on social justice from another perspective. We choose an issue in the students' community, conduct research and

interviews, and write letters to community and school leaders with a proposal for change. This challenges the students to think local, while acting both locally and globally through social media campaigns.

I also adopted the Global Classroom DC curriculum under the Model United Nations USA, and my students attended the Model UN Conference, representing a country and various global topics. They collaborated with their peers globally and nationally to engage with the Sustainable Development Goals of 2030.

YOU ALSO CO-FOUNDED US ELITE INTERNATIONAL TRACK AND FIELD, INC. WITH YOUR TWIN SISTER DR TREISHA THORPE. WHY DID YOU SET THIS UP AND WHAT IS ITS AIM?

Having attended Howard University on a fully funded track and field and academic scholarship, and having derived tremendous personal and lifelong career benefits from this, I wanted to help others in my position realise the same advantages. So, after graduating, Treisha and I set up US Elite in 2005 as a registered non-profit organisation. It comprises athletes with a passion for track and field and who want to continue to excel during or after their college years. We also welcome at-risk high school student-athletes who are looking for scholarship opportunities to continue with track and field and their academic pursuits.

Our Liaison International Scholarship Program helps students worldwide from low-to-moderate income households and those considered at risk to access higher education and graduate college debt-free to help remove their barriers to success. During the pandemic, when so many high schoolers faced an uncertain future, US Elite was one of the first to organise an international virtual college event to enlighten students about changes to college admissions, giving them and their families hope. With SAT exams cancelled, which so many need to attend colleges in the US, I collaborated with other teachers and coaches worldwide, and a SAT company, to offer free SAT prep classes and SAT practice exams each quarter. I mentor and assist students from many different countries in the college matriculation process.

YOU HAVE WON QUITE A FEW PRESTIGIOUS AWARDS. WHAT DOES THIS MEAN TO YOU?

Keishia Thorpe receives the Varkey Foundation Global Teacher Prize trophy at the UNESCO Headquarters in Paris, France, from Stefania Giannini, UNESCO Assistant Director-General for Education, and Jay Varkey, Trustee of the Varkey Foundation. © Varkey Foundation

I am grateful that these prizes have brought new attention to the education causes I care passionately about. The Global Teacher Prize, in particular, shines a light on the teaching profession and the great work teachers do all over the world, so it is a huge honour to have been selected. I want to thank Sunny Varkey and the Varkey Foundation for the platform the Global Teacher Prize now gives to teachers, helping tell their stories while raising the status of the profession.

WHAT ARE YOUR TOP TIPS FOR TEACHERS WHO WANT TO MAKE A DIFFERENCE TO THEIR STUDENTS' LIVES?

As I said, I believe every child deserves a champion, an adult who will never give up on them, who insists that they become the best they can possibly be. From my personal perspective, it's also about being committed to your school community, mentoring new teachers, designing and sharing best practice with your team and presenting these in your professional learning communities.

I encourage teachers to follow their passions in education outside of the classroom, to help create greater social impact in their school communities. Find opportunities to contribute to public debates, attend board of education meetings and advocate on students' behalf. I have testified on a whole range of issues, including teacher retention and funding, improvements in schools and teacher capacity, advocating for minority students and social justice in education, and so on.

My hope is that more educators will become involved with the community in which their students and families live. We need to do more research to continually improve the education system globally, but the system must put students first. Teachers are on the frontline but often do not get the opportunity to have an input. They must be given a seat at the table, as they are the ones who understand the needs of students. They can relay some of the challenges faced within the system and be better able to impact those policies that need changing.

ABOUT THE GLOBAL TEACHER PRIZE

On Wednesday 10 November 2021, US teacher Keishia Thorpe was named winner of the Varkey Foundation Global Teacher Prize, in partnership with UNESCO. Now in its seventh year, the US$1 million award is the largest prize of its kind.
Keishia was selected from over 8,000 nominations and applications for the Global Teacher Prize from 121 countries around the world. She currently teaches English to 12th grade students at the International High School Langley Park in Maryland, USA, a school where 100% of her students are English language learners and 95% identify as low-income.

Keishia completely redesigned the 12th grade curriculum for the English department to make it culturally relevant to her students who are first-generation Americans, immigrants, or refugees from mostly Africa, the Middle East, the Caribbean, and South and Central America. As a result of her interventions, her English language learners have shown a 40% increase in their reading, which contributed to the school meeting its growth-to-target rate with a 10% increase in WIDA scores for 2019-2020 and the highest in the school district for ELLs.

For more information, visit:
www.globalteacherprize.org

Keishia Thorpe celebrates winning the Varkey Foundation Global Teacher Prize 2021. © Varkey Foundation

UNDERSTANDING LANGUAGE COMMUNITIES: THE MULTILINGUAL, THE TRANSNATIONAL AND THE TRANSLINGUAL

PROFESSOR STEPHEN HUTCHINGS, BASED AT THE **UNIVERSITY OF MANCHESTER** IN THE UK, HAS BEEN LEADING A MODERN LANGUAGES RESEARCH PROGRAMME EXPLORING THE RELATIONSHIP BETWEEN LANGUAGE AND COMMUNITY

The internet, international business and travel, migration, climate issues… in many ways, our world is getting 'smaller'. Globalisation facilitates interactions that are no longer restricted by borders or distance and brings people from different backgrounds together. So, how does language operate within this modern era? To what extent are communities defined by language? Does the transcendence of boundaries affect our sense of belonging? How does each language preserve its integrity at the same time as opening communities to the wider world?

It is with these fascinating questions in mind that, in 2016, Professor Stephen Hutchings embarked on a research programme called Cross-Language Dynamics: Reshaping Community. While Stephen is based at the University of Manchester, this highly collaborative programme, due to end in 2021, is composed of three research strands, each led by colleagues at different core institutions: Professor Yaron Matras of the University of Manchester (multilingual), Professors Andy Byford and Anoush Ehteshami at Durham University (transnational), and Professor Catherine Davies at the School of Advanced Study, University of London (translingual).

Digital technologies and unprecedented global population movements have transformed the relationships between individuals and the communities they belong to (national, local, religious and other), between those communities, and between communities and nations. It is impossible to understand the processes involved in these shifts and changes without studying language's central role in creating and transcending the boundaries that define communities.

THE THREE STRANDS

The project strands reflect what the team sees as the main ways that language helps configure communities. "Many of our large, global cities are characterised by increased linguistic diversity and this was the focus of our multilingual strand," explains Stephen. "The technological advances that are driving the most recent phase of globalisation have also reinforced the ability of speakers of single languages to communicate across national boundaries, strengthening ties across the Russian-speaking, Spanish-speaking and Arabic-speaking worlds, for example. These communities were studied within our transnational strand."

Finally, the translingual strand is related to how enhanced global connectivity is fostering the creation and maintenance of communities defined by their ability to cross boundaries between languages,

PROFESSOR STEPHEN HUTCHINGS

Russian Studies, School of Arts, Languages and Culture, The University of Manchester, UK

FIELD OF RESEARCH

Modern Languages

RESEARCH PROJECT

'Cross-Language Dynamics: Reshaping Community': investigating the relationship between language and community for the benefit of a more open world

FUNDER

Arts and Humanities Research Council (AHRC)

whether through a shared appreciation of non-linguistic art forms like music, or as the result of a tendency to mix languages in everyday communication, or via the skills and commitment of translators.

COLLABORATION

The team has collaborated with stakeholders that share interest in communities within the UK, other nations, and across national and linguistic boundaries. These include foreign policy makers, arts organisations, local authorities, schools and community groups. "Collaboration has involved helping stakeholders solve problems important to them, while we have benefited from policy-maker expertise in our research," says Stephen. "We have worked together with our partners on joint initiatives that include a city-wide celebration of linguistic diversity in Manchester and a play that explores the experiences of cancer sufferers across the Arabic-speaking world. Without these collaborations, we could not have realised our research goals or demonstrated the value of languages."

HIGHLIGHTS

One of the things that Stephen is most proud of is the central role that young early-career researchers have played. "Their involvement bodes well for the future of our profession and confirms that modern languages is benefiting from the injection of new creativity and dynamism," he explains.

LONG-TERM

The Cross-Language Dynamics: Reshaping Community programme has achieved a number of legacies. "First, we have succeeded in raising the profile of modern languages within and beyond Higher Education. Our contributions to addressing key societal issues – including those associated with societal cohesion, health, conflict and cultural diplomacy – have helped re-establish modern languages as one of the foremost humanities disciplines," says Stephen. "Secondly, the partnerships we have forged with stakeholders have changed attitudes to the value of the discipline to policy makers. Thirdly, we have changed the public narrative around the discipline, helping to break down the false 'community/modern' languages distinction, demonstrating the importance of linguistic diversity, promoting the extent of multilingual talent and creativity within and beyond the UK, and confronting negative perceptions of a subject 'in decline'."

THE POWER OF MODERN LANGUAGES

Stephen explains what modern languages mean to him.

There is a tendency to view modern languages as providing little more than practical knowledge for use in business and diplomacy. This, of course, is important, but the subject is so much more than a useful skill. It is worth studying for the unique insights it offers into other cultures, mindsets and value systems. Knowledge of multiple languages is a source of huge creativity and talent within the arts. It fosters wellbeing within individuals, and within and across entire communities. Modern languages provides a distinctive perspective on international conflict, cross-community cohesion and intercultural understanding. We should stop seeing the subject as an exotic and peripheral 'add on' to the core curriculum, and recognise that, with its focus on communication and what it means to be 'different', it represents the essence of humanities.

Rather than extending the dominance of English, the impact of globalisation on international trade is highlighting the advantage to businesses of 'selling in the language of the client'. However, the range of career options open to modern linguists is much broader than those on offer in the world of commerce, or translation, important though these are. With ever-increasing migration movements, management of diversity – for example – is becoming critical to national and local policymaking within individual countries. And as the clearly defined ideological blocs of the Cold War fade away, countries are turning to softer, more subtle approaches to promoting their values and interests. Without the relevant linguistic and cultural knowledge, such approaches cannot succeed. There is a growing appreciation of the benefits of multilingualism to public health and creativity in the arts. All these areas are generating opportunities to young people with an interest in languages. Finally, for those young people who choose to study a language at university, the year they spend abroad practising and honing their linguistic skills becomes the defining year of their lives. This was certainly my experience!

I am a child of the Cold War. During my school years, anxiety over nuclear conflict with the Soviet Union and the communist world was central to my experience. Even at that early stage, it struck me that fear on both sides was exacerbated by a lack of understanding of how ordinary people felt and thought. I recognised that it is only through taking the trouble to learn the language of the other that such understanding can be properly attained. It was this that motivated me to learn Russian.

Some of my most memorable experiences come from periods I spent in the Soviet Union and in post-Soviet Russia in connection with my studies. I will never forget long, intense conversations into the small hours of the morning around the kitchen tables of those ordinary Soviet families who had welcomed me into their homes at the height of the Cold War. It was here that I learned to appreciate the true meaning of what it is to communicate and the value of understanding what makes us similar to, and different from, one another.

WHAT IS A HERITAGE LANGUAGE?

According to *Ann Kelleher, University of California, Davis*, "The term 'heritage language' is used to identify languages other than the dominant language (or languages) in a given social context. In the United States, English is the *de facto* dominant language (not an "official" language, but the primary language used in government, education, and public communication); thus, any language other than English can be considered a 'heritage language' for speakers of that language."

cal.org/heritage/pdfs/briefs/What-is-a-Heritage-Language.pdf

THE MULTILINGUAL

DR LEONIE GAISER

ROLE ON THE PROJECT:
PHD STUDENT AND RESEARCH ASSISTANT

CURRENT ROLE:
LECTURER IN LINGUISTICS AT THE UNIVERSITY OF MANCHESTER, UK

Our research explores how speakers of 'heritage' languages maintain their languages and dialects in the linguistically diverse city of Manchester, and how language can help create a sense of community in the diaspora setting. One of our research interests is to learn more about the work of language supplementary schools, which teach heritage languages to children on the weekend. We have set up a support platform for supplementary schools to offer a range of activities for pupils and teachers.

We have worked together with the Manchester Institute of Biotechnology and a range of multilingual scientists from across the University of Manchester to deliver interactive sessions in the languages taught at the schools. Our enrichment sessions have included enzyme experiments and strawberry DNA extraction, led by multilingual scientists. Experiments are followed by hands-on activities for students, for example making 'DNA bracelets' to take home. The day ends with (typically multilingual) question and answer sessions about the scientists' work.

Our sessions give children opportunities to experience their heritage language in the context of scientific experiments or museum exhibitions, and in interaction with university staff. The sessions expand pupils' vocabulary in the heritage language and allow them to link their language skills with science and museum exhibits. Meeting university researchers who speak their language enhances students' confidence in their language skills and their complex, multi-layered identities.

My doctoral research has shown how experiences of 'community' are both imagined and practiced. People's mutual identification with languages and their efforts to maintain languages serve to create and strengthen a sense of belonging and identification with the multilingual setting, as well as a way to inter-connect with family and friends.

Our research has offered insights into the various ways in which language users maintain their languages and acquire new ones. Supplementary schools vary widely in size, curricula, staff qualifications and training, the type of premises used, and their teaching and learning approaches. My doctoral research has shown that, contrary to what is often discussed in public discourse, maintaining heritage languages is anything but self-segregating. These languages are relevant in the present-day UK context and for its global future, and supplementary schools help children turn their heritage into valuable skills.

DR MARÍA SOLEDAD MONTAÑEZ

ROLE ON THE PROJECT:
RESEARCH FELLOW,COMMUNITY ENGAGEMENT IN THE LATIN AMERICAN COMMUNITY IN LONDON

CURRENT ROLE:
VISITING FELLOW, THE INSTITUTE OF MODERN LANGUAGES RESEARCH, SCHOOL OF ADVANCED STUDY, UNIVERSITY OF LONDON/LECTURER IN SPANISH, UNIVERSITY OF GLASGOW, UK

I worked with Southwark Council to explore new tools, resources and opportunities for collaboration and engagement between the Latin American groups in Southwark and the wider community. I co-designed and co-delivered Cartonera workshops for young Latin Americans. Cartoneras (also known as cardboard publishers) is a unique grassroots Latin American publishing phenomenon, which offers alternative forms of community engagement, activism and social change. The Cartoneras grassroots initiative in Latin America catalyses civic participation and activism within vulnerable and marginalised communities.

The Cartoneras Creative Engagement Project was a multi-party collaboration involving two AHRC projects – 'Cross Language Dynamics: Reshaping Community' and 'Cartonera Publishing: Relations, Meaning and Community in Movement', the British Library, a group consisting of the Indoamerican Refugee and Migrant Organisation (IRMO), Southwark Council and the Migration Museum.

This project explored notions of community, identity and language through a series of workshops, from creative writing to book making with young Latin Americans. The idea was to publish the voices of young Latin Americans in London as the UK was preparing to exit the EU.

Creativity plays a vital role in community engagement in cross-cultural contexts. Creativity should be understood as a source of free expression, adaptability and innovation, and an alternative to more bureaucratic forms of consultations. Creative practice offers the opportunity to (re)connect with diverse communities through multiple media and languages, allowing alternative methods of communication and understanding.

The Cartoneras workshops allowed the young people to develop a better sense of identity and belonging, as the motto chosen by them was 'to work as a team'.

The Latin American community is diverse – ethnically, linguistically, culturally, and geographically distinctive from each other – Latin American is far from a homogenous concept. Language barriers play a role in preventing many Latin Americans from accessing key services.

My research is community-focused, so a typical day would involve lots of talking with different stakeholders, from formal and semi-structured interviews to meetings, and delivering community projects myself. Working on community engagement means that most of the research is done 'on the ground'.

THE TRANSNATIONAL

DR JULINE BEAUJOUAN

ROLE ON THE PROJECT:
PHD STUDENT INVESTIGATING THE ISLAMIC STATE'S DISCURSIVE POWER IN THE MENA REGION

CURRENT ROLE:
POST-DOCTORAL RESEARCH FELLOW, PEACE AND CONFLICT RESOLUTION EVIDENCE PLATFORM (PCREP), UNIVERSITY OF EDINBURGH, UK

My research looks at how the Islamic State's (IS) message gained significant traction in the Middle East and North Africa (MENA) region. It also looks at if/how it shaped the way local populations understand conflict dynamics in the region.

IS used language to break the geographical and concrete borders between Iraq and Syria, but also the invisible and imagined borders between nations, regions, religions and cultures. Language was used as a tool to deconstruct as many competing identities, to allow each individual to enter the global and communal culture promoted by the group.

By self-declaring itself a new 'state' actor, IS entered in direct competition for power and legitimacy over territories and populations with the existing MENA states. This prompted military offensives against IS in Iraq and Syria. Despite the common threat, the war against IS created additional layers of inter-state frictions in the MENA and shed light on the failure of regional bodies to take collective measures.

While reclaiming their Islamic heritage and identity, the populations I interviewed in Jordan and Tunisia rejected IS' methods and the strict application of Shari'ah law. Rather, they favoured a more humanistic Islam that recognises diversity and endorses living together. As such, IS failed to transform the very nature of Islam and Muslim communities.

One of the best parts of this project was that there was no such thing as a 'typical day'. While I spent hours collecting and coding IS' material during the first months of the project, I also spent several months in the MENA region where I conducted interviews and co-organised and participated in international events.

During this research, I became aware of the value of academic endeavours. They function as relational matters that can endorse a form of more sustainable, humanistic, universal way to carry out informed research that promotes connections between spaces and individuals to open dialogue and debate among a multitude of voices.

I co-authored a book with my colleagues Professor Ehteshami and Dr Rasheed that collects the key findings of our research. I also edited and contributed to another volume that brought together local voices from the Middle East on a key consequence of IS' project, which is the Syrian refugee crisis. Finally, my first single-authored article recently got published by Studies in Conflict & Terrorism.

Communities are shaped by language. When it is used in a discourse, language becomes a powerful unifier that brings people together in the same community, and at the same time, a factor of exclusion.

For me, language is the key that opens the door to knowledge and, most importantly, understanding. My knowledge of several languages – French, English and Arabic – allowed me to widen my professional horizons by studying in the UK and researching the MENA region.

DR POLINA KLIUCHNIKOVA

ROLE ON THE PROJECT:
POSTDOCTORAL RESEARCH ASSOCIATE, LANGUAGE BORDER: RUSSIAN IN FORMER SOVIET UNION MIGRATION

CURRENT ROLE:
ASSOCIATE LECTURER IN RUSSIAN LANGUAGE AND CULTURE, THE UNIVERSITY OF ST ANDREWS, SCOTLAND, UK

My research project studied the changing role of the Russian language in the present-day migration to Russia from other post-Soviet countries. What do the language requirements introduced by the Russian state look like and how does the language testing procedure shape the lives of people who want to receive a work permit or apply for a leave to remain? What are the social and cultural effects of using a 'non-standard' variety of the language? How do local communities see and perform their role in helping migrants to adjust to the new context in terms of language use?

Citizens of most of former Soviet Union (FSU) countries enter Russia visa-free. But for employment of any duration, most migrants require a work permit which, in most cases, includes a language test. The test has three parts – language tasks (including reading, grammar, listening, speaking, and writing), as well as questions on Russian history and legislation – and is now valid for three years.

The main discussion about the tests is not about their necessity, but the content of them. While the language tasks are rather simple, they require knowledge of formal grammar rules that lots of current migrants don't have. The other two components of the test, Russian history and especially law, are also presented in a complicated, advanced language.

Many people who come to Russia are multilingual. However, FSU migrants find themselves in a different environment where the Russian language is given priority in most communication. A slight accent or non-standard grammar do not go unnoticed. The effect may take many forms – from casual comments to limited job options or restricted access to basic welfare.

The life of migrants in Russia is not easy and language issues do not come first in the list of daily challenges. But the significance of at least threshold language competence has started to come to the foreground – people have become more aware of it while looking for accommodation, registering at a clinic, or enrolling their children at a local school. This is where support networks are vital; migrant communities have developed ways to adapt to their new reality.

For many people who come to another country, 'community' usually stands for a group of their compatriots – people with a similar trajectory who speak the same language. In this project, we also worked with another type of community – that emerging around providing language support and promoting multilingualism. For example, an afterschool course for migrant children which creates a network of parents and volunteering teachers in the area or a language class for female migrants which also provides them with a safe social space to discuss their experiences.

I was lucky to do most of my fieldwork in 2017, when the importance of language provision for migrants was realised in Russia. I witnessed the emergence of a country-wide network of educators and activists working with migrant children and adults. Another interesting and unexpected angle was to explore the Russian language provision practices in other post-Soviet countries (Kyrgyzstan and Tajikistan). We are now at the very final stage of the project, editing articles for publication.

Juline's research focuses on the Middle East and North Africa (MENA) region, while Polina has studied the role of language in migration to Russia from other post-Soviet countries.

THE TRANSLINGUAL

DR NAOMI WELLS

ROLE ON PROJECT:
POSTDOCTORAL RESEARCH ASSOCIATE, DIGITAL HUMANITIES AND TRANSLINGUAL COMMUNITIES

CURRENT ROLE:
LECTURER IN ITALIAN AND SPANISH WITH DIGITAL HUMANITIES/CO-DIRECTOR OF THE DOCTORAL CENTRE INSTITUTE OF MODERN LANGUAGES RESEARCH/ DIGITAL HUMANITIES RESEARCH HUB SCHOOL OF ADVANCED STUDY, UNIVERSITY OF LONDON, UK

My research aims to help us better understand how multilingual individuals and groups use the internet and social media to communicate and represent their identities and interests. While people have always moved across languages in their daily lives, the internet provides new ways for people to use and mix languages, and to communicate and share media content with speakers of different languages around the world.

As the pandemic has highlighted, it is important to recognise the ways the internet and social media can help us to stay connected. They also strengthen our feelings of belonging to our close community of family and friends, as well as new communities we can form online. Focusing on language, online communication may allow people who have migrated to a new country to stay connected and continue using their languages in ways that can help prevent feelings of isolation.

Latin American communities' digital presence has increased the visibility of the community in the UK. While Latin Americans have been one of the fastest growing communities in London in the past decade, their interests and concerns have often been politically and socially marginalised. Online communications can also help to build networks of people with shared interests and feelings of solidarity that can be particularly important for groups who are marginalised.

My research is revealing that the internet and social media provide new ways for people to express their sense of belonging to a community, but also greater possibilities to identify with and move across different communities. For example, someone might use a Spanish-language hashtag to show they belong to the Latin American community, but then switch to English for most of their communications. This is particularly true for young people who have grown up in the UK mainly using English with their friends online and offline, but for whom Spanish remains important for expressing their belonging to the Latin American community.

I enjoyed studying languages at school and experiences of travelling to different linguistic and cultural contexts. Studying languages at university, I realised I wanted to pursue research that would allow me to better understand the importance of languages in our daily lives and the cultural practices of different countries and communities.

One of the most valuable experiences has been the experience of studying, working and conducting research abroad. This was important not just for improving my language skills, but also for developing the ability to live and work across different languages and cultures, and for learning to be adaptable and open to the different perspectives and experiences that people may bring.

EXPLORE CAREERS IN MODERN LANGUAGES

- Stephen suggests you should engage with speakers of the language you're interested in learning, as well as the cultures and societies you would like to learn more about. He recommends Target Jobs (**targetjobs.co.uk/careers-advice/degree-subjects-your-options/301040-what-can-i-do-with-a-modern-languages-degree**) and the University of Manchester's Language Careers page (**www.careers.manchester.ac.uk/whichcareer/languagecareers/**).

- Open Days references university and college open days across the UK, which are good opportunities to engage with staff and students and investigate future academic prospects: **www.opendays.com/calendar**/

- The Linguist List is a free resource that offers information about events and summer schools: **linguistlist.org/**

PATHWAY FROM SCHOOL TO MODERN LANGUAGES

"The pathway into a modern languages research career is, as for other subjects, usually via a PhD. Because, by its nature, the study of languages is closely interconnected with that of other disciplines, and because the relative status of different languages is changing all the time, my top tip would be to remain maximally flexible when identifying your PhD topic," explains Stephen. "Study more than one language and be prepared to acquire brand new ones; your existing linguistic experience and skills will serve you well. Take an interest in other humanities disciplines, depending on your own preferences and talents. The best PhDs (and the most successful research careers) are driven by sheer intellectual curiosity and passion. So, whilst following these tips, trust your own intuitions, instincts and interests."

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

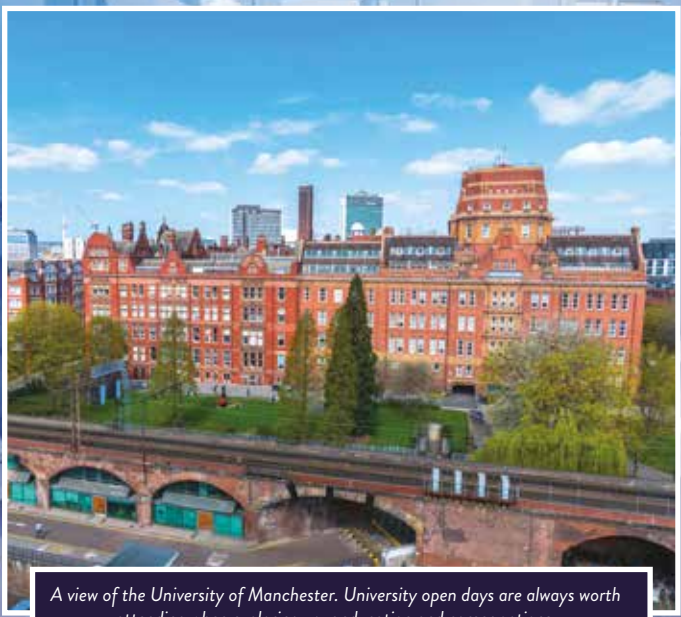
THE TEAM'S TOP TIPS

01 – Learning a language is a long, hard slog. The novelty value one senses at the start of the journey wears off quite quickly and those long evenings spent learning obscure grammatical rules can seem pointless, especially when one is still struggling to hold a conversation in the language in question. The key is stamina, perseverance, and keeping your eye on the end goal.

02 – Don't worry about not having an aptitude for language learning. Being good at languages comes with practice and time. Own your learning journey and be gentle with your mistakes. And most importantly, believe in yourself.

03 – Get involved in language-related projects or organisations as early as possible. Such opportunities will allow you to gain valuable experience and skills, and explore the richness and complexities of languages and 'communities' on your doorstep.

Part of Leonie's research was to learn more about the work of language supplementary schools.



A view of the University of Manchester. University open days are always worth attending when exploring your education and career options.

THE VIEW FROM ABOVE: A DRONE'S PERSPECTIVE ON THE WORLD

DRONES ARE USED INCREASINGLY BY AMATEUR PHOTOGRAPHERS, WHICH IS WHY **DR ELISA SERAFINELLI** AND **DR LAUREN ALEX O'HAGAN**, AT THE **UNIVERSITY OF SHEFFIELD** IN THE UK, ARE EXPLORING WHETHER AND HOW DRONE VISUALS ARE CHANGING OUR VISUAL CULTURE. THE PROJECT AIMS TO ENCOURAGE READERS AND VIEWERS TO REFLECT ON HOW DRONES HAVE CREATED NEW WAYS OF VISUALISING AND EMBODYING OUR WORLD

TALK LIKE A VISUAL CULTURE RESEARCHER

DRONE – the common name for an uncrewed aerial vehicle (UAV), an aircraft without a human pilot

DRONE VISUALS – photos and videos taken by drones

NON-COMMERCIAL DRONE USER – an amateur drone pilot who flies for a hobby

SOCIAL SEMIOTICS – a branch of semiotics, the study of symbology, which investigates how humans convey and understand meaning in social and cultural circumstances through signs and symbols

THEMATIC ANALYSIS – analysing themes by identifying and interpreting patterns of meaning

VISUAL COMMUNICATION – the use of images and videos to communicate meaning

VISUAL CULTURE – a term that refers to all visual forms and practices within a society, together with the processes of production, consumption and/or reception associated with them

Drones, or uncrewed aerial vehicles (UAVs), have the ability to provide a unique perspective on our world, enabling amateur drone photographers to capture truly beautiful views from above. Drones have experienced a boom in popularity in recent years. The decreasing cost of purchase has seen an increase in drone ownership. Today, many people can now enjoy the thrill of capturing views from above while flying their own personal drone.

This emerging method of photography has opened new avenues for research in the field of visual communication. How and why do non-commercial drone users take photos? How are these images circulated and shared with others? How do the public perceive photos taken from drones?

These are some of the questions that Dr Elisa Serafinelli and Dr Lauren Alex O'Hagan, at the University of Sheffield, hope to answer as they investigate how drones are shaping our visual culture.

ANALYSING DRONE IMAGES

Elisa and Lauren have been collecting photos taken by non-commercial drone users and using visual social semiotic analysis to explore their composition. "Visual social semiotic analysis is a methodological tool to investigate how different multimodal resources (e.g. colour, texture, framing and angle) work together in images to construct meaning and convey ideas and knowledge about our society," explains Lauren. Applying this methodology enabled them to identify ten distinct categories of drone image, such as panoramic views, bird's eye views, and 'dronies' – selfies taken by drones.

To assess public perception of drone images, Elisa and Lauren have curated a digital exhibition to display some of the drone users' photos. Visitors to the exhibition can comment on each image and complete a post-exhibition survey. In the survey, visitors are asked to reflect on the drone images, prompted by questions such as 'How do the

This work is supported by the Arts and Humanities Research Council under award number AH/T0125281. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the Arts and Humanities Research Council.

shadows change your experience of the image?' and 'What emotions does this image make you feel?'

"All comments and survey responses will be subjected to thematic analysis to tease out key topics related to people's opinions of drones," says Elisa, "whether in terms of the composition of visuals, the feelings they generate, or broader reflections on drones and the view from above."

PERCEPTIONS OF DRONE VISUALS

Survey responses so far have suggested that drone visuals can challenge people's current understanding of drones and drone photography. "Many members of the public expressed surprise that drones can be used artistically to create abstract art and that they were increasingly owned by 'ordinary people', not just techies or the military," says Lauren. "However, many viewers felt that drones could never replace traditional landscape photography as most users are pilots first and photographers second."

Survey participants have commented that drone images can offer new perspectives on the world, as drones provide a viewpoint that is not accessible to us on the ground. Quoted advantages of drone photography over traditional aerial photography (conducted from a plane) include how drones are more eco-friendly and socially inclusive, providing a greener and cheaper alternative for amateur photographers.

"Drawing attention to how drones are used in everyday life for photography definitely came as a positive surprise to many members of the public who still associated their usage with warfare and surveillance, and they openly stated that it had made them rethink their understanding of drones," explains Lauren. "While this is great from the perspective of our research, we must be careful not to down-play people's persisting concerns around drones."

Understandably, some respondents remained concerned about issues of drone surveillance and privacy. It would feel very intrusive to have a drone buzzing overhead if you were sitting in your garden or enjoying a day at the beach, knowing that it has the potential to be filming you from above. And while drones are reasonably quiet, noise was another concern raised by participants as the buzzing hum of a drone can spoil a peaceful landscape.

Elisa and Lauren are keen to emphasise they are not trying to create a utopian image of drones or deny that the view from above can be problematic, but they do hope to encourage people to reflect more critically on their artistic, aesthetic, social, cultural, historical and political connotations. Their digital exhibition should be seen as a springboard to open a dialogue on the topic. Museums and art galleries can also contribute to normalising the use of drones by exhibiting drone photographs.

Hopefully, Elisa and Lauren's research will help the public to appreciate the new and creative ways in which drones can operate and showcase the unique perspectives of our world that they can capture.

DR ELISA SERAFINELLI

Research Fellow, Department of Sociological Studies, University of Sheffield, UK

FIELDS OF RESEARCH

Digital Media, Media and Communication, Visual Studies

DR LAUREN ALEX O'HAGAN

Research Associate, Department of Sociological Studies, University of Sheffield, UK

FIELDS OF RESEARCH

Victorian and Edwardian Material Culture, Media and Communication, Visual Studies

RESEARCH PROJECT

Investigating public perceptions of drone visuals

FUNDER

Arts and Humanities Research Council (AHRC)

ABOUT VISUAL, CULTURAL AND DIGITAL MEDIA STUDIES

Elisa and Lauren's research is multidisciplinary, spanning the fields of visual, cultural and digital media studies. The field of visual studies is concerned with how visual artefacts are used and understood, while cultural studies focuses on everyday practices of life and how cultures are constructed and evolve. Digital media studies investigates how digital content is created and used and how it impacts society.

"When combined, all three disciplines offer a complementary way of exploring how our social, cultural and political worlds are shaped by media technologies," explains Elisa. "This multidisciplinary approach enables us to identify the motivations behind drone visuals and their sociocultural effects. In addition, we investigate how technological developments influence our visions, practices and understanding of the space in which we live."

VISUAL COMMUNICATION IN A DIGITAL SOCIETY

"Visual communication has always been an essential part of human communication," says Elisa. If a picture is worth a thousand words, then it is no wonder that we rely so heavily on images. But, in an increasingly digital society, our methods for producing and distributing visual artefacts are rapidly changing, as is the way we interpret visual information. A picture is no longer a canvas masterpiece painted over several weeks, to be hung in a grand house. Today, a picture is a moment snapped by a smartphone and instantly shared with the world.

"The internet has increased interactivity and connectedness like never before," says Elisa. "The expansion of social media, smartphones, artificial intelligence and virtual reality has altered the way we interact by extending options for unique visual communication."

APPRECIATING DRONE VISUALS

Lauren finds studying drone visuals to be a real pleasure (and looking at the photos exhibited for the project, it is easy to see why). Photographs have a way of transporting the viewer to the place in the image. When admiring drone images, you can travel to a Buddhist temple in Thailand or a snowy mountain pass in Switzerland from the comfort of your own home.

"The more you look at an image, the more subtle things you begin to notice in terms of framing, angle or the use of light and shade," says Lauren. "I find it extremely rewarding when sharing these findings with others leads to positive feedback or opens a debate about different aspects of drone photography. It means that all of our research has been worthwhile."

PATHWAY FROM SCHOOL TO VISUAL, CULTURAL OR DIGITAL MEDIA STUDIES

• The interdisciplinary nature of visual, cultural and digital media studies means many subjects are beneficial if you want to pursue a career in these fields. "Studying English, history, art, photography or sociology at school or college would provide a good grounding in forms of human communication, as well as how society has been (re)shaped by communication throughout history," says Lauren.

• Many universities offer degrees in visual culture, digital media, media studies, art history, and language and communication. "Any of these would provide an excellent foundation for someone wishing to study and research visual culture or digital media practices as a career," says Lauren.

EXPLORE A CAREER IN VISUAL, CULTURAL OR DIGITAL MEDIA STUDIES

- With a degree in visual, cultural or digital media studies, you could be a photographer, graphic designer, journalist or art consultant. You could find yourself working in an advertising firm, for a publishing company, on a film set, as a social media manager or at a museum. Or you could become an academic like Elisa and Lauren.
- Elisa advises broadening your knowledge of visual culture by joining local clubs that teach activities such as photography, art or computing. She also suggests trying to find work experience in journalism, social media or communication agencies.
- Explore the resources from organisations such as the Association of Internet Researchers (**www.aoir.org**), the International Association for Media and Communication Research (**www.iamcr.org**) or the European Communication Research and Education Association (**www.ecrea.eu**) to learn more about the topics studied by visual, cultural and digital media researchers.
- Prospects has information about what you can do with a degree in media studies: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/media-studies**

ELISA AND LAUREN'S TOP TIPS

01 Have an intellectual curiosity and be attentive to the world around you.

02 Going abroad to study or work will broaden your horizons and heighten your ambitions.

03 Don't take everything you read or see at face value – think about the deeper meanings and agendas behind it. This will help you develop many important skills that will be useful as a researcher.

MEET DR ELISA SERAFINELLI

When I was younger, I enjoyed photography and painting. I was also interested in visual communication and the history of art. For my PhD, I explored how Instagram changed people's visual experiences and online social practices. As a result of this work, I published a book titled *Digital Life on Instagram* and wrote several academic journal articles. Publishing this book is one of the highlights of my career so far.

I am currently the co-director of the Digital Society Network at the University of Sheffield. We are a loose network of researchers within the Faculty of Social Sciences, examining all aspects of digital-society relations. We aim to stimulate and support research into our digital society.

My ambition is to become a leader in the field of visual mobile communication in the digital age. I hope to bring visual communication and cultural studies researchers into conversation with other fields, especially internet, digital and mobile media studies.

In my free time, I enjoy doing sports and outdoor activities. I also like travelling and baking, and I still retain my interest in photography and painting.

MEET DR LAUREN ALEX O'HAGAN

I have quite an eclectic research background! But all my projects have been grounded in visual culture and are concerned with the ways in which a particular visual artefact communicates ideas.

My PhD focused on Edwardian book inscriptions and what they reveal about social class in early 20th century Britain. After my PhD, I became interested in exploring broader Edwardian visual culture and its overlap with socio-political issues, so I turned my attention to propaganda postcards.

I was interested in how postcards were used to promote political messages to the public using a combination of words, images, colour and typography. I studied political postcards related to the women's suffrage movement and the Irish campaign for Home Rule. At the same time, I also developed an interest in Victorian and Edwardian food and drink advertisements and the ways in which science was used to promote certain products.

More recently, I have investigated rock memorabilia, particularly tour t-shirts and battle jackets (denim cut-offs with patches worn by heavy metal fans). Using a combination of visual analysis and interviews, I have explored how their designs enable fans to signal individual and collective identity.

My greatest career highlight to date was the opportunity to work as a visiting scholar at Örebro University in Sweden after finishing my PhD. I was invited there by Professor David Machin, a leading academic in my field whose work I greatly admire. I am thrilled to be returning to Örebro in 2022 to take up a postdoctoral researcher role, where I will continue my research on the use of science in early 20th century food and drink advertising, but this time in a Swedish context.

Music is my biggest passion – I play bass guitar, go to live gigs and run an Instagram fan page for my two favourite musicians. I also love reading, learning foreign languages, travelling, swimming and playing squash.

TACKLING MODERN SLAVERY: A SUSTAINABILITY ACCOUNTING PERSPECTIVE

UNETHICAL WORKING CONDITIONS ARE A MAJOR ISSUE IN MANY PARTS OF THE WORLD, AND WORKERS ARE OFTEN EXPLOITED BY RETAILERS IN WEALTHIER COUNTRIES TO MAXIMISE THEIR PROFITS. **PROFESSOR MUHAMMAD AZIZUL (AZIZ) ISLAM** AT **THE UNIVERSITY OF ABERDEEN** IN THE UK IS INVESTIGATING HOW SOCIETAL DEMAND FOR SUSTAINABILITY ACCOUNTABILITY AND TRANSPARENCY CAN HELP DRIVE THESE ORGANISATIONS TOWARDS ETHICAL PRACTICES

GLOSSARY

ACCOUNTING – recording and disclosures of financial and non-financial transactions of a business

ACCOUNTABILITY – the concept of organisations being held to account/responsible for their practices

CORPORATE SOCIAL RESPONSIBILITY (CSR) – the concept of a business acting responsibly (for example, towards its employees and the environment)

TRANSPARENCY – the sharing of information about a business so that it can be held accountable for how it is run

GDP (GROSS DOMESTIC PRODUCT) – a measure of the size and health of a country's economy

GLOBAL NORTH – a generalised term for wealthy, industrialised nations

GLOBAL SOUTH – a generalised term for poorer, less-developed nations

MODERN SLAVERY – the severe exploitation of people through abuse of vulnerability for personal and economic gains

NGO – a non-governmental organisation, typically a charity

POLICY – a set of guidelines or rules, used by governments and businesses

READY-MADE GARMENT (RMG) – clothes that are mass-produced and sold on the high street

SUPPLY CHAIN – all the actors involved in the production, distribution and sale of a product

TRACEABILITY – the ability to be able to follow and scrutinise every point along a supply chain

Despite slavery now being universally condemned, there are more enslaved people today than in any other point throughout history. "Modern slavery in the form of forced labour, child labour and human trafficking is pervasive around the world," says Professor Muhammad Azizul Islam (Aziz) of the University of Aberdeen. "It is especially bad in nations in the global south such as Bangladesh, India, Pakistan, Myanmar and China."

Aziz's latest research project focuses on the ready-made garment (RMG) production industry in Bangladesh. This industry supplies clothing and fashion products to multinational companies across the global north – retailers that you are very likely to have heard of, and even bought from. "These RMG companies have moved their production locations to the global south to minimise production costs," says Aziz. "The reason that labour costs are so much cheaper is because of slavery and exploitation." Which begs several questions: As buyers, are we benefitting from unethical practices? Are we buying cheaper products at the expense of the workers who make them? How can we hold parties involved accountable? The garment industry is massively important for Bangladesh's economy, accounting for 80% of its export earnings and about 20% of GDP. It is a big industry, but is it one that we can – and should – influence with our purchasing power?

COVID-19 AND GENDER INEQUALITIES

Alongside Professor Pamela Abbott and Dr Shamima Haque, Aziz has run a project investigating how the COVID-19 pandemic has affected Bangladeshi workers, especially women, and is using their insights to develop policy recommendations. "Lockdowns and decreased demand led to the cancellations of orders by retailers, which in turn led to garment factory closures and job losses, leaving around 2.8 million Bangladeshi workers facing poverty and hunger," says Aziz. "In factories that remained open, workers were forced to work in unsafe conditions where they were vulnerable to catching the COVID-19 virus and passing it on to their families."

The project team has found that women were especially impacted by these effects. "Financial pressures on women were exacerbated given many of their husbands could not find work due to a lack of demand in the informal sector, where they were typically employed," says Aziz. "Our research has found that when the factories closed for the lockdown the contracts of pregnant women were terminated", adds Pamela. Once lockdown ended, employers focused on hiring young women to replace those made redundant, as they tend to be considered more loyal than male workers and can be pushed to work harder than older women. "Our findings show that COVID-19 has widened the already existing gender inequality, and that there is limited protection available for women workers in the Bangladeshi garments sector," says Shamima.

RESEARCH AND KEY FINDINGS

The research team investigated this issue through interviews, case studies, a survey, and an analysis of the legal protections in place for women workers in the garment industry. Interviewees were varied, including workers, factory owners, trade union representatives, advocacy NGOs and government officials. The survey focused on social compliance auditors, asking them how much they included gender equality issues within their audits, to get a sense of how Bangladesh is enacting its international commitments to tackle modern slavery and unethical working conditions.

The team found that disruption through lockdowns and buyers demanding lower prices amplified existing vulnerabilities, such as economic insecurity, job insecurity and negligence of employment rights, health and wellbeing, and sexual harassment and violence. Even when legal frameworks were in place to protect workers, they were frequently disregarded by factory owners and management. Buyers tended to be more concerned about health and safety than worker welfare and exploitation, and many social compliance auditors did not examine gender equality.

RECOMMENDATIONS AND RESPONSIBILITIES

These unethical conditions are allowed to persist through the actions (or inaction) of every stage of the supply chain – from factory owners, to regulators, to retailers, and even consumers. The research team recommends the Bangladesh Government reviews its protections and rights for workers, and that importing nations such as the UK use political tools to encourage Bangladesh to respect and enforce its international commitments. The team also recommends that retailers emphasise respect for workers' rights, and consider insisting on independent social audits, ensuring there is no forced or unethical labour practices in their sourcing. Government policy can help enforce this, with stronger legal measures and an independent 'watchdog' body.

There is also a role for consumers. "Young people, who are the main consumers of fast fashion, have a role in holding retailers accountable," says Aziz. "We hope our research will help inform consumers, such as students, about the unethical conditions behind some of their clothing choices, and influence their purchasing decisions."

IMPACTS AND NEXT STEPS

There is already a strong movement encouraging socially responsible consumption, and Aziz believes his team's research reinforces the importance of this. The research contributes to the campaigns of NGOs who are calling for independent fashion watchdogs in nations such as the UK to hold retailers accountable for enabling exploitation. "We are also partnering with Traidcraft Exchange, UK's major NGO fighting injustice in global trade, to make a lasting impact on global policy and elimination of slavery in global trade", says Aziz. The team has developed a policy brief that helps inform policymakers about its key findings and puts forwards its recommendations for positive change.

"For the full picture of how the pandemic exacerbated slavery and exploitation, further research is needed to investigate the impact of retailers' behaviour during that time – including cancellations of orders, increased production pressures, and demand for lower prices from suppliers," says Pamela. The team also believes that factories may have outsourced work to more informal and less-regulated suppliers during the pandemic. "The limited academic research into these suppliers suggests they may use forced labour," says Shamima. "There is a need to look into the traceability and transparency of the whole supply chain, to ensure that forced labour is spotted and eliminated," says Aziz.

RESEARCH PROJECT

Developing post-COVID gender policy measures to end modern slavery and exploitation in the Bangladeshi garment sector

FUNDERS

Arts and Humanities Research Council (UKRI/AHRC), The UK Modern Slavery PEC

NON-ACADEMIC PROJECT PARTNER

Traidcraft Exchange

PROJECT TEAM

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FIELD OF RESEARCH: Sustainability Accounting and Corporate Transparency

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FIELD OF RESEARCH: Gender, Feminism, and Development Studies

DR SHAMIMA HAQUE
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FIELD OF RESEARCH: Carbon (Climate Change) Accounting and Disclosure, Business and Human Rights, and Gender

ABOUT SUSTAINABILITY ACCOUNTING

"Throughout my research career, I have thought carefully about who within an organisation contributes to slavery and exploitation," says Aziz. For instance, retail CEOs may look for strategic locations for sourcing products with low-production costs, which may mean human rights are neglected. Similarly, accountants are typically tasked with minimising costs and maximising profits, without much consideration of human rights. "I find these roles, and the way topics such as accountancy are taught in schools and universities, to be flawed as they don't incorporate the importance of human rights and morality into these transactions," he says.

Emphasising that profit should be earned responsibly and not at the expense of people, planet and future generations, sustainability accounting creates a new space for the existing accounting profession.

"My research helps my students understand alternative and critical narratives on profit maximisation and cost minimisation," Aziz explains. "During my early career, it was challenging to integrate these ethical ideas into mainstream accounting, but, over time, widespread stakeholder concerns have led to a growing number of business schools' research realising the importance of incorporating these factors." Despite progress, curriculum development remains limited, and Aziz believes that teaching students – future accountants and CEOs – about how to include human rights within their decision-making is key to a brighter and more responsible future.

A career in this field is about facilitating positive change and making a difference. "I love to share what I learn from my research, especially lessons that challenge the status quo," says Aziz. "I teach my students how accountants are responsible for curbing slavery and emphasise the need to change irresponsible business practices."

"Sustainability accounting is still in its infancy," says Aziz. "However, it is a subject with the power to change the mainstream ideology." He believes that demand for accountants with knowledge of social responsibility (for people and the planet) will increase markedly in the future. This change is already happening, with global leaders and stakeholders showing greater interest in issues such as human rights and climate change.

EXPLORE A CAREER IN SUSTAINABILITY ACCOUNTING

- In addition to open days and career fairs, the University of Aberdeen, where Aziz works, offers campus visits: **www.abdn.ac.uk/study/campus-visit.php**
- The Centre for Social and Environmental Accounting Research (CSEAR) at St Andrews University has plenty of information on research into sustainability accounting and runs events and site visits: **www.st-andrews.ac.uk/csear/**
- Social Value UK is the professional body for social value and impact management, of which sustainability accounting is a part. Find out more: **socialvalueuk.org/about-social-value-uk**
- This article from Accounting Careers provides advice on incorporating sustainability into accounting practices: **www.accountancycareers.co.uk/profession-overview/accounting-and-sustainability/**
- This article, *Tackling Modern Slavery: What Role Can Accountants Play?*, from the International Federation of Accountants (IFAC) highlights the role of accountants and auditors in tackling modern slavery:

  www.ifac.org/knowledge-gateway/supporting-international-standards/discussion/tackling-modern-slavery-what-role-can-accountants-play
- This article from *Journal of Business Ethics* provides critical understanding of a modern slavery act (The UK Modern Slavery Act). 'Modern Slavery Disclosure Regulation and Global Supply Chains: Insights from Stakeholder Narratives on the UK Modern Slavery Act':

  link.springer.com/content/pdf/10.1007/s10551-021-04878-1.pdf

PATHWAY FROM SCHOOL TO SUSTAINABILITY ACCOUNTING

As Aziz highlights, sustainability accounting is an emerging field and is not specifically offered by most universities. Undergraduate courses in traditional accountancy, finance or management may offer modules in sustainability accounting or provide a route to more specialised qualifications such as a master's degree. Useful subjects to study for these degrees include mathematics, statistics, economics, finance, law and business studies. For a good knowledge of social and ethical responsibilities, subjects such as sociology, politics, law, English, history and geography can be useful.

TOP TIPS

01 Do something that makes a positive difference to society. This will involve obstacles and failures, but stick to your goal and you will succeed.

02 Success lies in motivation, determination, hard work and study.

03 Strong academic qualifications are important for a career in academia.

MEET THE TEAM

PROFESSOR MUHAMMAD AZIZUL ISLAM

I grew up in Dhaka, the capital of Bangladesh. The area was surrounded by garment factories supplying far-away companies, and I used to see hundreds of workers entering and leaving every day. When I studied accounting at Dhaka University during the 1990s, I found my education in profit maximisation contradicted my daily exposure to workers' livelihoods, which led me to realise that accounting avoids engaging with underprivileged workers, despite their importance in financial gains for the company. I realised the flaws in not only our accounting systems, but entire business school curriculums, when it came to human rights. This inspired me to pursue research that could challenge these mainstream education practices.

I am motivated by my passion for research. Being a successful researcher often involves challenging the existing knowledge base, which brings its own challenges. For example, corporate social responsibility (CSR) is often profit-driven – that is, a business runs CSR activities or maintains human rights in the workplace because it leads to more profit. This implies if you do not profit, you do not need to be socially responsible. I find such thinking flawed because it suggests you do not need to be moral or humane when you are not making profit. Sustainability accounting provides this critical perspective.

Having grown up in an underprivileged community, it has been a rewarding journey to ultimately become a university professor. My mother taught primary school students and often struggled to support our livelihoods on a limited salary, but still taught me the importance of discipline and inspired me to strive for better. Throughout my career, I have strived to make a difference. I was delighted to secure my professorship only eight years after completing my PhD.

I dream of finding a responsible profit mechanism for businesses and accounting bodies. This involves changing mainstream thought about the role of accounting and profit maximisation. I strongly believe that human rights must not be sacrificed for profitability.

PROFESSOR PAMELA ABBOTT

I am a co-investigator on the project and the expert on gender, health well-being and quality of life and socioeconomic development and transformations.

I have over 20 years' experience of researching in the Global South, and have also carried out research in Rwanda, the former Soviet Union, East Africa, North Africa and the Middle East.

My main motivation is curiosity. I find my work both challenging and rewarding, and gain new knowledge every day. One challenge is gaining an understanding of the context in which the people who participate in my research live their everyday lives.

Despite some progress towards gender equality in the Global North, little progress has been made in many countries in the Global South. Women remain responsible for most unpaid care work even alongside paid employment, and sexual harassment and violence remain part of the everyday experience for many women. On average, women are paid less than men, even when doing work of equal value that involves the same level of skill and knowledge.

COVID-19 has widened the gap between the 'haves' and the 'have nots'. It has exacerbated existing inequalities, such as race and ethnicity, disability, age, gender, and those between the Global North and Global South. It has resulted in a reduction in people's quality of life and well-being, with many countries, especially in the Global South, struggling to offer their citizens support during this time of crisis.

DR SHAMIMA HAQUE

I am a co-investigator of the project. I am an expert in exploring different corporate accountability practices by using qualitative research methods, such as surveys and interviews.

My main research interests are in corporate sustainability accounting and reporting practices. This includes a focus on carbon accounting, human rights and labour rights. I am also interested in research into gender, which stems from my experience as the research lead of the Aberdeen Business School's Athena SWAN committee, which recognises the career progression and personal development of women in STEM.

I believe in accountability and transparency. This is important to me on a personal level – being accountable to society, my organisation, the people around me and to myself. This motivates my research into organisations' accountability practices and their responsibilities to wider stakeholder groups and society.

I teach a course on corporate governance and ethics. I aim to teach students that, as a rational decision-maker, they can choose to make their own profit, but as a human being they are accountable to wider society. The next generation of researchers should explore the role of ethical practices within organisations, to shape good governance and sustainability practices and make ethical behaviour a more mainstream part of corporate behaviour.

HOW SUSTAINABLE IS YOUR FOOD?

MODERN FOOD PRODUCTION AND TRADE HAVE COUNTLESS IMPACTS ON THE ENVIRONMENT. SUSTAINABLE FOOD SYSTEMS ARE THEREFORE INDISPENSABLE FOR FUTURE FOOD SECURITY, BUT HOW CAN WE ASSESS THE ENVIRONMENTAL SUSTAINABILITY OF FOOD? **DR CAROLE DALIN**, A SUSTAINABILITY RESEARCHER AT **UNIVERSITY COLLEGE LONDON** IN THE UK, IS DEVELOPING INTEGRATED ENVIRONMENTAL INDICATORS TO TRACK PROGRESS TOWARDS SUSTAINABLE AGRICULTURE

TALK LIKE A SUSTAINABLE FOOD SYSTEMS RESEARCHER

BIODIVERSITY – the variety of species in an environment, comprising all forms of life including plants, animals, fungi and bacteria

CASH CROP – an agricultural crop grown to sell for profit

FOOD SECURITY – the availability of sufficient food for the whole of the world's population

FOOD SYSTEM – all activities and infrastructure involved in producing food for a population, including planting, growing, harvesting, livestock rearing, processing, packaging, transportation, marketing, distribution, consumption and disposal

GREENHOUSE GAS – an atmospheric gas that absorbs and re-emits thermal infrared radiation, insulating the Earth so causing the planet to warm up. Important greenhouse gases emitted by human activities include carbon dioxide, methane and nitrous oxide

MONOCULTURE – the cultivation of a single crop

SUSTAINABILITY – using resources without depleting them so that future users can continue to benefit from them

Agriculture is essential. Without farms and farmers, we would have no food to eat. And yet the way we grow crops and raise animals has a huge impact on the environment, as does the process of transporting food from the farm to your plate. Not only that, but global population growth means that the world will have to produce even more food in the future.

"If current diets remain, it is projected that food production will need to almost double by 2050," says Dr Carole Dalin, Associate Professor in the Institute for Sustainable Resources at University College London. "If current agricultural practices also remain, this could lead to catastrophic consequences for water resources, climate change and biodiversity."

Moving towards sustainable agriculture is therefore essential to ensuring that everyone has enough food to eat in the future, while also ensuring everyone has access to water, fighting against climate change, and protecting against biodiversity loss. To help achieve this, Carole is developing indicators that measure how environmentally friendly agricultural activities and products really are. Her work makes it possible to track our progress towards sustainable agriculture and make better choices in our food production and consumption.

HOW DOES AGRICULTURE AFFECT THE ENVIRONMENT?

Agriculture requires vast quantities of water to grow crops and raise livestock. Globally, 70% of the water we extract from the environment is used to irrigate crops and 90% of all the water we consume is used for agriculture. This overuse of water is drying up rivers and depleting underground water reserves in many parts of the world.

Agricultural practices also pollute water sources and reduce air quality. Chemical fertilisers, pesticides and herbicides are added to crops to increase productivity and decrease pests and weeds, and these are washed into rivers. Livestock produce vast quantities of manure which also contributes to water and air pollution.

Greenhouse gases emitted by agricultural practices are significant contributors to climate change. Nitrous oxide, a potent greenhouse gas, is a by-product of fertilisers, and agriculture accounts for over 50% of human-induced nitrous oxide emissions. Cattle produce huge amounts of methane, another powerful greenhouse gas, and are responsible for over 40% of human-induced methane emissions. It will be difficult, if not impossible, to reduce greenhouse gas emissions from agriculture to zero.

Agriculture is also reducing global biodiversity, not only through the use of pesticides and herbicides, which kill insects and plants, but also

due to the clearance of land to create space for farming. About 40% of the world's ice-free land is pasture and cropland. Humans occupy so much land that habitats for wild species have shrunk and the numbers both of individual animals and of existing species have declined steeply in recent decades. As all species in an ecosystem are interconnected through complex relationships, biodiversity loss is dangerous; the reduction of just a few species may lead to the collapse of a whole ecosystem.

The global trade of food also has an impact on its sustainability, as 10-20% of food is exported from where it is produced to other countries. Some foods, such as tropical fruits, coffee and cocoa, are grown in only a few regions and are then shipped around the world, resulting in greenhouse gas emissions from transportation. Food trade provides economic opportunities in many developing countries, but often at the detriment of local ecosystems. Huge swathes of rainforests are cut down every day in southeast Asia to grow palm oil and in the Amazon to grow soybean and raise cattle. This intensive cultivation of cash crops not only destroys the original ecosystems but results in monocultures with very low biodiversity.

The industrialised, out-of-sight production and trade of food often keeps consumers in the dark about the environmental consequences of how the food on their plates has arrived there.

QUANTIFYING THE ENVIRONMENTAL IMPACT OF FOOD PRODUCTION

Carole's research project, Developing Integrated Environmental Indicators for Sustainable Global Food Production and Trade (FOODIES), is about developing indicators that distil multiple pieces of information into one metric to measure the environmental impact of an agricultural activity. "Sustainability is about whether future users will be able to continue to obtain the same benefits," Carole explains. "To determine environmental sustainability, we look at whether different agricultural activities use more resources than are naturally renewed and whether the systems supporting the agriculture (climate and biodiversity) are negatively affected."

Carole and her team use satellite data to identify regions of cropland and irrigation. They use data from national surveys, such as reported quantities of crop production or fertiliser use, to assess the agricultural productivity of different areas. And they examine accounts of imports and exports to determine the nature of global agricultural trade. They then combine these data and use models of environmental processes to establish the sustainability of different agricultural practices, products and regions. "We have selected four key environmental pressures from agriculture – water use, greenhouse gas emissions, fertiliser use and land use," explains Carole. "I have developed sustainability indicators for each, and we are now working on integrating these into a composite indicator, to compare the sustainability 'performance' across different regions and products." These sustainability indicators developed by the FOODIES project will make it possible to quantify how sustainable food systems are and track our progress as we try to make them more environmentally friendly.

SUSTAINABLE AGRICULTURAL PRACTICES

Many changes need to be implemented to improve the sustainability of agriculture. Increased agricultural efficiency will mean fewer resources are needed to produce the same outputs. Chemical fertiliser use can be reduced by testing soil nutrient levels and only applying fertilisers in calculated amounts, thereby reducing nitrous oxide emissions. Agroforestry (growing trees together with agricultural crops) fights climate change by sequestering carbon in the trees and boosts biodiversity by providing habitats for tree-living species. And cultivating crops that are more suitable for local soils and climates will help to save water and support biodiversity.

Carole's research teases out the impact of each of these reforms. "We build models of food systems covering key relationships (physical and socio-economic) and then use these models to test the impact of a scenario where one or more changes are implemented," she says. Carole's models and sustainability indicators allow quantitative comparisons of different potential future food systems to be conducted.

WHAT CAN WE DO AS INDIVIDUALS?

Carole's research is immensely practical and impactful. Her results can help government policy-makers, farmers and consumers make better decisions about producing and buying food. "I hope my research identifies priority targets, helps design sustainable diets, highlights that both the location and the method of producing food matter (local food is not always more sustainable!) and encourages coordination between trade partners to ensure sustainability," she says.

But individuals also have a role to play in ensuring that food production is sustainable. The attitudes and practices of both food producers and consumers will have to change if we want to avoid climate catastrophe and biodiversity collapse and still feed the people of the future. Methane emissions from livestock would be reduced if we cut down our consumption of milk and red meat, in favour of plant-based proteins. Oat milk is generally the most environmentally friendly vegan milk because almond milk is very water-intensive and soy milk is linked to deforestation. The majority of global crops are grown to feed animals rather than humans, so switching to a plant-based diet will also mean that agricultural land is used more efficiently. As so many resources are used to produce food, avoid food waste. Food in landfill produces greenhouse gas emissions, so if you must dispose of food, compost it if you can. Try to buy food that is not packed in plastic and recycle all packaging waste if possible. To reduce the emissions associated with transportation, try to buy local produce rather than food from the other side of the world. But remember that the method of production also has an impact, and locally produced food is not always better for the environment!

Stay hopeful – we can all contribute to a sustainable future, where enough food is produced for everyone while still conserving the environment.

DR CAROLE DALIN

Associate Professor, Institute for Sustainable Resources, University College London, UK

FIELD OF RESEARCH

Sustainable Food Systems

RESEARCH PROJECT

Developing integrated indicators to measure the environmental impact of food production activities, products and regions

FUNDER

Natural Environmental Research Council (NERC grant NE/N01524X/1)

ABOUT SUSTAINABLE FOOD SYSTEMS

A sustainable food system delivers food security for everyone in such a way that the economic, social and environmental systems required to generate this food security are not compromised for future generations. It is not enough to simply provide sufficient food – it must also be economically sustainable (profitable), socially beneficial and have a positive (or at least neutral) impact on the environment.

Sustainable food systems are key to the health of humans, animals and the planet. But it is far from obvious how to make our food more sustainable. Sometimes there are trade-offs between two sustainability objectives. For example, increasing land-use efficiency (producing more crops on the same amount of land) means less land needs to be cleared for agriculture. But this often requires more water and fertiliser use, contributing to water scarcity and atmospheric or water pollution from fertilisers. Careful and detailed research is needed to determine the most sustainable course of action.

PATHWAY FROM SCHOOL TO SUSTAINABLE FOOD SYSTEMS RESEARCH

• Sustainable food systems is an interdisciplinary subject, so it can be approached from many different directions. Human and/or physical geography, economics, biology, ecology and statistics/data science will all provide a good foundation for specialising in sustainable food systems.

• Many universities around the world offer master's degrees in sustainable food systems or food security. To become an academic researcher like Carole, you will often need to complete a PhD, for example through the UK Food Systems Centre for Doctoral Training (**www.foodsystems-cdt.ac.uk**).

EXPLORE A CAREER IN SUSTAINABLE FOOD SYSTEMS

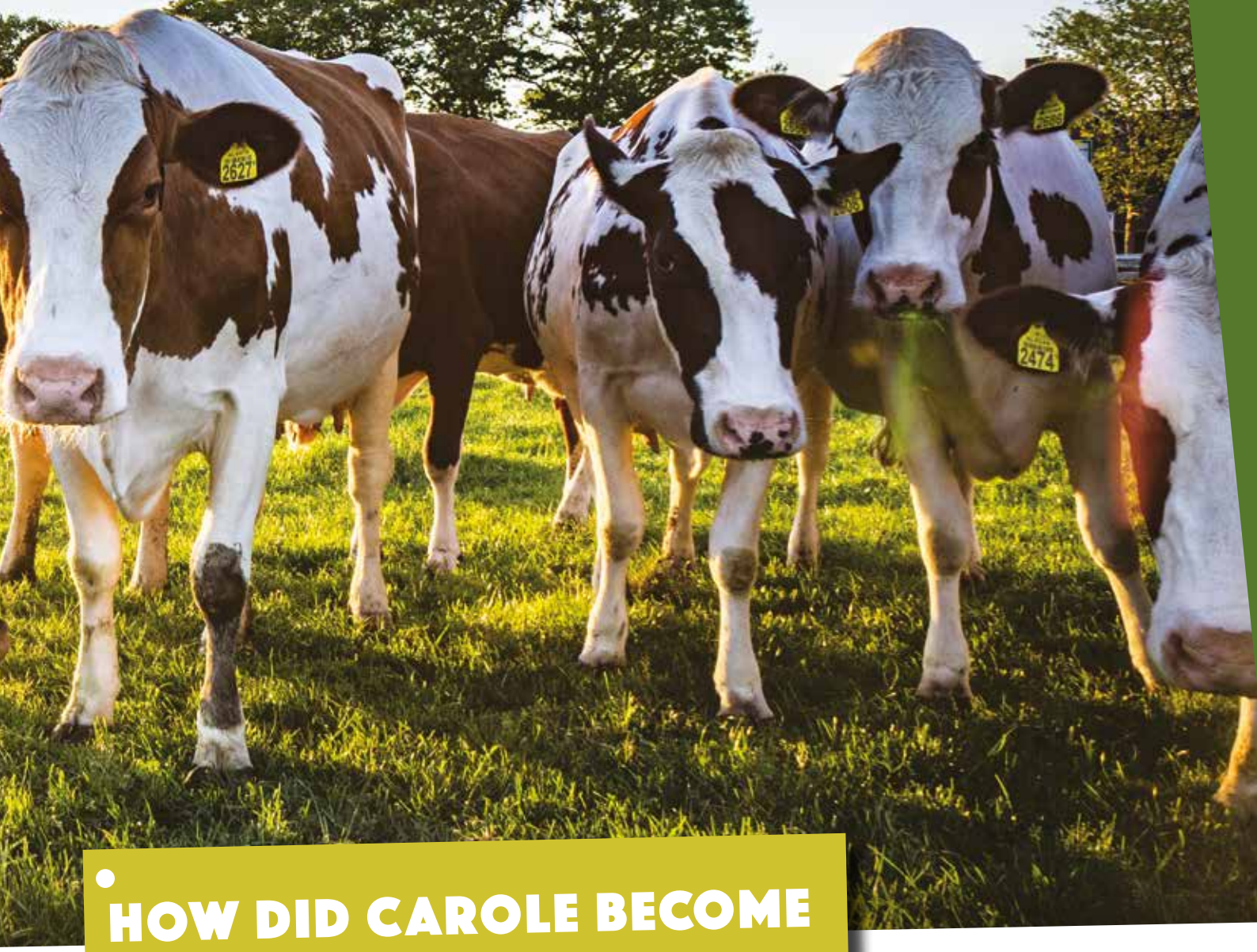
- With knowledge of sustainable food systems, you could become an academic researcher like Carole. Or you could work in agriculture, governmental policy, consulting, non-governmental organisations, the food trade industry...
- The Food and Agriculture Organization of the United Nations (**www.fao.org/home/en**) aims to irradicate global hunger and ensure that the world's population will have sufficient access to food in the future. The FAO works in over 130 countries around the world, and to achieve these goals they need people who are passionate about sustainable food security to conduct research and develop national and international policies.
- As a sustainability consultant, you could help food and agricultural businesses adjust their processes to become more environmentally friendly, or you could provide advice to government agencies to help develop sustainable agricultural or food trade policies.
- The Sustainable Food Trust (**www.sustainablefoodtrust.org**) offers internships and volunteering opportunities for those who want to experience sustainable food-related research, policy or communication work.
- Evironmentjob (**www.environmentjob.co.uk/volunteering**) lists environment-related volunteering opportunities and training courses available in the UK.

CAROLE'S TOP TIPS

01 Find a topic that inspires you!

02 It is normal to feel like your contribution to huge global challenges is small, but remember that every pair of hands helps!

03 Don't be afraid to adjust your career choices.



HOW DID CAROLE BECOME A SUSTAINABLE FOOD SYSTEMS RESEARCHER?

AS THE LEADER OF THE FOODIES PROJECT, ARE YOU A 'FOODIE' PERSON YOURSELF?

Yes! I choose this acronym because it names the main theme: food, but the "FOODIES" acronym is also a sort of joking reference to myself, as leader of the project. I love making recipes and trying different foods at restaurants, too. I discovered vegetarian food during my PhD from my Indian roommates – eating less meat is much better for sustainability. But I am from France, so I still probably eat too much cheese than what is recommended for health and the environment – old habits die hard!

WHAT MOTIVATED YOU TO STUDY SUSTAINABLE FOOD SYSTEMS?

I have always been interested in human lives, and in how they depend on – and interact with – the natural environment. I first focused on climate change and energy after high school, but was then drawn to the issue of water resources. Studying water use, I discovered that agriculture is by far the most water-intensive activity, and this is how I ended up studying sustainable food.

WHAT HAVE YOU MOST ENJOYED ABOUT YOUR CAREER SO FAR?

After my undergraduate degree in France, I had the opportunity to study abroad in the USA for a master's degree in environmental engineering and water resources. I stayed on for a PhD, and then continued working abroad, moving to the UK. I have met so many different people with their own cultures, interests and insights. This has brought huge benefits to both my professional career and my personal life.

WHAT PERSONAL QUALITIES HAVE MADE YOU SUCCESSFUL AS A RESEARCHER?

Curiosity to find the truth – I like to search for the evidence behind a statement. Also, the ability to tease out the key elements in a complex picture helped me a lot. Being able to write well and concisely are also key skills for researchers.

HOW DO YOU SWITCH OFF FROM WORK?

I try to stop work at a given time each day. Once I have finished, I avoid reading emails on my phone. Instead, I go outside, exercise, turn music on… or I cook!

WHAT FACT SHOULD EVERYONE KNOW ABOUT SUSTAINABLE FOOD SYSTEMS?

Food production alone accounts for about a third of the ecological impact of all our activities – we can all make a big difference by making small changes in our food habits.

DOES SCIENCE HAVE ALL THE ANSWERS?

DR SIOBHAN MADERSON, FROM **ABERYSTWYTH UNIVERSITY**, UK, HAS BEEN INVESTIGATING HOW TRADITIONAL ENVIRONMENTAL KNOWLEDGE IS OFTEN OVERLOOKED BY SCIENTISTS AND POLITICIANS. HER RESEARCH INTO THE KNOWLEDGE OF BEEKEEPERS COULD HELP PUT SUSTAINABLE, NATURE-FRIENDLY FOOD ON OUR PLATES

TALK LIKE A HUMAN GEOGRAPHER

TRADITIONAL ENVIRONMENTAL KNOWLEDGE (TEK) – knowledge about the environment and environmental practices handed down through generations

INDIGENOUS PEOPLES – people native to a place that has been colonised by another ethnic group. Indigenous peoples retain a distinct culture and way of life, which is often threatened by colonial occupiers

COLONIALISM – where a country takes political or economic control over another area and its inhabitants, in order to settle people there or exploit its resources

PARTICIPANT OBSERVATION – a research method whereby the researcher watches someone do an activity, or takes part in it themselves

You might have heard talk about bees being in trouble and what this could mean for our food supply. But are we really going to starve if we lose bees? "No," says Dr Siobhan Maderson, a post-doctoral researcher at Aberystwyth University. "We would just have a very boring diet." Siobhan has been taking her bee questions not to scientists, but to people who have been living alongside these amazing little insects for generations. These people are beekeepers, and their unique insights into the life of bees are a great example of traditional environmental knowledge.

WHAT IS TRADITIONAL ENVIRONMENTAL KNOWLEDGE?

There are three things that define traditional environmental knowledge (TEK): who teaches it to you, how you learn it, and what you do with it. Firstly, TEK is intergenerational. It is passed to you from older people in your community. Secondly, learning TEK is not about reading a textbook, but a process of learning by doing, like herding reindeer, fishing for salmon or cultivating the land, through which you understand new things about living beings and their relationships with the environment. Finally, TEK is not a fact you memorise for an exam and then forget about, but something you put into practice, develop over your lifetime and pass on to others. TEK often has a strong ethical dimension – you use what you know to help your community, including both humans and other living beings.

WHO HOLDS TEK?

Anybody can hold TEK, but communities who farm, hunt and fish tend to have the richest reserves. Herders know exactly when pastures are ready for grazing, farmers can tell which crops will survive in different types of soil, and fishing communities can locate shoals of fish in a vast tract of ocean.

Indigenous peoples often live directly from the land, giving them a deep connection with their environment. "Their environmental knowledge (also known as indigenous knowledge, or IK) is usually combined with strong ethical values and distinct cultural identity, often including a religious or cosmological sense of connection to the wider physical environment," says Siobhan.

And TEK can also be found in towns and cities. "If your family have lived in the same locality for three generations, your grandparents might talk about how their laundry gets dirty when

they hang it on the line, which didn't happen when they were younger," says Siobhan. From their TEK (also known as local environmental knowledge, or LEK), they know that air pollution has increased, and they may wonder if there is a link with increases in asthma in the community.

WHY IS TEK OFTEN NOT RESPECTED?

Scientists have a set idea of how knowledge is produced, and often disregard anything that is not the result of objective experiments. They look for repeatability, clearly defined aims and rigorous statistics. In contrast, it is hard to trace exactly where TEK comes from and it is not repeatable in an experimental setting. Therefore, scientists often consider TEK to be unreliable and subject to bias.

Furthermore, the communities who use TEK in their daily lives tend not to have a lot of political power. Colonialism supresses many of the communities that hold TEK around the globe. They often suffer racism and live in areas exploited by extractive industries, leaving them in poverty and their voices unheard.

Science has become the mainstream way of understanding, discussing and managing the world. This has led to an expectation that politics should be led by scientific knowledge and leaves little room for TEK to influence decisions.

WHY IS IT IMPORTANT TO COMBINE TEK WITH SCIENTIFIC DATA?

"Both TEK and scientific data have their benefits for helping us understand our environment," explains Siobhan. "TEK can bring temporal richness that is often missing from scientific experiments." Scientific methods struggle with some environmental questions. Long-term experiments are difficult to fund and manage, meaning that scientists rarely have data covering more than a five-year timespan. TEK can fill this gap, as it is built from decades or centuries of people interacting with their environment.

Communities that hold TEK understand their environment in ways which embody sustainable values and emphasise the importance of responsible relationships between all living beings. Policymakers tasked with managing the environment can learn from their knowledge and sustainable practices. It will be crucial to properly value TEK if we are to meet global challenges such as climate change, biodiversity loss, soil degradation and food security.

WHAT TEK DO BEEKEEPERS HOLD?

Many of the beekeepers Siobhan interviewed learnt how to keep bees from their parents or grandparents, meaning the families have an intimate understanding of their local environment. They notice how the timing of the seasons and weather patterns have changed over the decades, affecting both the bees and whole ecosystems. They have seen how changes in land management, such as removal of orchards and the industrialisation of agriculture, have negatively influenced bee health and well-being. Beekeepers constantly update their TEK as they observe these environmental changes and incorporate wider knowledge from biology and botany.

HOW CAN WE LEARN FROM THE TEK OF BEEKEEPERS?

As well as conducting interviews, Siobhan investigates beekeeper TEK by participant observation and archival research. "Archives are amazing! I love them!" she says. By searching through old logbooks and journals kept by beekeepers, she can rediscover knowledge and forgotten stories. Archives reveal detailed descriptions of daily weather, the dates on which different plant species began to flower and records of bee health. Combining this with other environmental data provides insights into how bees are affected by climate change and changes in farming practices.

Archives have also shown how beekeepers have used their TEK in the past, for example to campaign against the use of chemicals that are dangerous to insects. "This gives a rich picture of how beekeepers have worked with scientists and policymakers in the past," explains Siobhan. "Understanding this is important if we want to use their knowledge effectively, now and in the future."

CAN TEK HELP US EAT SUSTAINABLY?

Current methods of intensive agriculture leave little room for nature. Large fields of a single crop mean a lack of biodiversity and, as a result, many species of insect are in decline. Siobhan thinks that TEK could hold the key to protecting biodiversity while still producing enough food. Utilising the environmental knowledge held by beekeepers, farmers and other communities around the globe can help us develop more sustainable land use practices. "I'm interested in how people can effectively work together for a better food system that has fewer negative impacts on the environment," she says. "I hope my research can contribute to better land management, for the sake of all living creatures, and the wider environment we all share."

DR SIOBHAN MADERSON

Post-Doctoral Researcher, Aberystwyth University, UK

FIELD OF RESEARCH

Human Geography

RESEARCH PROJECT

Investigating how we can use traditional environmental knowledge to help make agriculture more sustainable

FUNDER

Economic and Social Research Council (ESRC)

ABOUT HUMAN GEOGRAPHY

Where are humans located around the globe? How do they organise themselves? How do they interact with their environment? These are the broad questions that human geographers tackle, and the answers lie where culture, economics and politics intersect with the physical world.

WHY IS INTERDISCIPLINARITY SO IMPORTANT?

"There is a growing recognition of the importance of interdisciplinary research to solve 21st century challenges," says Siobhan, who considers herself to be an 'interdisciplinary researcher'. "Geography is the study of our world," she says, "of people, rivers, volcanoes, oceans, ecosystems, economics, and so much more. And all of it is interrelated." This means geography relies on knowledge from many other disciplines to discover and understand these links. While Siobhan's research primarily lies in the field of human geography, it also relates to many other topics, and she has worked with botanists, soil scientists, ecologists, entomologists, veterinarians, geneticists and international politics researchers. "I love learning about multiple fields," she says. "Human geography, physical geography, land use, biology - all of these, and more, connect with human geography."

WHAT ARE THE NEXT BIG CHALLENGES FOR GEOGRAPHERS?

"We are living in a time of many enormous challenges," says Siobhan, "such as climate change and biodiversity loss. Geography offers many opportunities to tackle these challenges." Human geographers will have an important role to play in understanding the social, economic and political forces that are driving these problems and in finding solutions to them. It may be a daunting prospect, and stressful at times, but these geographers will be empowered by the knowledge that they are working for the greater good.

EXPLORE A CAREER IN GEOGRAPHY

- The Geographical Association has advice on work experience, volunteer opportunities and career prospects: **www.geography.org.uk/Jobs-and-careers-in-geography**
- The Royal Geographical Society has lots of information on why you might choose to study geography: **www.rgs.org/geography/choose-geography/careers**
- Watch this TEDx talk called 'The Power of Geography to Make a Sustainable Future' by Lisa Benton-Short: **www.youtube.com/watch?v=C6b3pQ8Tox0**

SIOBHAN'S TOP TIPS

01 Don't worry about how your career will unfold, and don't worry about making mistakes. One step leads to another.

02 Follow your interests, do the right thing by your family and community, and things will fall into place as you go along.

03 Talk to people with lots of different interests. You never know who you'll end up working with one day!

PATHWAY FROM SCHOOL TO GEOGRAPHY

- As an interdisciplinary field, most subjects at school will help prepare you for a geography degree at university. A geography degree may cover both human and physical geography, or you may be able to choose which branch to study.
- If you are interested in human geography, subjects such as geography, history, economics, English and philosophy will be useful. If you are interested in physical geography, then geography, maths, biology and physics will provide a good foundation.
- Alternatively, you might transition to human geography from a degree in another field, such as anthropology, politics or sociology. For these degrees, study English and humanities subjects at school.

GEOGRAPHY AT ABERYSTWYTH UNIVERSITY

- Aberystwyth University's Department of Geography and Earth Sciences offers a range of geography degree schemes, all taught by world experts who are happy to help you whenever you need it.
- Whether you are interested in studying human geography or physical geography, Aberystwyth provides unique opportunities to study geography in a magnificent setting. You also have the option to explore both branches in more depth, by taking a range of modules in human and physical geography, before deciding which you want to specialise in. "We often find that students' final decision is different from what they had originally thought they would do when in school," says Siobhan.
- Find out about the different geography degrees and courses offered by the Department of Geography and Earth Sciences at Aberystwyth University at **www.aber.ac.uk/en/dges**.

HOW DID SIOBHAN BECOME A HUMAN GEOGRAPHER?

I've always been a fanatical reader. I'd read anything and everything – novels, sci-fi, history, natural sciences, comic books, humour. And I've always loved animals. When I was a kid, I wanted to be a veterinarian, or work with dolphins at an aquarium.

I've always been interested in food and the environment – my mum was a chef, and my first job was baking for her. She got me interested in how food was produced, and what environmental issues were affecting our food supplies.

After completing a BSc in Social Anthropology, I spent 24 years working in a range of food and sustainability-related sectors, before returning to university to complete an MSc in Food and Water Security. Working with the Environmental Law Foundation really showed me the importance of interdisciplinary collaboration when trying to fix environmental problems. Then one day, I saw a sign at Aberystwyth University advertising the MSc in Food and Water Security, and I knew it was the course for me. I was particularly drawn to the fact that the course was interdisciplinary, with modules in geography, international politics, biology and environmental sciences.

So many wonderful things have happened since I came back to academia. I've made lots of new friends, I've spoken at conferences all over Europe, and I was a semi-finalist for the 3 Minute Thesis competition. I was also a finalist for the ESRC 'Making Sense of Society' writing competition. I've now been awarded an ESRC Post-Doctoral Fellowship, which is a huge honour. This will allow me to build on and publicise my PhD findings. It's great!

Out of work, I love swimming and paddle boarding. And my dog is the world's best Frisbee-playing dog – no doubt about it! I also love cooking, baking and watching films with my kids (especially Marvel films – Iron Man is my favourite).

I used to keep bees, and I love the peaceful, quiet engagement with another species and the wider environment. Beekeeping really connects you to the seasons.

EXPERIENCE, GROW AND LEARN TO BE A HORTICULTURALIST

ODILE HUCHETTE, FROM THE **NC A&T STATE UNIVERSITY** IN GREENSBORO, USA, HAS DEVELOPED THE URBAN FOOD PLATFORM, A THRIVING EDUCATIONAL SPACE THAT ENABLES STUDENTS TO PUT SCIENTIFIC LEARNING INTO PRACTICE AND TRAINS THEM TO BE THE NEXT GENERATION OF HORTICULTURE PROFESSIONALS

TALK LIKE A HORTICULTURALIST

CULTIVAR – a plant produced by selective breeding, usually for a particular characteristic, such as taste, colour or resistance to pests

GREENHOUSE – a structure with walls and roof made mostly of a transparent material, such as glass or polycarbonate. Inside, plants can grow under controlled conditions

HORTICULTURE – the branch of agriculture concerned with growing, improving and promoting cultivated plants used for food, medicinal purposes or aesthetic purposes, such as fruits, vegetables, flowers, herbs, and ornamental plants

HYDROPONICS – the technique of growing plants in a solution containing dissolved nutrients. Plants can have their roots completely submerged in this nutritious liquid, or be supported by an inert medium

MICROCLIMATE – the particular climate of a small or defined area

SUSTAINABILITY – refers to the ability to preserve environmental resources for future generations while maintaining a balance with equity and economic principles

URBAN AGRICULTURE – "The growing, processing and distribution of food and other products through intensive plant cultivation and animal husbandry in and around cities." (Bailey and Nasr, 2000)

In our world of convenience and technology, it is easy to forget the complex science behind many everyday aspects of our lives, and food production is no exception. From plant propagation to disease management, managing micro-climates and practising sustainability, the intricacies of horticulture are wide and varied, which is why Odile Huchette of NC A&T State University in Greensboro, USA, is determined to get her students out of the classroom and into a living learning space, the Urban Food Platform.

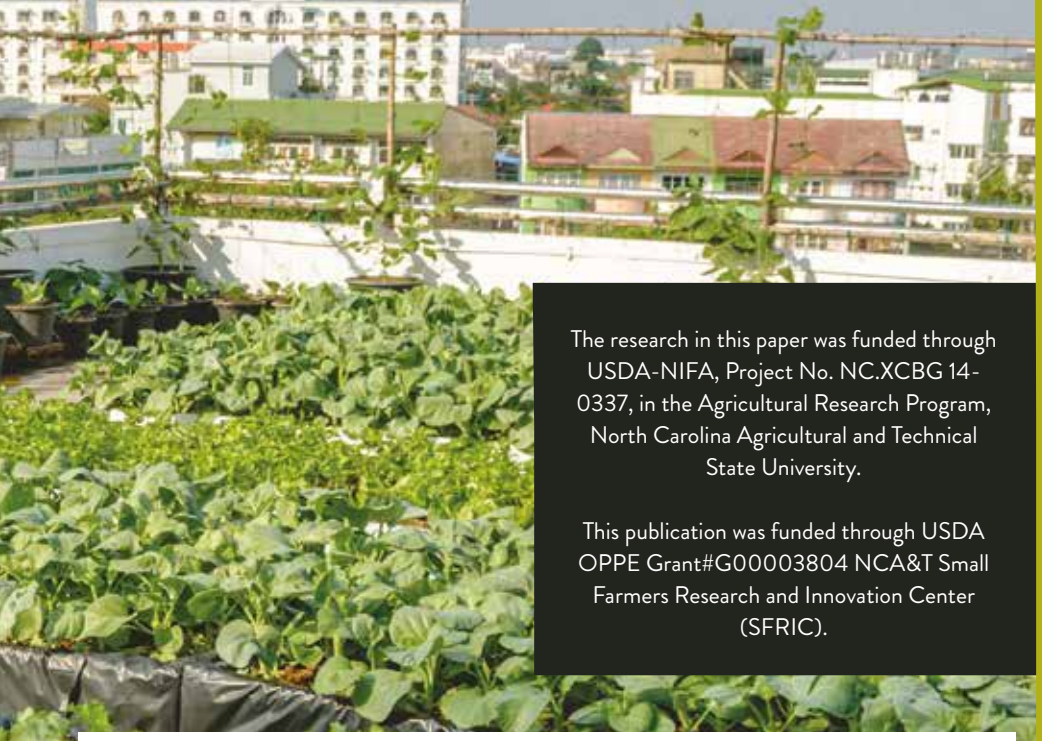
With many of her students coming from an urban background, lacking hands-on experience in horticulture or agriculture, Odile decided to immerse them in the practical aspects of horticultural science, alongside the academic learning of the scientific concepts required. In the Urban Food Platform (UFP) students conduct scientific research, collecting crop and climatic data from sowing to harvest, and manage all aspects of urban food production in a working horticulture space that contains a greenhouse, raised beds, cold frames and hydroponics. Students also organise outreach activities to engage the campus and wider local community with the UFP.

INTRODUCING THE UFP

"With rural communities shrinking and urban and suburban populations growing, a lot of students coming into agricultural sciences have little practical experience in horticulture and food production," explains Odile.

As a solution to this problem, Odile's brilliant programme allows students to understand how all the components of horticulture come together in practical terms – she believes students need to understand the connection between practical agriculture and the scientific theory learned in the classroom. "It is important to include experiential learning and develop programmes that are relevant to urban and suburban students," she says.

The UFP culminated with a greenhouse – built by the students. "It ended up being a very successful project, which contributed to participants developing a sense of community, and helped build confidence," says Odile. "The effort required also taught them about leadership, community, soft skills and the value of teamwork." The greenhouse project was completed with the installation of raised vegetable beds with a drip irrigation



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ODILE HUCHETTE

Department of Natural Resources and Environmental Design, NC A&T State University, Greensboro, USA

FIELD OF RESEARCH

Horticulture

RESEARCH PROJECT

Developing experiential learning in urban and community horticulture through the Urban Food Platform (UFP)

FUNDER

United States Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA)

system. The UFP learning space has been in use ever since, with theoretical learning supporting the practical work – and vice versa.

EXPLORING DATA AND MICROCLIMATE

An essential part of the UFP is data collection. Students research and collect data for many different aspects of their studies, including the rate of plant growth, final yield and crop health. The UFP has several weather stations, so students can record and monitor microclimate data, such as soil temperature, air temperature, light and humidity. Students observe plants and connect their observations with weather data in order to evaluate the effect the microclimate has on the growth of the plants. "We're in an urban environment but we do have trees that are partially shading our platform," explains Odile. "So, we look at the effect of the shade on the beds and with some plants it's really visible. This helps to illustrate the requirements for growing food in an urban setting and, if problems arise, students are asked to identify, research and find solutions. Students can also use data to evaluate the risk of disease using a forecasting system associated with the weather stations (such as for tomato plant diseases, which we have). They can then discuss possible actions to take based on the forecast of the system."

This approach allows students to learn about experimental design and understand how data analysis is vital to assess how different cultivars perform. Students can see the impact of different growing techniques, as well as factors such as planting density, water, nutrition and microclimate – all specific to growing food in an urban setting. The hands-on application of science facilitated by the UFP develops students' independence – and their professionalism.

ESSONS LEARNED

A significant benefit of the UFP is that everything happens in 'real-time'. Students see the impact and processes of the different seasons and gain an insight into the essential stages the growth of a plant requires. Odile says, "In a world where so much is online and instantaneous, this process of time and patience provides a vital lesson. Students have to understand there is a time for doing things – a time for planting and a time to harvest. Although season extension can be possible in horticulture, we cannot force or manipulate time that easily!"

The UFP also helps students to learn from mistakes. "Students are able to go through the process of diagnostics, identifying a problem and researching a solution." When students are faced with a plant suffering from a fungal disease, bacteria or virus, they will have to make observations, apply their knowledge and work to solve the problem. "We have a good diversity of plants," says Odile, "so, there are always case studies for them to apply their classroom knowledge to."

THE END GOAL

Motivated by her desire to provide the highest quality of education possible for her students, Odile gets them out of the classroom and into the UFP on a weekly basis. "I do not believe they can get the best level of education and knowledge if they are not experiencing the concepts we are teaching them," she explains. "For instance, when we talked about using a soil test as an example for building a fertility programme for crops, we were able to take our own soil samples, send them to the lab and get results that were more tangible to us. We discussed the results together, how to interpret the data and what the fertility of the soil would require us to plan for." The decisions that Odile's students make are based on real life data they have collected – and their learning is all the greater for it.

SUSTAINABILITY

Odile knows that sustainability is of huge importance to horticulture in general, but also to students wanting to further their skills in the field. The UFP allows her to teach students that conducting processes systematically and thoughtfully is vital to sustainable practice. She explains, "We do not do things automatically, without understanding. From being efficient with our water use to only ever seeing pesticides as a last resort in cases of plant disease, sustainability comes through care and planning."

As the UFP is a small-scale space, being sustainable can be easier than in large-scale crop production. However, this is a good model to teach students about the essentials, such as testing soil before applying fertilisers, managing the start of a disease, and observing the different plant stages in order to develop an understanding of the crop needs in response to the environment. "I am teaching students a holistic approach, where we are understanding

what makes a healthy plant environment and what is needed to grow an optimum crop."

COMMUNITY

The joy of the UFP is that this connection goes beyond Odile and her students and into the wider community. Recently, Odile was asked by the campus' chef to provide food for the university's Earth Day celebrations. Students were able to showcase sweet potatoes, lettuce, kale and herbs they had propagated and grown themselves. The chef was very happy with the quality of the produce and the students were proud of their achievements. Odile says, "From learning the time of propagation to the harvesting, including the growing of speciality herb crops, the students did everything from A to Z." Such a project also requires a huge amount of teamwork, something that Odile instils in her students when thinking about food production in general. "Students need to understand that it takes a lot of different people to actually get food in place – food production requires a myriad of jobs."

LOOKING AHEAD

Not only is the UFP an essential learning space for Odile and her students, it is also a visible and celebrated space on the university campus. But the learning does not stop there; the university's off-campus Student and Community Farm is also being developed to facilitate even more experiential learning. Offering insights into food production on a larger scale, the farm can be overwhelming to some students at the early stages of their learning journey. However, with the UFP as their foundation, Odile's students have the experience, skills and confidence such work will require.

The UFP is a springboard for scientific education, practical experience, sustainability awareness and community connections. It is multi-faceted and developing constantly; a thriving space for growth in more ways than one. The future looks bright for the Urban Food Platform and the next generation of horticulturalists it is training.

"Many thanks to my colleagues Dr Randle, Dr Yang and Ms Alexandra Wofford for their assistance in bringing this project to reality and making it a success," says Odile.

EXPLORE A CAREER IN HORTICULTURE

• There is a huge range of opportunity in the field. You can choose a career in soil science, agriculture, ecology, or botany. Odile's academic research interests include breeding and genetics, plant disease, and local and urban food production systems, while her industry experience has included her role as an onion breeder.

• Horticulturists can get certifications from organisations such as:

The American Society for Horticultural Science - **www.ashs.org/**
The American Society of Agronomy - **www.agronomy.org/**

• According to the US Bureau of Labour Statistics, salaries in 2020 relating to horticulture, plant and soil science, and agriculture and food science ranged between $69,000 and $73,000 a year.

PATHWAY FROM SCHOOL TO HORTICULTURE

• An interest in biology, in general, and plants, in particular, is essential. Subjects like plant physiology, plant propagation, plant nutrition, crop protection and plant disease management are all important in this career.

• There are university-level degrees in horticultural science, or plant sciences, at many institutions. Useful sites to explore include:

Niche:
www.niche.com/colleges/search/best-colleges-with-horticulture/

Seed your future (ASHS): **www.seedyourfuture.org/students**

Universities.com:
www.universities.com/programs/horticultural-science-degrees

ODILE'S TOP TIPS

01 Be curious and open to new opportunities. Never stop wanting to learn!

02 Have a goal in mind but realise it might take several steps - maybe years - to achieve what you ultimately want. Enjoy each experience as an opportunity to be one step closer!

03 Enjoy the people you meet along the way. The connections and network you build are the most valuable for you, they can help and support you all along your career path.

MEET TWO OF THE UFP STUDENTS

NAME: *TREQUAN MCGEE*

CURRENT ROLE: *PHD STUDENT IN HORTICULTURE SCIENCES AT THE UNIVERSITY OF FLORIDA*

"Being able to engage the community around food was a special feeling. To see folks get their hands dirty, form fellowship and bond with others while growing their own food brought me so much joy.

A lot of the experiential learning prepared me for my graduate studies. You learn so much by doing – the practical experience is unmatched. The material you learn in class really hits home once you put it into practice.

The UFP taught me that not everyone appreciates agriculture. I had to learn that though they might not initially appreciate it, it is something people interact with every day and a little education around it can go a long way.

My great grandmother's love for plants got me interested in horticulture initially. Once we started working in the garden, I realized there is a whole world that plants experience that the average person does not even consider. I often find myself taking the road less travelled and, well, here I am now studying for my PhD in horticulture sciences!

I am proud of the kids I have had the honour of interacting with. During my studies, I have had a couple experiences that have allowed me to get young kids out in the garden and touring agricultural operations. To see the shock and excitement in their eyes when they learned about agricultural things was amazing.

I hope to continue having opportunities to develop the next generation of agricultural leaders and to get more underrepresented people involved in this wonderful industry that has so much to offer.

I would advise anyone looking to study horticulture to get as much hands-on experience as possible and to not shy aware from some of the hard work that comes with agriculture. There are so many career options – traditional farming is only a small percentage of the overall agricultural jobs out there. Experiences on spaces such as the UFP are very enriching and I recommend them to anyone willing to embrace them."

NAME: *BAKER ZITAWI*

CURRENT ROLE: *GRADUATE RESEARCH ASSISTANT/ GRADUATE STUDENT IN NATURAL RESOURCES AND ENVIRONMENTAL DESIGN*

"The most rewarding part of my work at the UFP is definitely the people I've met along the way and how they've helped me grow and develop my skills as a person and horticulturist.

This experiential learning provided me with first-hand experience of efficiently growing crops in a small-scale urban environment. Through this experience, I was able to learn why what we cover in lectures is important and appreciate the benefits of applying proper technique.

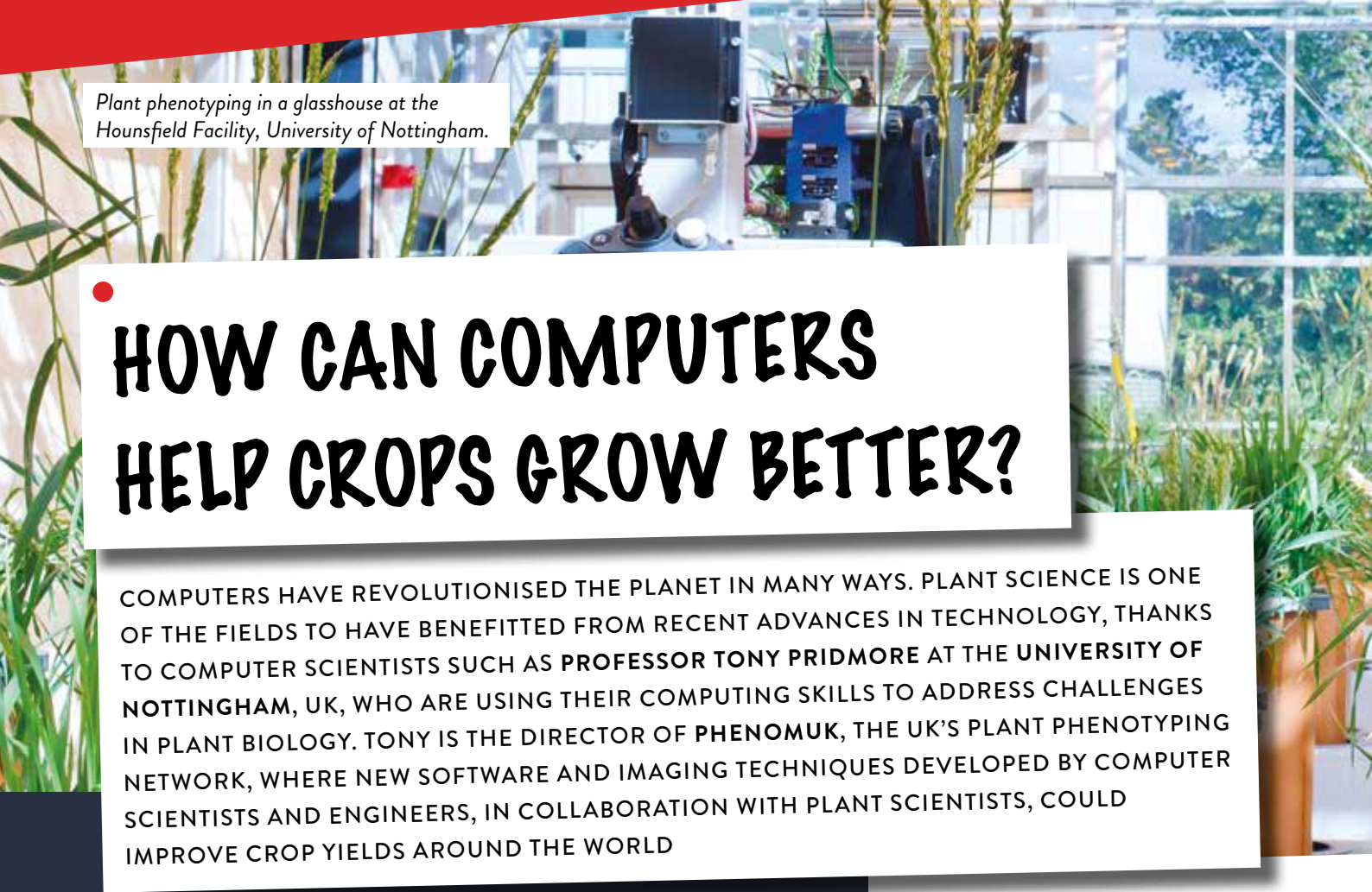
My horticultural skills were developed through everyday work. Life skills such as communication and teamwork were developed while working with less experienced students and volunteers. You have to take the time to teach and guide them along the way.

I took horticultural classes in high school but went into university as chemistry major. In my junior year studying chemistry, I got a part-time job working in a greenhouse. I loved the work, so I transferred schools and changed majors!

My proudest achievement would be the level of responsibility I am now trusted with on the platform, coupled with watching the platform grow and improve year after year.

I'm not sure what the future holds, but I would like to study more proteomics and develop a deeper understanding of how biochemical pathways function in plants and then utilize that knowledge to breed improved plant varieties.

The best advice I can offer would be to start reading scientific papers early, then pursue the topic you find most interesting."



Plant phenotyping in a glasshouse at the Hounsfield Facility, University of Nottingham.

HOW CAN COMPUTERS HELP CROPS GROW BETTER?

COMPUTERS HAVE REVOLUTIONISED THE PLANET IN MANY WAYS. PLANT SCIENCE IS ONE OF THE FIELDS TO HAVE BENEFITTED FROM RECENT ADVANCES IN TECHNOLOGY, THANKS TO COMPUTER SCIENTISTS SUCH AS **PROFESSOR TONY PRIDMORE** AT THE **UNIVERSITY OF NOTTINGHAM**, UK, WHO ARE USING THEIR COMPUTING SKILLS TO ADDRESS CHALLENGES IN PLANT BIOLOGY. TONY IS THE DIRECTOR OF **PHENOMUK**, THE UK'S PLANT PHENOTYPING NETWORK, WHERE NEW SOFTWARE AND IMAGING TECHNIQUES DEVELOPED BY COMPUTER SCIENTISTS AND ENGINEERS, IN COLLABORATION WITH PLANT SCIENTISTS, COULD IMPROVE CROP YIELDS AROUND THE WORLD

TALK LIKE A PLANT PHENOTYPING RESEARCHER

CANOPY CLOSURE – a measure of plant density in an area

COMPUTER VISION – a branch of computer science aimed at extracting information about a viewed scene from images

GENOTYPE – the genetic makeup of an organism

MACHINE LEARNING – a computer program that can teach itself to perform a task

MAGNETIC RESONANCE IMAGING (MRI) – an imaging technique using magnetic fields to view the internal structure of an organism

PHENOTYPE – the observable physical properties of an organism resulting from its genotype and the environment it inhabits

PLANT PHENOTYPING – the assessment of plant traits

PLANT TRAITS – any feature of a plant that is measurable (e.g., growth rate, drought tolerance) from a cellular to organism level

With an ever-increasing population, the world needs more food. Yet climate change and ecological destruction mean food must be produced in increasingly hostile environments. We therefore need crops that are not only more productive but are also productive in harsher conditions, with significantly less or significantly more water than before, for example.

Plant phenotyping is changing the way crops are developed by assessing how plants grow in different environments. Images of plants are captured and converted into data that can be statistically analysed, allowing researchers to determine which plants are most suitable for which conditions. While plant scientists are needed to conduct plant experiments and interpret the results, the process of converting images into data requires computer scientists like Professor Tony Pridmore. A professor of computer science and head of the Computer Vision Laboratory at the University of Nottingham, Tony is also director of PhenomUK, the plant phenotyping network that aims to address issues in plant biology by bringing computer scientists and engineers into the field.

PLANT PHENOTYPING METHODS

The phenotype of a plant is defined by its characteristics and traits, which are controlled by interactions between the plant's genotype and its growing environment. "Plant phenotyping is about measuring plants in an objective and quantitative way, by measuring the structural and functional properties of a large number of plants," explains Tony. "How big are they? What shape are they? How fast are they growing? How do they react to drought, pests and various stresses?"

Phenotyping researchers grow plants in different experimental environments, from climate-controlled growth chambers in labs, to greenhouses and, finally, to open fields. To study them, these plants are imaged with digital cameras viewing the plants at different scales depending on what the researchers are interested in, from a whole field to an individual plant to a plant organ such as a single leaf. The large number of images required means data collection and analysis are usually automated.

"Different technologies are used to take images in different environments," explains Tony. "In growth chambers, conditions are artificial so a camera can be placed anywhere." Imaging becomes more complex in greenhouses, as other objects interfere with the plant of interest, while in fields, wind and rain cause plants to move which adds further challenges. "Cameras taking these images may be in a fixed

PROFESSOR TONY PRIDMORE

Professor of Computer Science, Head of the Computer Vision Laboratory, University of Nottingham, UK

Director of PhenomUK

FIELD OF RESEARCH

Plant Phenotyping

RESEARCH PROJECT

Using computing methods to extract information about plants from images

FUNDER

UK Research and Innovation (UKRI), through the Technology Touching Life programme

position, or mounted on moving platforms, drones or automated vehicles," Tony says.

As well as standard camera images, researchers also take hyperspectral images which detect features outside the range of visible light. "Hyperspectral photos can be split into hundreds of images, all showing different things, such as features visible in ultraviolet," explains Tony. The interior of plants can also be imaged, with X-ray images providing information about the plant's internal structure and magnetic resonance imaging (MRI) showing how fluids move through the plant. Standard colour images can be used to build 3D models of the plant if multiple photos are taken at different angles.

CONVERTING PLANT IMAGES INTO STATISTICAL DATA

To convert images of plants into useful data that can be statistically analysed requires skills from computer science, which is where Tony's work in computer vision comes in. "An image is composed of pixels," explains Tony, "and to extract data from an image usually involves segmenting the image by writing computer code to define what the different pixels represent. For example, we might define which pixels represent a leaf so the computer can separate out all the leaves from the background of an image."

This code is no longer written by hand as machine learning means computers can now be taught to segment images and recognise objects. By marking all the leaves in a set of images and feeding them into a computer, the machine learning algorithm will develop its own rules to identify leaves in other images.

Once the computer has identified the features of the plants in the images, more code is written so the computer measures the characteristics of these features, such as leaf length, plant height or growth rate. With the images converted into numerical data, phenotyping researchers can then statistically analyse the properties of the plants. "We might do correlation analysis between genetic profiles and plants traits to determine which genes result in which physical traits in the plant," says Tony.

PHENOMUK

A significant challenge for addressing global food production is that plant scientists do not often have sufficient computing skills to develop the tools they need to extract the required data from their plant experiments, while computer scientists do not have the biological knowledge necessary for answering plant-related research questions. PhenomUK aims to solve this problem by establishing collaborations between plant and computer scientists. Then, with their combined knowledge and expertise, they can find solutions to crop development together. "Plant phenotyping involves applying skills from computing to address issues in plant science," Tony explains. "Our main goal is to build a phenotyping community by bringing computer scientists and engineers into contact with plant biologists."

PhenomUK also funds research projects which have components from both plant and computer sciences. One project is probing the internal structure of plants using microwave radiation, a cheaper alternative to X-ray and MRI imaging. This could be used to detect abnormalities in the internal structure of fruit or visualise underground root structures. Another project uses drones to take high quality, high frequency aerial images of wheat crops to automatically measure plant height, canopy closure and leaf area.

A recently funded project focuses on speeding up plant development by using deep machine learning to predict the future growth of plants. If software can be built to predict what a plant's roots will look like in the future, based on a series of images of the roots' growth so far, then plants will not need to be grown for as long before useful data can be collected. Another project is developing a laser scanning device which can produce high resolution 3D models of plant features. This technique could replace current imaging techniques which struggle in outdoor growing environments due to changing light and wind conditions.

THE FUTURE OF PHENOTYPING

The equipment required for plant phenotyping, such as X-ray and MRI resources, is expensive. It would be uneconomical for every country to have their own equipment, which is why PhenomUK is closely related to EMPHASIS, a European research infrastructure that will share phenotyping facilities and data across Europe. This will allow researchers across the continent to contribute to the expanding field of plant phenotyping, enabling plant biologists and computer scientists to ensure crops will be able to feed the population of the future.

ABOUT PLANT PHENOTYPING

The plant science community urgently needs computer science expertise to develop the tools needed to collect and process the data required by plant biologists to ensure food security. Plant phenotyping is the crucial link for plant breeders to grow crops that produce high yields, can tolerate droughts and floods, and are resistant to pests and diseases.

Working in plant phenotyping allows computer scientists to apply their skills to address real-world problems. "A satisfying aspect of phenotyping work is that technical problems are interesting and need real developments in computer science to be made," says Tony. The collaborations between research fields also offers huge scope for research innovation and discovery, though this interdisciplinary work can be challenging. "Explaining to plant scientists what we, the computer scientists, have done and how they should use the techniques can be challenging," Tony says.

EXPLORE A CAREER IN PLANT PHENOTYPING

• For more information about plant phenotyping, visit the websites for PhenomUK (**www.phenomuk.net**) and the EMPHASIS project (**emphasis.plant-phenotyping.eu**).

• Most phenotyping researchers will work in academic institutions such as universities or research facilities. As a plant biologist, you could design experiments to assess the effect of different conditions on plant growth. As an engineer, you could build new equipment and imaging technology to collect images of the plants in these experiments. As a computer scientist, you could write code and develop software to convert these images into quantitative data. As a statistician, you could analyse the data extracted from these images to interpret the results of the experiments.

• With knowledge of plant phenotyping, you could also work in plant breeding, using the information provided by phenotyping researchers to develop more productive crops. The British Society of Plant Breeding has a webpage explaining careers in plant breeding: **www.bspb.co.uk/plant-breeding/careers-in-plant-breeding**

PhenomUK, the UK's national plant phenotyping network. © Alena Koval (from Pexels.com)

PATHWAY FROM SCHOOL TO PLANT PHENOTYPING

• You can enter the field of plant phenotyping from the computing/engineering or biology/plant science side. Knowledge of both sides is useful, but not essential. It is more important to have an interest in both.

• For computer science degrees, A-levels in maths, computing and physics are useful, though not always necessary. For biology, sciences like biology, chemistry or physics, as well as maths, are useful.

• During a computer science or engineering degree, a focus on artificial intelligence, data analysis or robotics would be useful. Likewise, for a biology degree, modules in computing would be important. The University of Nottingham offers a plant science degree that includes a year of computer science.

TONY'S TOP TIP

Develop your computer coding skills and take an interest in real-world challenges that plant phenotyping can help address.

HOW DID TONY BECOME A PLANT PHENOTYPING RESEARCHER?

Computers weren't easily available when I was growing up, so I wasn't exposed to programming until I was well into my teens. Music has always been a huge interest, and my first career choice was to be a guitarist and bass player.

I grew up in a small town in Northamptonshire where all school pupils had to do a vocational course to prepare them for a career in the local steelworks. I chose computer science, where I saw a demonstration of an early artificial intelligence (AI) program that analysed written English. From then on, I was hooked on the idea of AI.

I worked in computer vision for many years, developing techniques to extract information from images. One day, someone came into my office and told me about a biologist who wanted to bring mathematical modelling to plant science. The problem was that biologists produced microscope images and mathematicians needed numbers – I was the glue between them. While working on that project, it became apparent that phenotyping was holding back advances in crop improvement.

After 15 years developing plant phenotyping methods, I have a good understanding of the problems faced by plant scientists, but I'm not a plant scientist. I am one of the few phenotyping researchers who came to the field from the computer science side (most are biologists who become interested in computing), giving me a better understanding of what is technologically possible. PhenomUK is about bringing computer scientists and engineers into plant phenotyping, and I was well-placed to do that.

I don't actually know very much about plants – I'm still a computer scientist at heart. For example, I was surprised to learn that when pests attack a crop, some plants react by releasing chemicals through their roots. Nearby plants pick these up through their roots and produce a kind of insect repellent through their leaves, thereby protecting the rest of the field.

MEET CLAIRE

CLAIRE HAYES IS THE NETWORK MANAGER OF PHENOMUK

I loved horses when I was younger and wanted to be a veterinary nurse. I worked at a local vets after leaving school, but realised I needed to continue my education so I went back to college to do my A-levels.

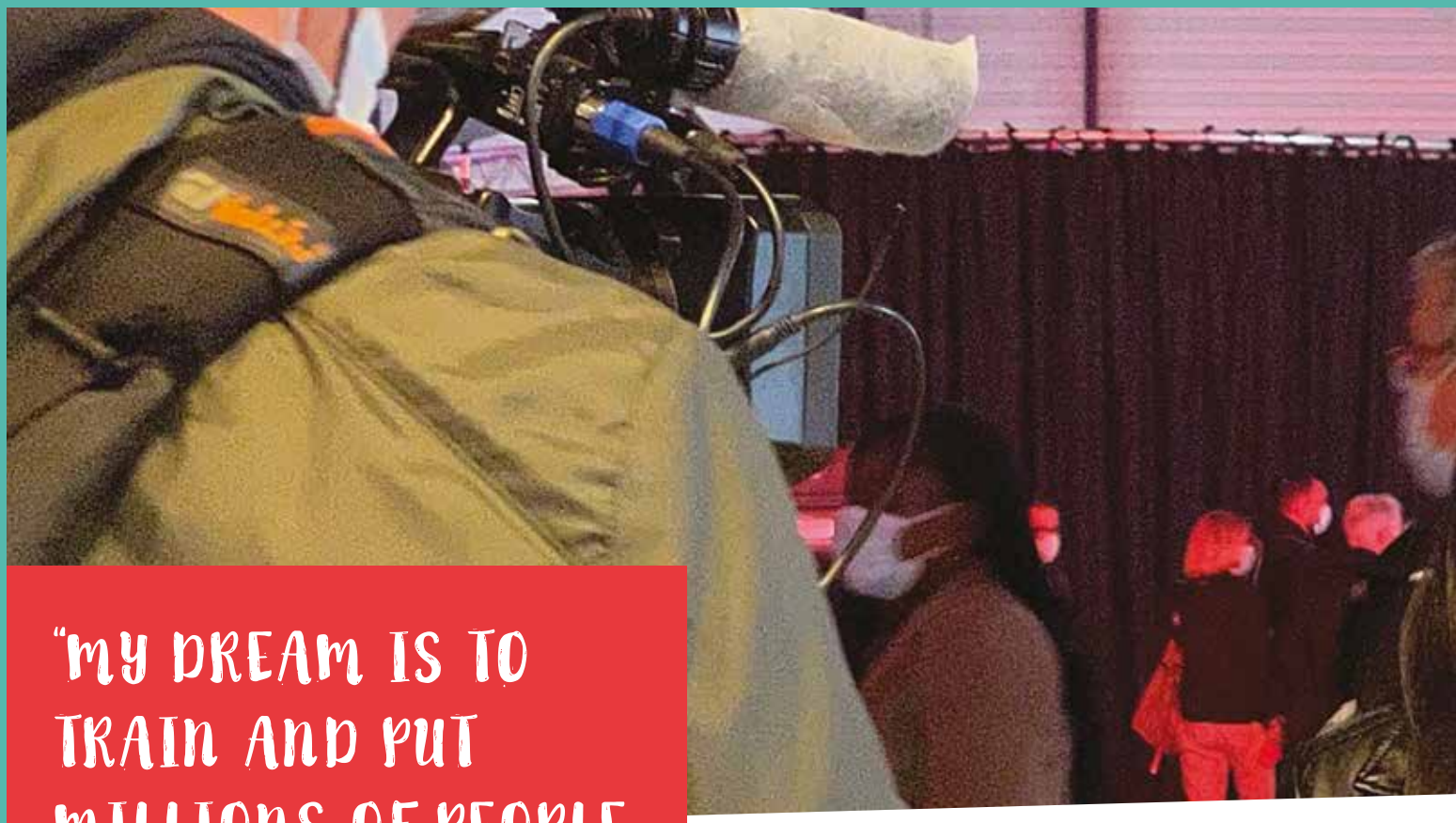
I then studied biomedical science at university and worked in pathology when I graduated. After having children, I wanted a part-time position so came back to work at the university in administration, first in the Faculty of Engineering and now as the Network Manager for PhenomUK.

My work involves everything from branding and webpage design to arranging meetings and events. I manage our social media accounts, collaborate with other academics and institutions, host online workshops and oversee the application process for research funding.

Good communication skills are key for my role. It can be challenging to keep on top of all the tasks, so being pro-active and organised is also essential.

I love the variability of my job. Some days I'll be promoting the network on social media, other days I'll be planning workshops. Phenotyping has such a wide scope of interesting topics so it's a great subject to be involved with, and I enjoy hearing about the interesting research happening in the field.

I love the fact that plants and humans are uniquely connected by the photosynthesis and respiration process. As we breath out carbon dioxide, plants take it in and provide us with oxygen. That is why we must take care of nature – so it can take care of us.



"MY DREAM IS TO TRAIN AND PUT MILLIONS OF PEOPLE INTO WELL-PAID AND SKILLED JOBS."

23-YEAR-OLD **MATINA RAZAFIMAHEFA** EXPLAINS WHY SHE DROPPED OUT OF SORBONNE UNIVERSITY IN FRANCE TO SET UP AN ONLINE CODING SCHOOL IN MADAGASCAR AND BEYOND

© SAYNA

ABOUT EDUCATION IN MADAGASCAR

- According to UNICEF, only 1 out of 3 children completes primary education
- Families support 40% of recurrent costs in the education system
- Only 20% of teachers are civil servants and 97% do not have a professional teaching diploma
- At the end of primary school, only 17% of students have minimum reading competencies in French, one of the country's official languages, and 20% for maths

www.unicef.org/madagascar/en/programme/education

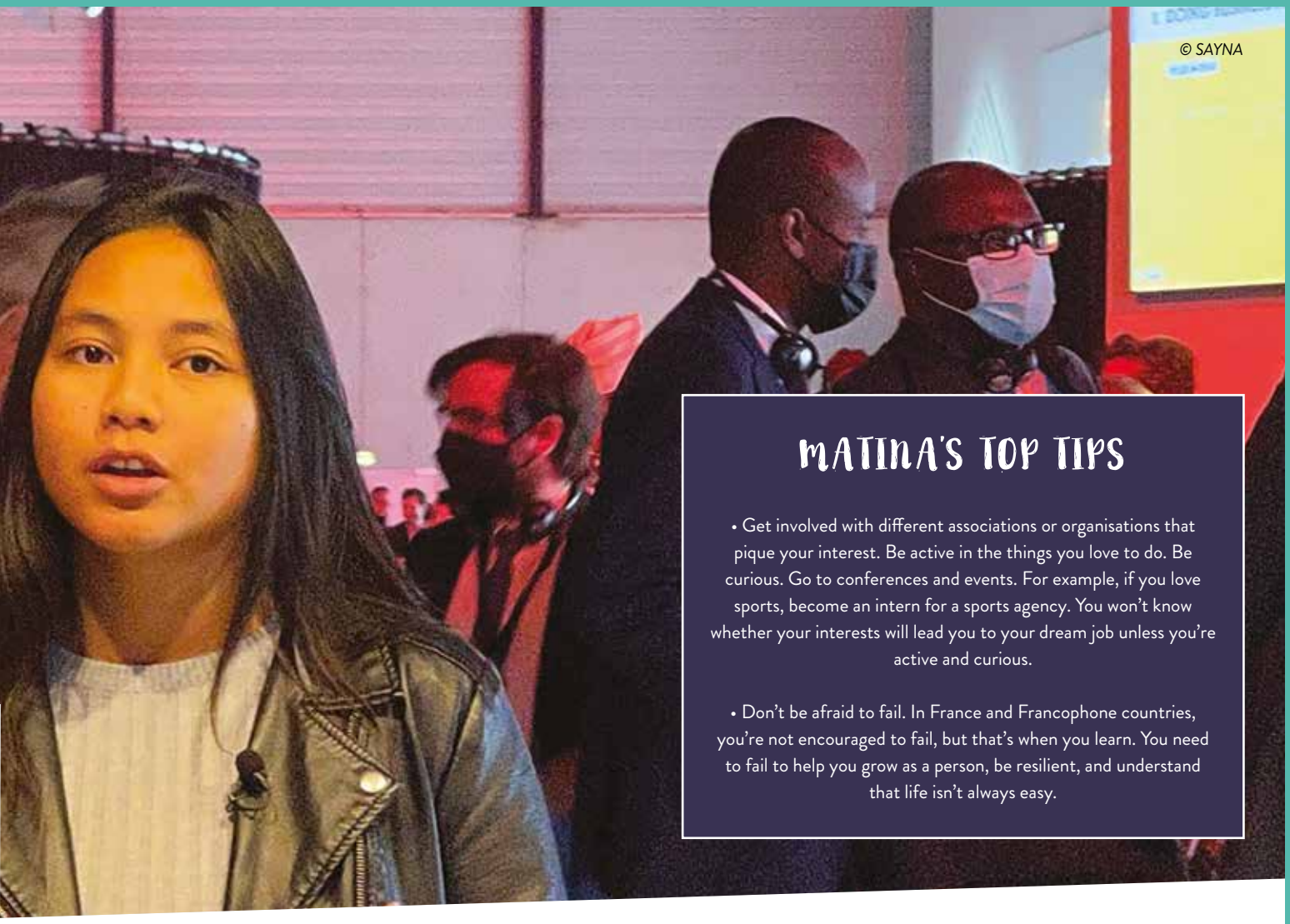
WHAT INSPIRED YOU TO SET UP SAYNA?

The French state school system. I went to a private school in Madagascar where there were between 6-10 students per class, but when I attended a state school in France, I realised that private schools aren't the norm. It's not normal for access to education to be so limited or expensive. I felt it was unfair and I asked myself, why me? I could've been born into another family, and I would've had a completely different life. This was when I decided I wanted to make education more accessible for everyone in Madagascar.

I also wanted to make work more accessible, because I realised that even if people were trained, they wouldn't have access to jobs. They wouldn't have the educational background or experience. That's why I decided to set up SAYNA, a platform that enables people to access jobs according to their skills, and not their resumes.

DOES EDUCATION HAVE TO BE PAID FOR IN MADAGASCAR?

There is free education in Madagascar, but the quality isn't very high because the resources aren't there, and teachers aren't trained. For example, in IT classes, students write code on paper. Students also have to



© SAYNA

MATINA'S TOP TIPS

• Get involved with different associations or organisations that pique your interest. Be active in the things you love to do. Be curious. Go to conferences and events. For example, if you love sports, become an intern for a sports agency. You won't know whether your interests will lead you to your dream job unless you're active and curious.

• Don't be afraid to fail. In France and Francophone countries, you're not encouraged to fail, but that's when you learn. You need to fail to help you grow as a person, be resilient, and understand that life isn't always easy.

share and pay for books, which means education is definitely not accessible for everyone.

WHAT WERE YOUR AMBITIONS WHEN YOU STARTED STUDYING POLITICAL SCIENCE AT SORBONNE UNIVERSITY IN PARIS, FRANCE?

[When Matina applied to study political science at Sorbonne University in Paris, only 44 applicants were selected out of 40,000. She was one of those 44 applicants.]

I wanted to change the world and I thought political science was the best way to do it. I want to lobby and influence government policies for the good of people and countries. Now I know that I can't change the world, but I can change something. I've discovered that a better way to change the world is to create a business that adds value and makes money. We can't help people if we don't have enough money, and the more money we have the more we can help people.

WHY DID YOU DECIDE TO LEAVE SORBONNE IN YOUR SECOND YEAR TO FOCUS ON SAYNA?

When I launched SAYNA, I didn't realise how much it would grow. I started to have a lot of responsibilities – clients, a team to manage, partnerships, and there were a lot of people who relied on me. So, I decided to say goodbye to Sorbonne with the idea that maybe I'll go back there.

HOW HAS SAYNA BEEN ABLE TO EXPAND ITS WEB DEVELOPER TRAINING TO COMOROS, CÔTE D'IVOIRE, BENIN AND SENEGAL?

We have a team in Madagascar and Paris, but a lot of what we do is semi-automated, so we mainly work online and with partners in those countries.

HOW MANY PEOPLE HAS SAYNA HELPED SO FAR?

SAYNA has trained and placed over 200 Africans in the global IT marketplace, and we're going to work with another 27,000 students. This is through the University of Fianarantsoa, one of the big tech universities in Madagascar.

HOW DO YOU FEEL ABOUT BEING IN THE PUBLIC EYE?

[Matina has appeared in various high-profile interviews for DuoLingo, France 24, Change Now and others, and has won the Anzisha Prize, which celebrates innovative young African entrepreneurs.]

I find it hard to accept being in the public eye. It feels weird, especially in Madagascar where there are always people asking me for a selfie. But, at the same time, my team tell me that I'm the voice behind SAYNA and I understand that I have a responsibility to be that voice. Overall, I feel honoured to be able to represent my team at SAYNA and my country on an international scale. It's quite exciting!

WHAT HAVE YOU LEARNED ABOUT YOURSELF THROUGH LAUNCHING SAYNA?

I used to play tennis, which requires a lot of resilience. You lose a lot, and it can be difficult to manage your emotions when this happens. When I started SAYNA, I knew I could manage my emotions, but I didn't know I was capable of absorbing so much knowledge, and so quickly. I didn't know anything about finance, managing teams or marketing; I learned everything from scratch, and I've found that I'm more capable than I thought.

WHAT ARE YOUR HOPES FOR YOUR FUTURE?

I strongly hope that we will be able to train and put millions of people into well-paid and skilled jobs. This is my dream!

ABOUT SAYNA

SAYNA performs two roles: it is both an online learning platform aimed at developing learners' IT skills, and a crowdsourcing platform aimed at providing innovative, digital solutions for clients.

AN ONLINE LEARNING PLATFORM

Reviewed and reinvented over time, SAYNA's training programme has been translated into a gamified course, which provides a rich and unique experience for learners. Learners are 'placed' in a space universe where they must conquer planets to validate key skills. At present, the training programme has been divided into seven content themes that promote the development of skills in web development, graphic design, digital marketing, IT management and SEO. Importantly, there are no pre-requisite qualifications needed to undertake SAYNA's training programme, which can be adapted to everyone's needs, including novices.

A CROWDSOURCING PLATFORM

SAYNA is also a crowdsourcing platform intended to offer trainees access to the IT job market in a fair and sustainable way. Clients' IT projects are broken down into micro-tasks, which are redistributed

to the community of freelance developers, who have trained with SAYNA. In this way, projects are completed very quickly thanks to the dozens of developers , called Microtaskers©, working on the same project. The objective is to provide work to a maximum number of Microtaskers©, depending on their skills and availability.

ALGORITHMS

The bridge between the crowdsourcing and training platforms is connected by an algorithm, which selects the profiles of SAYNA's Microtaskers© whose skills match the micro-task in hand. As they work with SAYNA, Microtaskers© can continue their training, move up through a total of six grades, and increase their earning potential from 25% to 50% of the cost of the task.

For more information, visit:
http://sayna.io

GET SOCIAL WITH MATINA AND SAYNA

- **HelloSayna**
- **Sayna / Matina Razafimahefa**
- **hellosayna / matina_razafimahefa**
- **Matina Razafimahefa**

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THE STEAM TEAM – ENGAGING STUDENTS THROUGH INTERACTIVE AND IMMERSIVE LEARNING

THE STEAM TEAM ACADEMY, THE HUGELY SUCCESSFUL BRAINCHILD OF **DR ODESMA DALRYMPLE, DR JOI SPENCER** AND **DR PERLA MYERS** OF **THE UNIVERSITY OF SAN DIEGO**, USA, HIGHLIGHTS THE IMPORTANCE OF HANDS-ON, COMMUNITY-BASED LEARNING IN ALLOWING STUDENTS TO CONNECT CONCEPTS FROM STEAM TO EVERY ASPECT OF THEIR LIVES

All too often, we consider individual subjects as isolated. Mathematics teachers teach mathematics in classrooms, chemistry teachers teach chemistry in labs, and PE teachers teach sports on the playing field. In school settings, timetable allocations can suggest all subjects are distinct but, in reality, every subject is connected and it is essential students know this if they are to appreciate the interdisciplinary nature of life.

To address this, Dr Odesma Dalrymple, Dr Joi Spencer and Dr Perla Myers of the University of San Diego established the STEAM (Science, Technology, Engineering, Arts, Mathematics) Team Academy, a week-long summer programme providing middle and high school students with the opportunity to engage in hands-on learning. "We wanted to create a STEAM program that is fun, engaging and challenging, providing opportunities for growth and development through productive struggle," says Odesma.

Complementing the STEAM Team Academy, they also run the STEAM Youth and Community Conference, to which students' families, local educators and community members are also invited. "Learning is a social endeavor heavily influenced by the environment in which the learning occurs" explains Joi, which is why it is crucial to engage the whole community in this effort. "Since our focus is on informal learning, we want to facilitate STEAM learning even after students have left the Academy."

Odesma, Joi and Perla specifically focus on raising the STEAM literacy of students and increasing their ability to see STEAM as an integral part of their everyday lives.

WHAT IS STEAM LITERACY?

In a broad sense, the term STEAM covers science, technology, engineering, arts and mathematics. But to be 'STEAM literate' does not mean that you must excel in every subject. Instead, it requires transferable skills, independent of any one specific domain of subject knowledge.

"This includes an ability to observe carefully and be curious," explains Perla, "to ask questions, especially ones you can't immediately answer. And to embrace failure and productive struggle as necessary steps along the path, as they are part of the learning process." It includes critical thinking and the capacity to understand data presented in various forms. The ability to communicate ideas, through oral stories or drawings, written narratives or movies, is equally important. "We must be empathetic," says Odesma, "understanding the human element in STEAM and the ways in which our society shapes, and is shaped by, STEAM."

COMMUNITY ENGAGEMENT

Most students who attend the STEAM Team Academy come from communities that are underrepresented in STEM professions. But these communities contain a wealth of knowledge that can be utilised to ignite the spark for continued learning. "We seek ways to engage in explorations of the many assets within these communities," says Joi.

As rich sources of wisdom and practical knowledge, the communities themselves provide "a starting point for conversations about equity, advocacy and the importance of standing up for social justice and making change," explains Perla. And by using the students' own communities as a learning resource, not only do students feel that this education is relevant to their own lived experiences, but they can appreciate how all aspects of their lives are underlain by STEAM concepts.

A visit to Chicano Park provides an opportunity to learn from the community. Situated below a freeway junction in a predominantly Mexican neighbourhood of San Diego, the park is home

to the country's largest collection of outdoor murals. Academy students immerse themselves within this national treasure, experiencing history, marginalisation and inequities with all their senses. They meet artists who work in the park and hear how they create murals on the arches of the very highway that fragments and pollutes their community, and understand how art can be a vehicle for getting their voices heard.

"We have talked to a mural artist who advocates with his art," says Odesma. "It was wonderful for students to hear how he uses mathematics to create art." Like many of the students, the artist did not initially consider his work to be mathematical. Yet, the ability to scale a plan from a small piece of paper to the size of a large mural and to represent three-dimensional shapes in two dimensions shows how mathematics and art are interrelated. "There is so much mathematical richness embedded in the art he has developed and perfected throughout his life."

Rather than feeling that 'STEAM' represents subjects they must study, the Academy teaches how STEAM can answer questions significant to students' lives. "We want students to appreciate that all the practices they engage in are also examples of STEAM activities," explains Joi. "These activities are just as important as the STEAM subjects they learn in school."

UN DEVELOPMENT GOALS

Many discussions at the Academy are based around the United Nations' Sustainable Development Goals, particularly focusing on reducing inequities, which enables students to see themselves in the larger context of global citizenship. "When students read these goals, they see that others around the world are grappling with the same challenges that we face in the US," explains Joi. They also highlight the huge inequalities that still exist. "Students are surprised that there are still places where girls cannot go to school, or where basic medical care is not available."

"The Sustainable Development Goals are an opportunity to recognize our collective responsibilities as citizens of the world," says Joi. "Most importantly, students see how STEAM skills can be applied to the world's most challenging dilemmas. Gaining STEAM skills is no longer about getting a high paying job, but about addressing these problems. We believe that STEAM should be of service to humanity. That is the message we want our participants to come away with."

To highlight the concept of inequity, students play Inequity Monopoly, where each player has a different set of rules. Some receive $200 when they pass Go, others do not. Property prices are different for each player. Some can purchase certain properties, others cannot. "At some point in the game, the rules become 'fair' again and we continue playing," says Joi, "but those who had an advantageous start are so far ahead that it's impossible for those who are behind to catch up. We have important conversations about real-life examples of this, and the implications of these situations."

SUCCESS

Since its creation in 2015, the STEAM Team Academy has continued to grow. Many students return year after year, proof that this is an enjoyable setting in which to learn. And many students who pass through the Academy return as enrichment facilitators, now leading the activities they once participated in. Sharing the same background as the facilitators allows current students to identify with their near-peer mentors. Former students act as role models, inspiring the next generation to engage in STEAM.

"We witness our students' growth and maturation," says Perla. "We see our model of peer mentorship and community immersion actualized in the lives of our students, many of whom are now pursuing STEM majors in college."

"Recently a former student wrote to us, sharing the impact of the program on her first year of college," says Odesma. "She explained how the idea of Productive Struggle (a concept that we emphasize throughout STEAM Team Academy) helped her in overcoming the difficulties she faced in her STEAM courses. Instead of seeing the challenges as a sign of failure, she was able to see academic struggle as a springboard for deeper thinking and reflection."

"Our belief is that students have a natural desire to learn. When work is engaging, interest is sustained and deepened," says Joi. "We have seen our students accomplish amazing things."

DR ODESMA DALRYMPLE

Associate Professor, Industrial and Systems Engineering, Faculty Lead of the Engineering Exchange for Social Justice, Shiley-Marcos School of Engineering

DR JOI SPENCER

Interim Dean and Professor, Mathematics Education and Teacher Education, School of Leadership and Education Sciences

DR PERLA MYERS

Professor, Department of Mathematics, Director of K-12 Community Engagement for the College of Arts and Sciences, The University of San Diego, USA

FUNDERS

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WHY ARE ODESMA, JOI AND PERLA SO PASSIONATE ABOUT STEAM EDUCATION?

ODESMA

I was a typical child from a middle-class family – engaged in a lot of sports and extra-curricular activities. I showed great strength in mathematics and science and was fortunate I demonstrated that interest early.

My dad was a teacher, and I will firmly say he was the best mathematician of all time! His ability to teach and contextualise mathematics, and to tell stories, was amazing. My dad taught me and my friends at home, and was also very active in his community, so I saw that example of being engaged. My mother worked in the government service. She didn't like to see disadvantage and always got excited about solving problems. She was good at bringing in humour when working with people and I learnt from observing her.

By watching my parents, I saw how leadership, creative thinking and storytelling all tie in. For me, this led to engineering.

I've always been attracted to the fact that there's never one answer to an engineering problem. There's so much possibility to be explored, which means there can be individuality in approaching a problem. This complexity is exciting! Engineering is an opportunity for such intersection, in terms of the way we see problems and the way we approach them.

I like the human elements of engineering. It's often seen as techno-centred, but I see it as a socio-technical endeavour. You have to see the social context in which people and problems exist in order to find a technical solution.

ODESMA'S TOP TIPS

01 Mix the liberal arts with scientific and mathematical subjects. Develop your critical thinking.

02 Remember, you have flexibility to make your engineering pathway individual to you. Link your engineering to your passions and interests.

03 The tool of social media and the ability to connect can help you to follow your curiosity and make connections with people. Ask, what am I curious about? The more you read, the more your world will open up. Seek out people and groups you're interested in and say hello!

04 You don't have to conform to stereotypes. Bring your culture and who you are into engineering.

Investigating electrical circuits at the STEAM Youth and Community

Ideating and sense-making through theatre games in STEAM Team Academy Conference

JOI

As a child, I loved to read about science and animals. I was obsessed with the natural world. I also read about civil rights leaders like Malcom X, Martin Luther King and Fannie Lou Hamer. We didn't learn about black history in my school, but I went to the library and read about it.

I grew up in South Central Los Angeles. People all around me were being brutalised by the police and some were dropping out of school. But I also had a counter-narrative – I had a family and their love in my life, so I was able to navigate it. If it wasn't for my mother and my grandparents, I wouldn't have had encyclopedias, I wouldn't have gone to the library. I've also had some very inspirational teachers in my life.

I liked mathematics enough, however I felt that it lacked the depth of some other subjects. But when I started teaching it, straight after college, I saw how it helps us understand social phenomena. With my students, I looked at social issues like homelessness and patterns of wealth. For me, the value of mathematics is that it helps us to understand the society we live in.

I love learning and I see education as a liberating tool. As a mathematics teacher, I want my students to see that all kinds of people can do mathematics and that they can be socially active and love mathematics.

Now that I train teachers, my reward is exponential. I can train one mathematics teacher who will go on to inspire thousands of young people. That is incredible!

JOI'S TOP TIPS

01 Don't be afraid of mathematics, even if you haven't done very well in mathematics courses. Keep exploring – the world of mathematics is vast.

02 Explore a lot of things, find what you love and pursue it.

03 If you're a good reader, you can learn anything, in my opinion. To become a good reader, you've got to have something you're interested in reading about!

04 History is really important and I would encourage young people to study it. My family exposed me to the history of black people from very early on and it helped me to understand the world I was experiencing. Wherever you are in the world, study history and it will unlock a lot of the challenges our world is facing.

PERLA

As a child, I would spend hours with music playing loudly while painting, drawing and building. I also loved to read any book that I could get my hands on and explore new worlds. My family played a lot of games and enjoyed solving puzzles. We also loved going on adventures. My mom would pile us into our Volkswagen bug and take us to visit factories to learn about the way they manufactured toothpaste or soft drinks or soap, or we would go to museums or parks. Cycling, roller skating, crafting, singing, cooking with my grandmother, playing with my friends… My childhood was very busy!

My calculus professor and undergraduate advisor at university 'informed' me that I would become a mathematician. He wrote a detailed plan of what classes I needed to take and which books I needed to read. I had no idea what a mathematician did or what the possibilities were, so I hadn't considered it, but throughout my elementary, middle and high school I loved mathematics and was really excited to learn new concepts. I also learned the most while exploring mathematics with others and while I was helping my friends understand mathematical ideas. I loved finding ways to help them grasp the concepts and relished those awesome 'Aha!' moments.

What I find most challenging about my field is that there are so many people who have not had positive mathematics experiences, and for some, even hearing the word 'mathematics' causes anxiety. Many people see mathematics as just computation, or as a disconnected set of rules and regulations that they have to memorise and regurgitate. When they can't recall all that information, they blame themselves and believe that they are just not 'math people' or that they don't have 'math brains'. That is not true.

What I find most rewarding is working, learning and creating with my colleagues and students, especially when we are finding ways to provide opportunities for others who may not have yet figured out that they are 'mathematics people' to explore mathematics, realise that mathematics is a beautiful, creative endeavour and that they are capable of asking questions, making discoveries and truly enjoying mathematics. I also have loved working with my colleagues in engineering and education to create experiences in STEAM.

Mathematics can be applied to every area. The more we know about other areas, from engineering and computer science, to architecture and political science, the better we can see how mathematics can help address the important challenges facing the world.

PERLA'S TOP TIPS

01 Learn as much as you can about many different areas and from everyone around you. This can lead to insightful problem-solving.

02 Ask lots of questions and be willing to make mistakes. Mistakes can evolve into new ideas.

03 Work hard and find ways to challenge yourself and engage in productive struggle – enhance your brainpower!

04 Believe in yourself, work within a supportive community and seek the help you need.

05 Find time for self-care and to fun!

HOW MODELLING CAN SHED LIGHT ON MEMORY RETRIEVAL

COMPUTATIONAL THINKING DESCRIBES THE WAY WE BREAK DOWN PROBLEMS OR DRAW CONCLUSIONS FROM OBSERVATIONS. WE USE IT IN EVERYDAY LIFE, BUT **PROFESSOR OSMAN YAŞAR**, BASED AT THE **COMPUTATIONAL MATH, SCIENCE, AND TECHNOLOGY INSTITUTE** AT **THE STATE UNIVERSITY OF NEW YORK** IN THE US, BELIEVES WE CAN LEARN TO USE IT MORE EFFECTIVELY. HE TRAINS TEACHERS TO TEACH STUDENTS TO THINK IN WAYS THAT IMPROVE THEIR MEMORY AND PROBLEM-SOLVING ABILITIES, SETTING THEM UP FOR SHINING CAREERS IN STEM

GLOSSARY

BLOCKED PRACTICE – a way of learning involving repeatedly practising a skill or process, without the interruption of other activities

COMPUTATIONAL THINKING – a way of thinking that uses deductive thinking and inductive thinking to tackle complex problems, understand them and generate solutions

DEDUCTIVE THINKING – taking a general conceptual idea and applying it to various circumstances, observations or possibilities to examine its validity. Also known as a top-down approach, decomposition or analysis

GENERATIVE RETRIEVAL PRACTICE – a form of memory retrieval and learning involving effort and prompts to answer a question, solve a problem, or draw conclusions without being presented with possible answers or solutions

INDUCTIVE THINKING – taking data and/or observations and using them altogether to come up with general ideas, concepts or theories. Also known as a bottom-up approach, abstraction or synthesis

INTERLEAVED RETRIEVAL PRACTICE – a form of memory retrieval and learning involving meshing topics and solutions together (as opposed to blocked practice)

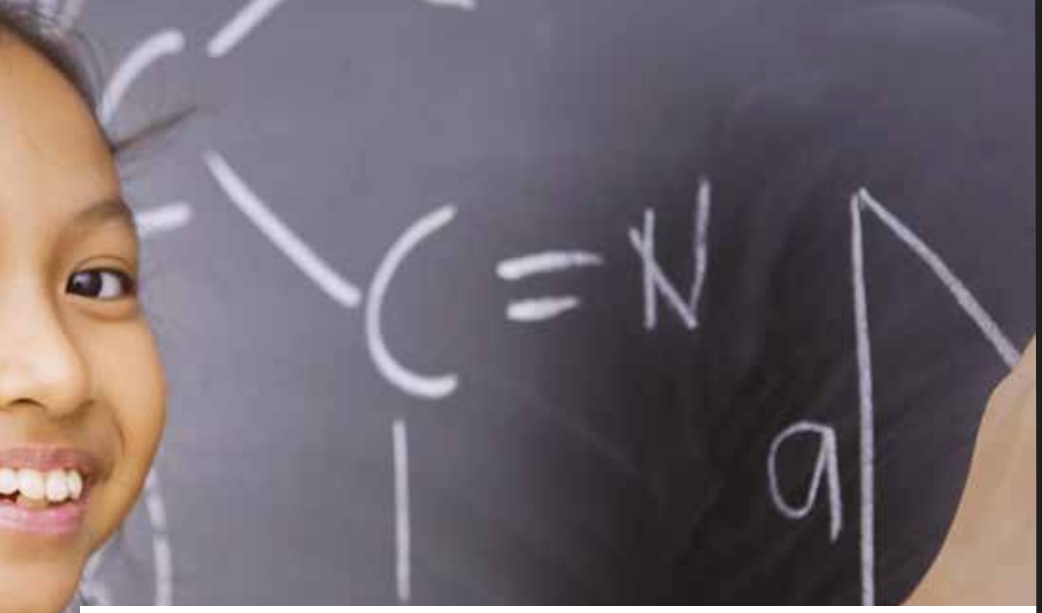
SCIENTIFIC THINKING – a way of thinking that a scientist employs during inquiry. It includes both the content of sciences and a set of cognitive processes that permeate the field of sciences. These processes include problem solving; the formation and testing of hypotheses, concepts and models; conceptual change; and a set of reasoning skills such as deductive, inductive, abductive, causal and analogical thinking

Professor Osman Yaşar has been working with schools for over two decades, initially as a pioneer of bringing computer science into the classroom. Now, he shares important lessons from computational and cognitive sciences to help teachers improve lesson and curriculum structure. Osman's aim is to enhance students' memory capacity and set them up with effective ways of thinking for life.

COMPUTATION IN THE CLASSROOM

Osman has been involved in the computational sciences since the mid 1980s, when advances in computer modelling made it an effective alternative research strategy to real-world experiments. "Computational modelling and simulation technology (CMST) helped surpass issues of experimental studies, which were held back by their size, the risks involved and prohibitive costs," says Osman. "However, this transition required professionals proficient in computational methods and tools, as well as skills in mathematics and science." Given that computational science was not taught below graduate level at that time, procuring new talent was a real issue.

"In response to this lack of a qualified workforce, I decided to form the world's



first undergraduate degree programme in computational science," says Osman. "Several years into this programme, I realised that the pool of STEM-orientated students was shrinking long before they reached universities – so I took the challenge to the school level." This involved training teachers in how to use CMST tools and why they were useful. This naturally gathered pace as computers became household items, with computational thinking now often recommended in curriculums.

Funding from the National Science Foundation gave a welcome boost to Osman's training efforts. "Participation by teachers was voluntary, but funds and other incentives were used to encourage teachers to attend training," says Osman. "Recruitment of students for project activities was left to teachers, though they were first educated about the importance of diversity." Over the years since, Osman's work has expanded to include younger and younger students, with even elementary students now able to participate using easy-to-use computer simulations.

COMPUTATIONAL THINKING

Osman's work does not just purely focus on paving the way for the next generation of computer scientists. He also draws parallels between computation and cognition, lately through the ITEST (Innovative Technology Experiences and Teachers) programme. "Our teacher training work initially involved the use of computational modelling and simulation tools, but as we discovered the link between computation and cognition, we started teaching teachers and students memory retrieval strategies to help retain knowledge and support meaningful and in-depth learning in STEM," he says.

This way of processing information is known as computational thinking (CT). Osman states that all computing devices – which includes our own brains – process information in similar ways. "Our brains are efficient computing devices, quantifying the information we perceive around us," he says. "By using these computational processes consistently, frequently and methodically, we can become smarter, more knowledgeable and better able to retain information."

CT can be categorised further into two directions. Deductive thinking involves taking a broad concept and testing it using observations at a smaller scale. Inductive thinking covers the reverse process: making observations, collecting data, and using this to formulate a broad concept. ITEST's latest venture is building mobile apps to teach computational thinking and memory retrieval strategies in a STEM context.

Osman highlights scientists and engineers as two groups who often deliberately employ computational ways of thinking in their work, but emphasises that everyone thinks in these ways in their day-to-day lives to some degree. He believes that employing these methods early on in education could bring benefits to students' cognitive capacity. "We know that such capacity can be improved beyond what is inherited through experience and education," he says.

IMPROVEMENTS AND ACCOLADES

Osman has the data to back up his claims. "Our decades-long experience and empirical data indicate that computational pedagogy and the use of CMST tools foster STEM learning and boost interest in CT and computer programming," he says. He has partnered with secondary schools in the Greater Rochester area of New York, training over 1,200 teachers in total. Students taught by these teachers saw test scores improve by 15% to 40% in mathematics and science, and experienced big boosts to interest and enrolment in physics and computer science courses.

Osman's team has also offered professional development to secondary school teachers to use memory retrieval practices in STEM courses. Resources they have supplied include simple quizzes spaced out throughout the year and computer simulations. "Studies found that students who learned STEM topics through retrieval practices consistently scored up to 30% better than those using standard practices," says Osman. "Retrieval practices involve mixing topics and types of questions, and students are faced with choosing a strategy to solve a problem."

The team has received a number of accolades that reflect the impact of their work. "Our peer-reviewed publications have received best-paper awards in conferences, and our main partner, Rochester City School District, received the National Superintendent of the Year Award in 2006," says Osman. He has also testified before US Congress along with two teachers, advocating the effectiveness of his teaching methods. "We hope to scale up our work to a national level and expand its utilisation to include elementary teachers and students," he says.

PROFESSOR OSMAN YAŞAR

Computational Math, Science, and Technology (CMST) Institute State University of New York (SUNY)-Brockport, USA

FIELD OF RESEARCH

Computational Science, STEM Education

RESEARCH PROJECT

Training teachers to use computational thinking to improve learning and memory retrieval in the classroom, and inspire an interest in computational science

FUNDER

US National Science Foundation (NSF)

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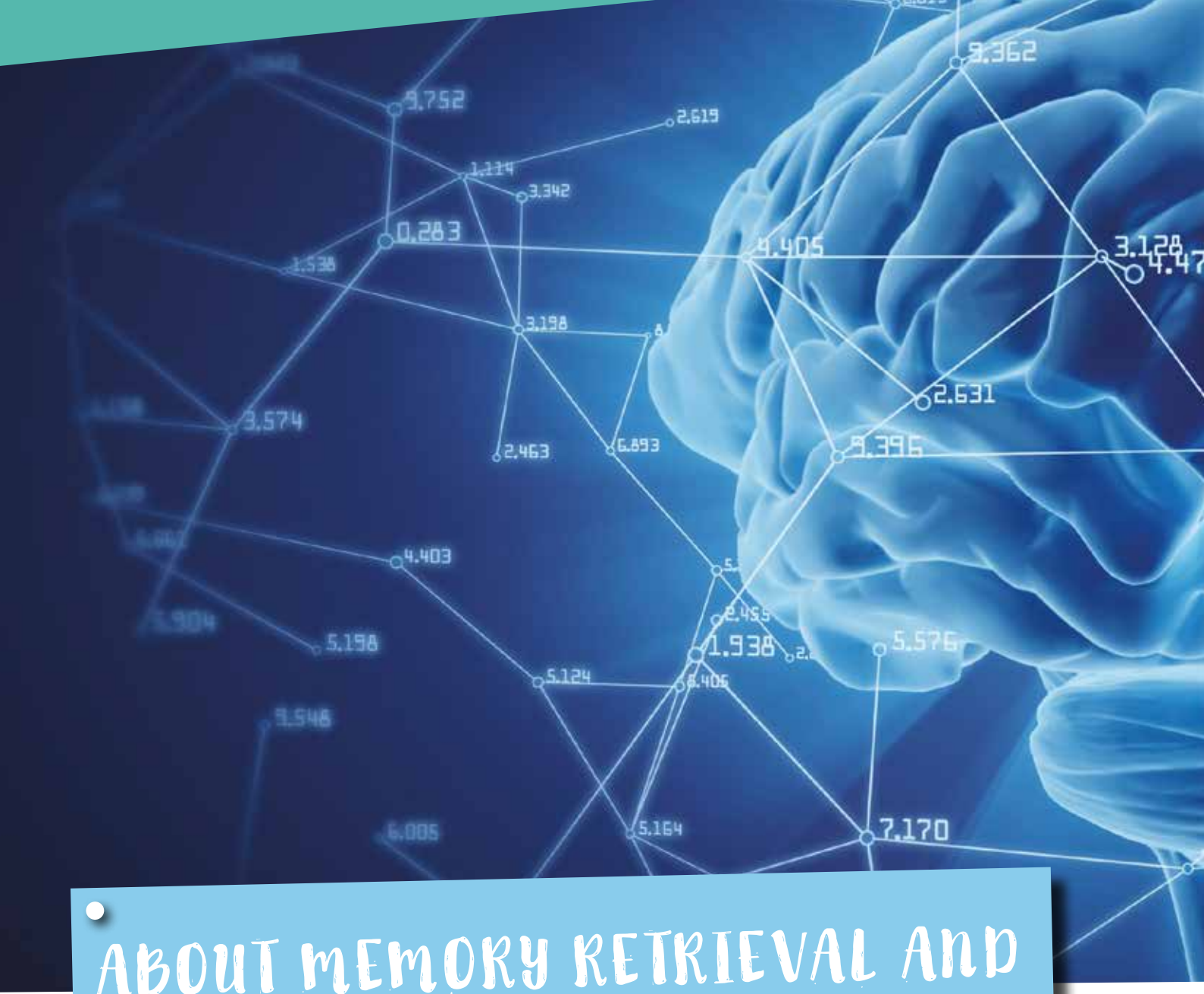


ABOUT MEMORY RETRIEVAL AND COMPUTATIONAL THINKING

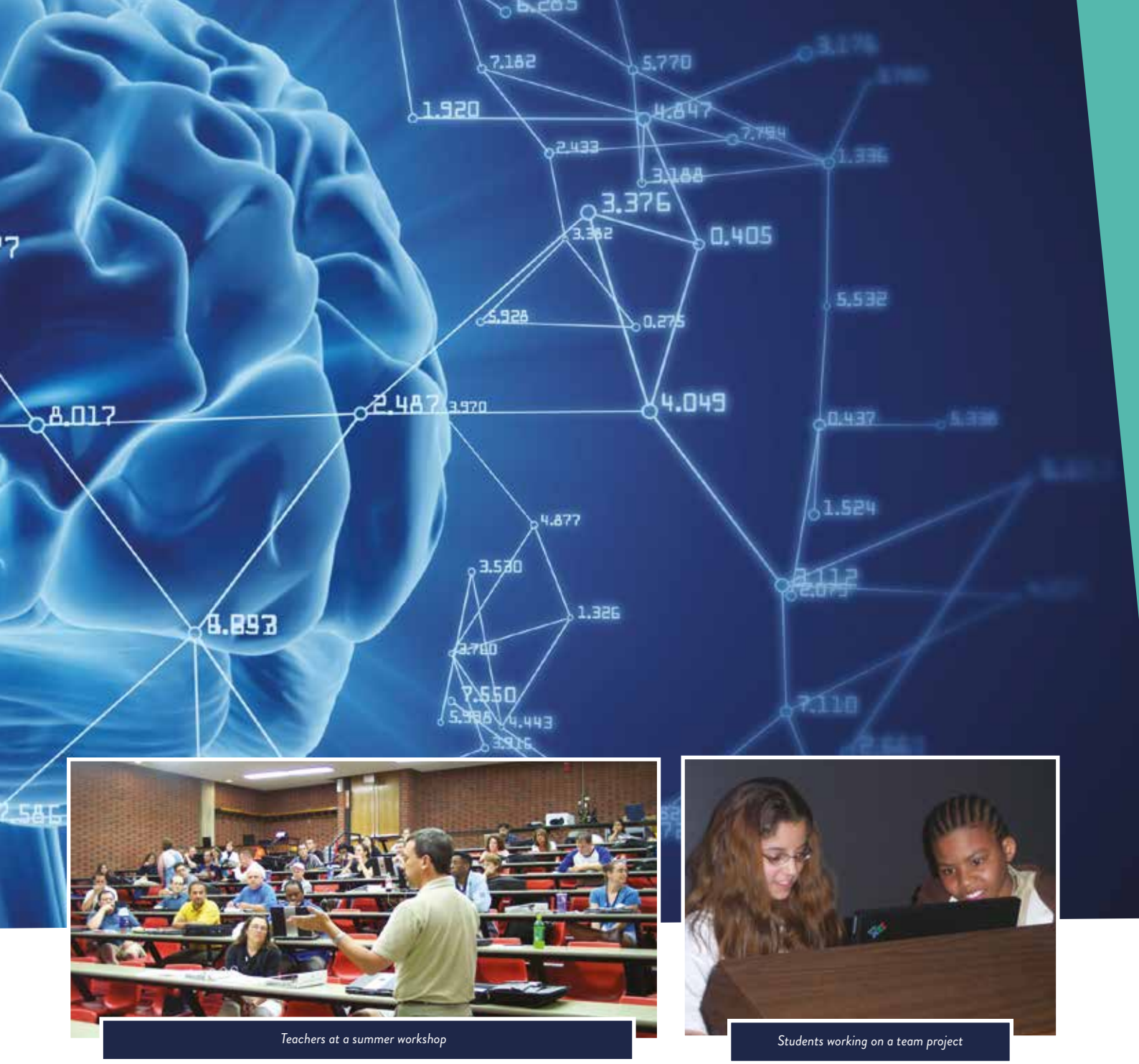
Computational thinking is not just done by scientists. "For years, society believed that scientists had a special mindset to help them pursue scientific work," says Osman. "Now, through laboratory observations and findings in neuroscience, we know that the cognitive processes that scientists use are no different from what everyone uses in their day-to-day lives. The difference comes from how they are used." Osman believes that people can be taught to use computational thinking and scientific thinking skills more effectively, helping them perform better in school, work and the everyday.

The ITEST programme puts this idea into practice. "We should teach everyone how to think like a scientist," says Osman. "Inductive and deductive thinking are the most important elements, but only when used in combination. Most of us tend to use one of them more than the other, which leads to problems." Learning to use both ways of thinking frequently and cyclically can be taught but may require moving away from the standard ways of teaching.

OLD AND NEW TEACHING PRACTICES

'Blocked practice' refers to the way that subjects are traditionally taught in schools. This method teaches well-defined rules and methods linked to a particular topic for a block period of time, testing them, and then moving on to another topic. Osman says this is not an efficient way to learn. "Repeated practice of a method in a short period of time does build up skills and memory, but only for a short period of time," he says. "These skills deteriorate once the topic is ended, such as right after a test." To ensure the information learned enters long-term memory, a different approach is needed.

Osman is an advocate of interleaved retrieval practice as an alternative. "This practice takes place when the memory retrieval process is spaced-out, with topics overlapping with one another in time," he says. This means that rather than teaching one topic after another, they are instead enmeshed over a longer period of time. This means that students will return to a topic after learning something else, rather than learning a whole topic at once. "This process involves some forgetting, but this can be a good thing," says Osman. "When memory retrieval is more challenging,



Teachers at a summer workshop

Students working on a team project

it ultimately forms a stronger and longer-lasting memory."

A related and complementary technique is generative retrieval practice, which does not teach specific solutions to specific questions, but rather encourages students to decide what solution is appropriate. This draws on computational thinking. "We need to teach students to make a habit of using inductive and deductive thinking regularly, and in a cyclical fashion," says Osman. "This will mean that when they are taught a concept, they will first break it down (deductive thinking), and then use its constituents to understand new or modified concepts (inductive thinking)."

OVERCOMING CHALLENGES

With less efficient teaching methods, students can struggle to find STEM subjects engaging, especially when they feel overwhelmed by large quantities of facts to remember. Osman is keen to dispel such negative perceptions. "Learning can be a joyful activity with the right strategy in place," he says. "The challenge is that implementing a new strategy usually goes against the status quo." STEM involves a lot of problem-solving, which is best approached through deductive and inductive thinking. Training teachers to use these learning strategies is, Osman believes, key to changing perceptions and helping students become more enthusiastic about STEM – but they cannot do it alone.

"To help teachers enact these changes, they need the support of their schools," says Osman. "This applies to training, equipment, and the freedom to apply these new strategies." Educational organisations can often help with this, and Osman has a database of lesson plans and curriculum modules that can kick-start this process. "The first thing that's needed is the desire from the teacher to employ this new strategy," he says. "They can then become part of a community of like-minded people. From there, they need to obtain the support of their school administrators." Osman has already helped many teachers meet these challenges, and hopes to do the same for many more.

BUILDING A SMART ENERGY SYSTEM FOR THE PEOPLE OF PETERBOROUGH

LED BY **PETERBOROUGH CITY COUNCIL**, IN THE UK, THE **PIRI PROJECT** WILL DELIVER ENERGY FOR THE PETERBOROUGH COMMUNITY THROUGH AN INTEGRATED RENEWABLE ENERGY SYSTEM THAT COULD BE A BLUEPRINT FOR OTHER CITIES IN THE UK AND BEYOND

KEY TERMINOLOGY

ANAEROBIC DIGESTION – the process of bacteria breaking down biodegradable material

ENERGY CONSULTANCY – a company that advises clients on their energy consumption

ENERGY FROM WASTE – the process of generating energy in the form of electricity and/or heat from the primary treatment of waste, or the processing of waste into a fuel source

HEAT NETWORK – a distribution system of insulated pipes that takes heat from a central source and delivers it to a number of domestic or non-domestic buildings

INFRASTRUCTURE – the systems, facilities and structure that enable a town or city to run (such as transport and roads, water and sewage, and electricity networks)

LOW-CARBON ENERGY – energy that produces very little carbon dioxide, such as wind, solar, hydro or nuclear power

PHOTOVOLTAIC (PV) – the conversion of light into electricity

RENEWABLE ENERGY – energy that comes from natural sources or processes that are constantly replenished

SMART CITIES – cities that use technology to optimise city functions, promote economic growth and improve the quality of life for citizens

SOLAR THERMAL PANELS (STP) – panels used to collect and convert solar energy into heat

In our current age of the climate crisis, there are many challenges facing society; it can be all too easy to dwell on the problems and forget the incredible innovation that many people are working hard to develop. There is no escaping that our modern lives demand a huge amount of energy, and that energy needs to be affordable and sustainable. We need to be 'smart' about where we get our energy from and how we use it.

Creative thinking and ambitious collaboration are providing the solutions we need. There are many ways to generate energy, keep prices manageable and ensure that the negative impacts of energy consumption on the environment are minimised, which is where the innovative Peterborough Integrated Renewables Infrastructure (PIRI) project is leading the way.

INTRODUCING PIRI

The PIRI project is an exciting initiative that aims to deliver low-cost and low-carbon-emission energy for the Peterborough community. It is composed of six collaborative partners: Peterborough City Council, which manages and understands the future of the city; Cranfield University, which develops and shares scientific and engineering knowledge; SSE Enterprise, a major energy producer and supplier; Element Energy, a specialist energy consultancy with expertise in energy system analysis and design; Sweco, a large specialist energy consultancy with international expertise in heat network development; and Smart Grid Solutions, a specialist software and energy system management company.

Professor Phil Longhurst, based at the Centre for Climate and Environmental Protection at

PETERBOROUGH INTEGRATED RENEWABLES INFRASTRUCTURE

PETERBOROUGH CITY COUNCIL AND THE PIRI PROJECT TEAM

FIELD OF RESEARCH

Smart City Infrastructure

RESEARCH PROJECT

The Peterborough Integrated Renewables Infrastructure (PIRI) project: delivering 'clean' energy for the Peterborough community and providing a blueprint for other cities in the UK and beyond

FUNDER

This project is part-funded by Innovate UK under the Prospering From the Energy Revolution (PFER) programme

Cranfield University in the UK, tells us more about the project...

WHAT ENERGY SOURCES ARE CURRENTLY AVAILABLE IN PETERBOROUGH AND HOW WILL THEIR USE BE DEVELOPED?

Like all major UK cities, Peterborough is connected to the national gas and electricity grid. However, it also has its own energy-from-waste plant, known as the Peterborough Energy Recovery Facility (PERF). "In the future, Peterborough plans to develop the use of solar thermal panels (STP) for heat, as well as photovoltaic (PV) solar panels for electricity," explains Phil. "It can also use ground-source heat pumps and anaerobic digestion for gas energy."

The fact that Peterborough already has its own PERF, as well as a city centre and surrounding industries nearby that can supply and use heat and electricity on a nearby grid, makes it a particularly suitable location for a 'smart energy system'.

HOW IS THE PROJECT BEING INITIATED?

Phil and the team are beginning by looking at larger energy consumers. The aim of this is to collect data from companies that can be used and analysed to shape the future direction of the project. "We are collecting data on how much electrical and heat energy is needed for each large firm in the city, as well as the energy that can be produced by these industries, in particular heat," says Phil. "Many industrial processes produce heat which is not used and lost to the atmosphere. Indeed, this is currently the case for PERF which could heat a hot water grid for part of the city."

HOW WILL SMART ENERGY MANAGEMENT BE USED TO MEET DEMAND AND BALANCE SUPPLY IN THE CITY?

Heat energy can be stored using hot water and large insulated tanks. This can be heated when demand is low and released onto the hot-water grid when demand increases. While electricity is more difficult to store, it can be supplied to the national grid for other UK users to access at night when demand is low. Alternatively, local users can be encouraged to use electricity at night – for example, for industry or charging vehicles – when demand is low.

HOW WILL PIRI REDUCE THE AMOUNT OF CARBON BEING USED TO GENERATE ENERGY?

One of the most crucial elements of PIRI is balancing supply and demand, so there is a reduction in demand for fossil fuels by creating a grid that helps strike this balance – particularly during the day. Heat energy is a major cause of fossil fuel demand for the UK, so changing the times at which this form of energy is used will redress the problem. By designing a city-wide grid, new forms of energy can be connected, such as solar PV and STP from local premises, as well as new sources, such as using heat from the River Nene, wind power, or even anaerobic digestion to produce flammable gas from organic wastes, such as sewage.

WILL PIRI HAVE AN IMPACT ON THE LIFE OF THE AVERAGE PETERBOROUGH CITIZEN?

Yes! PIRI should reduce energy costs for users. "PIRI will allow energy users and suppliers in the community to benefit by supplying excess energy, as well as requesting energy from the local grid," explains Phil. "The local electricity grid will also be connected to the national electricity grid to help balance supply and demand. This facility could also encourage new industries and jobs to be created from lower cost and more reliable energy supplies."

Peterborough Energy Recovery Facility (PERF) – used to generate electrical and heat energy from waste

THE THREE STRANDS

THE PIRI PROJECT IS FOCUSED ON THE THREE AREAS OF ELECTRICITY, HEAT AND MOBILITY. WHILE THE STRANDS ARE RELATED, MAKING THEM DISTINCT ENABLES THE TEAM TO FOCUS ON WHAT EACH AREA REQUIRES TO BE SUSTAINABLE.

ELECTRICITY

Creating a local electricity network reduces the strain on the national grid and enables the system to meet local demand with local production. The team is collecting data from energy users and analysing it to understand current and future demand for electricity.

From here, it is hoped that current supplies can be assessed and new opportunities for supply can be created. Without affordable energy, businesses can close and households go cold. There are a huge number of benefits that the PIRI project can facilitate through a local electricity network.

HEAT

The Peterborough Energy Recovery Facility (PERF) is already demonstrating how heat loss can be minimised. It is worth acknowledging that some heat loss is essential for the system to work efficiently (in a similar way that cars have radiators to keep the engine cool) but, long-term, heat and electrical energy will be saved.

This will also have the effect of reducing energy costs and could attract new industries – if Peterborough is at the forefront of clean and efficient energy initiatives, it is likely that businesses will want to set up a base there.

MOBILITY

The creation of a local electricity network will have benefits for mobility, especially in terms of powering electric cars, buses and trains. A local low-carbon infrastructure will help connect Peterborough's public transport into the wider system, as well as providing charging points for individuals.

We often take transport for granted, but if the energy we use to facilitate transport can be made cleaner, then the benefits could be significant.

MEET THE PIRI TEAM

COMMERCIAL MANAGER: *ENERGY, INFRASTRUCTURE AND REGENERATION AT PETERBOROUGH CITY COUNCIL, UK*

ELLIOT'S TOP TIPS

Do what you have an interest in, don't give up, and remain resilient. Be alert to opportunities and take them when they are presented. Put effort in to get rewards out. Remain open minded and take every opportunity to learn new skills and gain new knowledge.

ELLIOT SMITH

As Programme Lead, I am responsible for leading the project and facilitating collaborative decision making, influencing others to agree what needs to be done and how best to do it, developing the culture within which we work, setting the vision and aims and enabling individual and collective efforts to achieve these shared objectives. The role is a strategic approach to the outcomes that we want to achieve from PIRI, but which often becomes quite granular and technical in nature.

There is no typical day as the project is so varied and this is the excitement of PIRI. We may be discussing project management tasks, actions and risk helping to drive the programme forward, then legal and regulatory considerations, and technical issues, with regard to the design, stakeholder engagement, investment and finance. There is a great variety and a steep learning curve.

The key professional challenge is leading a project in an area that can be very technical. This has required a lot of new learning to understand the terminology used, the approaches taken and the underpinning technologies. I am always learning new things, which again adds to the excitement of working on a project like PIRI. I am working with people who are highly skilled in their areas, who take the time to explain complex information. For me, this is invaluable and whilst I may not understand every aspect of the scheme in the level of detail that they do, I have developed enough knowledge to be able to contribute to discussions and make decisions.

There have been many highlights, but overall is observing and being involved in the development of the project. There have been many ups and downs and various challenges to navigate, but we have overcome them. Overcoming these issues, which at times appear insurmountable, is very rewarding and gives us confidence for the challenges that lie ahead.

I have been interested in the broader concept of 'smart cities' and the benefits this can bring for residents and businesses for a number of years. Energy and climate change initiatives are a critical part of this. I am a qualified lawyer and although law may seem like a very different subject, my legal skills do translate well into this area of work, specifically analysis and assessment, written and communication skills, risk management, organisation and research.

My immediate ambition is to see PIRI grow to become a successful smart local energy system which benefits the city and helps achieve decarbonisation. I am proud of this project as a whole and what it could become. From initially thinking about how it might work, drawing lines on a plan and developing the consortia to where we are now. It has been very difficult at times, but the outcomes that we can achieve keeps us all going.

When I was at school, geography wasn't a particularly interesting or engaging subject. My children are studying geography now and it is completely the opposite! I read through their course books and have discussions with them about all kinds of things, from regeneration to climate change. Human geography, in particular, is very much relevant to what I am doing.

Peterborough is a city in Cambridgeshire in England, in the UK. The PIRI project will deliver 'clean' energy for the Peterborough community and provide a blueprint for other cities in the UK and beyond.

PIRI PROJECT MANAGER SERCO IN PARTNERSHIP WITH PETERBOROUGH CITY COUNCIL

CLAIRE'S TOP TIPS

Work hard, be prepared for good times and bad times, but use both experiences to improve yourself. Be tenacious, confident, a good communicator and listener. Even if you have a career path in mind now, do not let that dictate to you that that is the career path you have to take – it's fine if it doesn't go according to plan. I wanted to be a bank clerk, then a teacher!

CLAIRE EVANS

My role as the PIRI Project Manager (PM) involves the day-to-day management of the project work, ensuring agreed deliverables are produced and issued in line with the agreed project plan, whilst maintaining governance across all the work packages within the programme.

A typical day for me varies! Some days are busy with meeting after meeting, discussing/progressing different elements of the project. Other days are spent updating/creating/reviewing documentation needed to ensure a successful project.

For me as PM, the rewards have been seeing the innovative project develop into a proposed scheme, from essentially a blank piece of paper (all whilst in lockdowns), and knowing if we can get this project to construction, the impact the blueprint will have, not only on opportunities to improve smart green energy systems in UK but also across the World, will be huge.

I started my PM career working for the National Grid many years ago and have moved and developed my PM skills across other industries since then. I have developed a unique ability to be able to turn my skills to whatever project I am asked to deliver. To be asked to PM PIRI was a very exciting opportunity for me. It's amazing how much you remember and understand during technical, engineering meetings!

I am very proud to have my name associated with PIRI – regardless of the outcome. I feel the work the team is doing is so unique, that just trying to come up with a scheme with the potential to be rolled out worldwide is a huge achievement. As for career ambitions, who knows where PIRI will take me once it's completed.

I started my working career after completing an administration course at college, providing administrative support to companies, and worked my way through to become a project manager. Since then, the projects I have managed have grown in size, budget and importance, through ongoing project management training courses. You never stop learning!

DIRECTOR OF URBAN RESILIENCE SWECO UK

DR TANJA GROTH

Sweco is the largest engineering consultancy in Europe, and for PIRI we act as the technical lead, supporting with the drawings, calculations and design for the upgrades to the electricity and heating networks supplying power and heat to stores and homes in the city centre.

I go to a lot of meetings! There are a lot of people involved in delivering this project, and I am responsible for coordinating the ones involved in the technical design. This means checking that we are asking the right questions and that the answers we are providing solve the questions that our partners are asking. It also means checking that we stay on time for our drawings and calculations and check that we are not missing anything!

This project demands I keep track of details, which can be a challenge. Working on other projects means deadlines can also be a struggle. I have a colleague who supports me (and keeps me on my toes). Also, my colleagues in the partner organisations are great at giving me a nudge!

The mix of people working on this project is a huge highlight for me. We have a great dialogue across the different partnering organisations, especially since most of us have only met once or twice in person due to COVID. Lots of laughs, open discussion and sharing of ideas between us in our meetings (we have a lot on Thursdays, affectionately known as "PIRI Thursday").

I have mostly worked for non-profits, start-ups and small to medium-sized enterprises (but am now at the largest engineering consultancy in Europe, which is quite a change!) and my background in collaborating across a lot of technical and non-technical companies working with renewable energy and the climate emergency made me a natural fit to working on this project.

There so many achievements I'm proud of. I started my career as an intern working at a non-profit community energy organisation in Denmark, convinced a renewable manufacturing start-up to hire me (I was a non-engineer and it took me a year), got my PhD and have worked for some of the best consultancies in my sector. Working on PIRI is very high on my list of milestones. Being invited by the British High Commission to give a keynote presentation on renewable energy at their annual conference is memorable for me. And, I was asked to write the government methodology for socio-economic valuation of heat and energy efficiency projects for Scotland.

Honestly though, it's the people I've learnt from and have shared learning with over the last 15 years that stand out for me. I love that I've had the opportunity to work with some amazing people.

There are two routes into energy economics – one through apprenticeships and one through university. Unfortunately, Sweco does not yet have an apprenticeship scheme for energy economists (since I am the only one in the UK) but other organisations, such as Amber Infrastructure and FTI Consulting, offer this route. The university route is more conventional, but you don't get a chance to specialise until after your undergraduate degree. I spent 10 years at university to be able to specialise. I am lucky that Danish universities are free!

TANJA'S TOP TIP

Learn statistics, the science of negotiation and MS PowerPoint/Excel. The median (similar to average but not quite) age in the UK is over 40 years. What do you think that means for you when you join the labour market? There are upsides and downsides, but the youngest successful colleagues we have are the ones who are good at those things.

The SSE rechargeable, battery-powered bus travelling from Peterborough to Glasgow for COP26

PIRI IN NUMBERS

PIRI aims to achieve significant carbon reduction, cost savings for consumers and to demonstrate an integrated energy scheme that can be replaced across the UK:

- 8.5km of network by 2030, with the potential to expand to 26km in the 2030s
- 70 Aragon Direct Services vehicles will be electrified by 2025
- 25 Giga Watt hours (GWh) of heat supplied to connected buildings annually by 2030, up to 60GWh by 2035
- 80GWh annual electricity demand identified for connection to low-carbon power network
- 7 Mega Watt peak (MWp) ground-mounted solar PV array installation, servicing buildings and electrical vehicle charging
- 80 – 90% CO_2 emissions savings, or up to 200,000 tonnes of CO_2 reduced over 40 years

SENIOR CONSULTANT ELEMENT ENERGY, LONDON, UK

SAM BENJAMIN

Element Energy is leading the 'concept design' of the PIRI project. This involves coordinating and developing the technical details of the project, and understanding the investment required to make the project happen. We are trying to answer the questions: "Will this project make money, whilst also reducing carbon emissions? What can we do to enhance carbon emission reductions and make the scheme more profitable?".

I manage the internal Element Energy team, as well as coordinating the wider PIRI project teams, to develop this concept design. I also directly run the financial analysis, to understand whether PIRI is financially viable (i.e. whether it will make or lose money). If it's not financially viable then PIRI is unlikely to happen, so it's an important role to play.

The key challenge for PIRI is how we make the project greater than the sum of its parts, as we are trying to integrate several low-carbon energy networks into one system. That requires a lot of joined-up thinking between all project partners, which means I am talking to a lot of different people with different ideas and motivations, so managing that can be challenging. The knowledge that, when built, PIRI will stop a huge amount of carbon dioxide being emitted into the atmosphere (up to 5,000 tonnes per year!) is hugely motivating.

I studied chemical engineering at university, but knew I wanted to use my science/engineering skills to solve the major challenges we face today. I took university modules relating to energy and the environment and followed that path from the start of my career.

I am proud of devising a smart, innovative engineering design that goes beyond what was initially expected. My ambition is to help as many people as possible understand the challenges we face with climate change, and what they can do to combat those challenges.

My advice is: study maths! If you study engineering at university, you will almost certainly study maths. At school, it may not feel like what you are learning in maths classes has meaning, but all the concepts and analysis methods will allow you to solve real-world engineering and technical problems. I promise you that algebra and calculus really are useful in the real world!

SAM'S TOP TIP

If you're planning on pursuing engineering as a profession, get as much technical/ 'on-site' experience as you can, before or after you begin your career. Whether you're a consultant, a design engineer or a project manager, understanding engineering systems is key to progressing your career.

EXPLORE A CAREER IN SMART ENERGY INFRASTRUCTURE

- Find out about internship and summer placements offered by Sweco: **www.sweco.co.uk/careers/internships-placements/**
- Explore the apprenticeship, trainee and graduate programmes and summer placements offered by SSE Enterprise: **careers.sse.com/early-careers**
- Prospects gives some interesting pointers about careers in energy consultancy: **www.prospects.ac.uk/jobs-and-work-experience/job-sectors/energy-and-utilities/7-things-you-need-to-know-about-being-an-energy-consultant**

PATHWAY FROM SCHOOL TO SMART ENERGY INFRASTRUCTURE

- One of the brilliant things about the PIRI project is that it highlights the range of people who work together to achieve a shared goal. And a range of people always means a huge variety of skills, qualifications and personal attributes.
- Having completed a chemistry degree at university before becoming an energy consultant, Sam emphasises the importance of maths, while Claire has developed her career in project management after an administration course at college, and Tanja mentions that her field of energy economics can be entered through apprenticeships or university.
- The PIRI team members have also referred to human geography, law, engineering, design technology and languages, but this is by no means a definitive list of subjects that can lead you to a career in smart energy infrastructure.
- It is vital that you ask yourself where your strengths and passions lie – what do you think you could contribute to a 'smarter' future?

CENTRE FOR CLIMATE AND ENVIRONMENTAL PROTECTION
CRANFIELD UNIVERSITY, UK

PHIL'S TOP TIP

Follow what interests you and find people in work who share your interests. Don't be afraid to be different – everyone is.

PROFESSOR PHIL LONGHURST

I lead the work sharing learning outcomes from the project. It is our role to understand the achievements, challenges and outputs and communicate these to different groups that we work with or who will benefit from the Smart Local Energy System (SLES).

The greatest reward from this project is working with energy experts and colleagues with experience of leading large-scale changes in cities. Highlights from our work include the project launch event, press releases and the visit of the SSE bus to Peterborough on its way to COP26.

My career pathway has taken me from the London School of Furniture to my role at the Centre for Climate and Environmental Protection, via a period of teaching Design and Technology. At each stage, I've had the benefit of working with experts in their field and been encouraged to discuss and develop ideas, as well as make mistakes and learn from them. Working with materials and designing products made me realise the importance of the complete production system. This led me to understand that learning and teaching is more than 'instruction' – it's about organising experiences for people. Research on climate change has since led me to understand the importance of understanding and explaining low carbon living that are feasible experiences in cities.

Working with enthusiastic experts from all fields of expertise such as economics, social sciences, technology and engineering motivates me hugely. The challenge is always having enough time to develop ideas, whilst delivering work to a tight schedule.

My proudest moments are seeing my students and early career staff being promoted and becoming recognised experts in their own fields. My own ambition is to continue to be part of the most exciting and challenging structural change in the energy sector since we moved from watermills and windmills to electricity, back to the similar energy sources with new designs.

Putting effort into being great at what you enjoy most is key. This gives you confidence and helps you learn skills that are transferable to all subjects. Written communication, languages and maths are always a benefit, but the greatest skill is completing things that are difficult and not giving up.

Drone image of willow and miscanthus taken in March 2021 at the Sustainable Bioenergy Centre (BSBEC). Credit: Institute of Biological, Environmental and Rural Sciences, Aberystwyth University, UK

CAN PLANTS AVERT THE CLIMATE CRISIS?

GROW PLANTS, BURN THEM FOR ENERGY, THEN BURY THE CARBON DEEP UNDERGROUND. THIS IS THE PRINCIPLE BEHIND BIOMASS ENERGY WITH CARBON CAPTURE AND STORAGE, BUT HOW EFFECTIVE CAN IT BE IN THE REAL WORLD? **DR ASTLEY HASTINGS**, FROM **THE UNIVERSITY OF ABERDEEN**, HAS BEEN INVESTIGATING

TALK LIKE AN ENVIRONMENTAL SCIENTIST

FOSSIL FUELS – materials made over millions of years from decomposed plants and animals that are burnt to produce energy

HYDROCARBONS - chemical compounds that contain the elements carbon and hydrogen

AFFORESTATION – the planting of new forests

BIODIVERSITY – the variety of life and number of species on Earth, which is currently in decline

Our planet is getting warmer. You will have seen in the news that this is already causing sea level rise, extreme floods, heatwaves and wildfires around the globe. The good news is, we know exactly what we need to do. To stop climate change from running out of control, we need to stop increasing the amount of carbon dioxide in the atmosphere.

To stabilise carbon dioxide, we need to change the way we generate our energy. This means leaving behind fossil fuels for new technologies such as wind turbines, solar panels and something called Biomass Energy with Carbon Capture and Storage (BECCS). But how do we find the right mix of these technologies, ensure we have enough energy, and minimise our impact on the environment? Dr Astley Hastings, a researcher at the University of Aberdeen, has been looking at the potential of BECCS in the UK and around the world, to help us answer exactly that.

HOW DOES BECCS WORK?

As with almost all energy sources on Earth, BECCS ultimately relies upon the sun. Plants use the energy of the sun to capture carbon dioxide from the air. In this process (called photosynthesis) the carbon is used to build the roots, stems and leaves of the plant. Collectively, this material is known as biomass.

If you have ever made a campfire or lit a wood-burning stove, then you have used biomass energy. When biomass burns, the energy stored up during photosynthesis is released as heat and light, which we can then use to generate electricity. At the same time, the carbon stored in the biomass is converted back into carbon dioxide. Overall, biomass energy reduces carbon dioxide in the atmosphere while the biomass is growing, then increases it by the same amount when the biomass is burnt.

What if we could stop that carbon dioxide from going back into the atmosphere? This is the idea behind carbon capture and storage. Chemicals called amines can be used to separate carbon dioxide from other gases released at a biomass power station. Following this, it can be stored by sealing it into rocky reservoirs deep under the ocean. That way, BECCS can produce useful energy while also reducing atmospheric carbon.

WHY DO WE NEED BECCS?

Imagine there is a leak in your roof, and you have put a bucket underneath to catch the water coming through. You are trying to fix the leak, but the bucket is nearly full and some drips are still coming through. What will you do? You will probably think of a way to remove water from the bucket before it overflows.

This is a bit like our situation with carbon dioxide in the atmosphere. To halt climate change, we must keep carbon dioxide below a

certain level. The best way to do this is simply to stop adding more, but there are some emissions that are difficult to get rid of, and we are starting to run out of time. Therefore, in addition to reducing emissions, we need to use technologies such as BECCS that actively remove carbon dioxide from the atmosphere.

TOOLS OF THE TRADE – SPATIAL MODELS AND LIFE CYCLE ASSESSMENTS

Astley has two important tools for researching the potential of BECCS. The first of these is spatial modelling, which he uses to estimate how much carbon can be captured by plants around the world. A scientific model is a set of equations and logic called algorithms, designed to mimic the behaviour of nature. For example, an algorithm inside Astley's models could be an equation that calculates the growth rate of a species of plant based on rainfall levels, hours of sunshine, and soil fertility and wetness. Each algorithm inside the model is based on scientific experimentation, and coded into a computer program. Given a set of input information – for example, climate and soil type – the computer program can apply the algorithms to predict what the modeller is interested in, such carbon accumulation.

The second important tool is life cycle assessment (LCA), which Astley uses to find the overall impact of BECCS on the environment. The idea behind LCA is to make sure absolutely everything is accounted for. In the case of BECCS, this means producing seeds, ploughing the soil, sowing the seeds, protecting the plants from weeds and insects, harvesting, transporting the biomass, generating electricity, transporting the captured carbon dioxide, and securely storing it offshore. For each step of the processes, the impacts of energy usage, materials, equipment and waste are all added up.

HOW MUCH CARBON CAN BECCS CAPTURE IN THE UK?

One of the tasks for Astley and his research team is to find out exactly how big a role BECCS can play in slowing climate change, and they have discovered that the UK may need to reduce its expectations. As part of its plan to reach net zero by 2050, the UK set a target to capture and store 50 megatonnes of carbon dioxide each year. That would be enough to fill 10 million swimming pools, even when pressurised into liquid form. However, to achieve this, a huge area of good quality agricultural land (3% of the country) would need to be converted for biomass production. In fact, Astley discovered that only half of the 50 megatonne target could be reached sustainably, considering the limited space the UK has for growing food as well as biomass.

IS THERE A ROLE FOR THE OIL AND GAS INDUSTRY?

Scientists agree that fossil fuels need to be phased out soon, but Astley believes that oil and gas companies will still play an important role in the future. For BECCS to be effective, the carbon will need to be securely trapped in rocky reservoirs deep under the sea. This kind of operation will require strong expertise in geology and engineering, as well as industrial-scale offshore machinery, and here is where the fossil fuel industry can help. As we make the move away from fossil fuels, the industry could change its focus from producing hydrocarbons to using its skills to remove carbon dioxide from the atmosphere instead.

DR ASTLEY HASTINGS

Reader,
University of Aberdeen, UK

FIELD OF RESEARCH

Environmental Science

RESEARCH PROJECT

Investigating how much carbon can be captured by plants in different climates and soils around the world to help predict the potential of Biomass Energy with Carbon Capture and Storage (BECCS)

FUNDER

Natural Environment Research Council (NERC)

ARE THERE OTHER WAYS IN WHICH PLANTS CAN TACKLE CLIMATE CHANGE?

The UK is already making use of biomass energy at Drax Power Station in North Yorkshire. However, BECCS is not the only way in which plants can help us remove carbon dioxide from the atmosphere. For example, growing trees, then using the wood for construction means the carbon becomes locked up in the beams of buildings. Instead of growing plants specifically for biomass energy, waste products from agriculture and the timber industry can be burnt instead. Furthermore, afforestation and protecting old forests are ways to absorb carbon while also protecting biodiversity.

These plant-based solutions are all part of the climate change puzzle, but Astley stresses that "land is the limiting factor". In a world where we also have billions of people to feed, and vital ecosystems to protect, BECCS will need to be accompanied by a sharp drop in carbon emissions over the coming decades and that will require all of us consuming less and being conscious that everything we do or buy causes emissions.

A lab trial with Dr Lin Huang and Dr Kai-uwe Schwarz. Credit: Professor John Clifton Brown.

ABOUT ENVIRONMENTAL SCIENCE

How do the materials we use, the chemicals we produce and the energy we consume affect the Earth's atmosphere, land and oceans, as well as the web of living creatures it supports? This is the broad question that environmental scientists tackle, by bringing together expertise from fields including engineering, geoscience, geography, ecology, biology, physics and chemistry.

WHY DO WE NEED ENVIRONMENTAL SCIENTISTS?

You have probably heard of many environmental problems: the widening of the ozone hole, acidic rain, oil spills and air pollution are just a few examples. When things go wrong, we put our own health and well-being at risk, as well as that of other species. The job of environmental scientists is to identify these risks, monitor them, and search for sustainable solutions. Unfortunately, environmental problems are becoming more common and more severe, with climate change and biodiversity loss being the two most critical examples. That is why environmental scientists will have such an important role in the future.

WHAT DO ENVIRONMENTAL SCIENTISTS DO?

Because environmental science covers such a broad range of disciplines, the job could include all sorts of things on a day-to-day basis. While some environmental scientists are measuring ice depths in Antarctica, others will be flying drones over agricultural fields, counting bats, performing experiments in the lab, evaluating the impact of industry, mining and construction on the environment or running computer simulations. On top of this, environmental scientists will spend time analysing their data, drawing graphs and writing up their results.

PATHWAY FROM SCHOOL TO ENVIRONMENTAL SCIENCE

- Most environmental scientists will come to this discipline during their PhD or after working in industry.
- The first step after school is usually to do an undergraduate degree in ecology, engineering (like Astley), biology, physics, chemistry, maths, computer science, geology or geography.
- To apply for these degrees, you will need to study maths and science subjects at school, but remember that writing and creative skills are also important.

EXPLORE A CAREER IN ENVIRONMENTAL SCIENCE

- The Natural Environment Research Council (NERC), which funds environmental research, has videos of environmental scientists explaining what life is like in their chosen careers: **nerc.ukri.org/skills/careers/scientist**
- Target Careers lists such a broad range of careers in environmental science that it is difficult not to be inspired! **targetcareers.co.uk/careers-advice/choosing-your-career/894159-environmental-careers-and-how-to-get-them**
- Prospects offers some great tips on how to get an environmental job: **www.prospects.ac.uk/jobs-and-work-experience/job-sectors/environment-and-agriculture/how-to-get-an-environmental-job**

OTHER CAREERS IN AFFORESTATION AND BECCS

- The future carbon capture industry will create new jobs in the coming years.
- Afforestation will require foresters to manage the trees, carpenters to use the wood, architects to design sustainable buildings and engineers to design forestry machinery and wood manufacturing processes.
- BECCS will involve plant breeders, biologists and farmers in growing the crops, as well as engineers with specialities in harvesting machinery, power plants, pipelines and offshore drilling.

HOW DID ASTLEY BECOME AN ENVIRONMENTAL SCIENTIST?

DID YOU ALWAYS KNOW YOU WANTED TO BE AN ENGINEER WHEN YOU WERE YOUNGER?

No, my first career choice was to join the navy, for which I needed to study STEM subjects. But as I was doing A-levels in physics chemistry, history and maths I became more interested in science and its applications. I was also interested in how stuff worked, so I changed course, got a student apprenticeship in mechanical engineering, and eventually became a chartered engineer.

WHY DID YOU MAKE THE MOVE FROM MECHANICAL ENGINEERING TO ACADEMIA?

I was always interested in the environment, and it became more and more important from an industrial point of view to make the working environment safer and more pleasant. I also saw a gap in scientists' understanding of the practicalities of industry needing to provide food, goods and services to the population. With my engineering background I thought I could help to bridge that gap, so I studied for an MSc then a PhD in environmental science.

ARE YOU CONFIDENT THAT WE WILL BE ABLE TO KEEP THE GLOBAL TEMPERATURE WELL BELOW 2 °C ABOVE PRE-INDUSTRIAL LEVELS?

No, I worry it will be hard for China, Brazil and India (and some other developing countries) to continue industrialising and improving living standards while reducing carbon emissions.

WHAT DO YOU DO, AT AN INDIVIDUAL LEVEL, TO LESSEN YOUR IMPACT ON THE ENVIRONMENT?

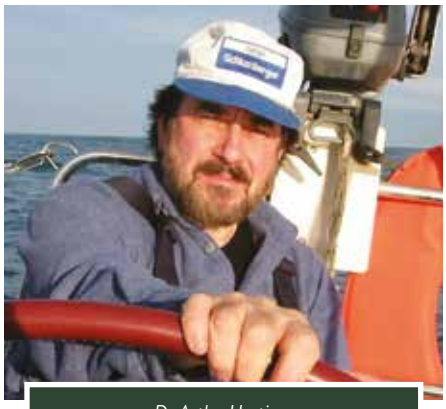
I only fly for work, and I only eat meat twice a week. I have also installed a wind turbine and heat pump at my house, and generally try to drive as little as possible: I worked from home even before the COVID-19 lockdown!

WHAT DO YOU LOVE ABOUT YOUR WORK?

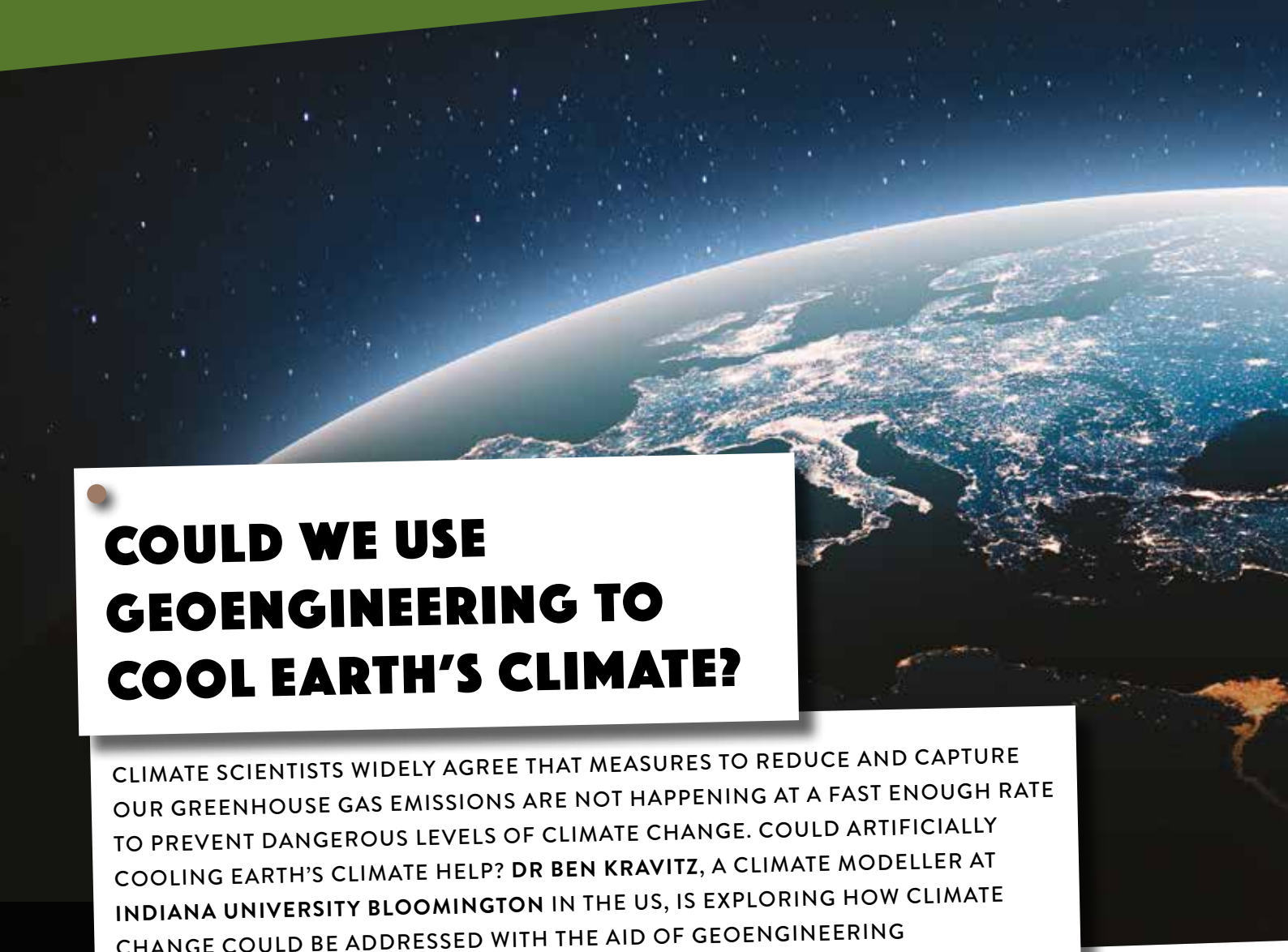
I love doing science research, transferring science to practice and mentoring my students.

Miscanthus (commonly known as Elephant Grass) is a high yielding crop that grows over 3 metres tall, resembles bamboo and produces a crop every year without the need for replanting. This is an image of the Penglais Eddy Covariance Experiment. Credit: Professor John Clifton-Brown

Different types of bioenergy grass. Credit: Dr Olena Kalinina



Dr Astley Hastings



COULD WE USE GEOENGINEERING TO COOL EARTH'S CLIMATE?

CLIMATE SCIENTISTS WIDELY AGREE THAT MEASURES TO REDUCE AND CAPTURE OUR GREENHOUSE GAS EMISSIONS ARE NOT HAPPENING AT A FAST ENOUGH RATE TO PREVENT DANGEROUS LEVELS OF CLIMATE CHANGE. COULD ARTIFICIALLY COOLING EARTH'S CLIMATE HELP? **DR BEN KRAVITZ**, A CLIMATE MODELLER AT **INDIANA UNIVERSITY BLOOMINGTON** IN THE US, IS EXPLORING HOW CLIMATE CHANGE COULD BE ADDRESSED WITH THE AID OF GEOENGINEERING

TALK LIKE A CLIMATE MODELLER

GEOENGINEERING – large-scale, artificial changes to Earth's atmosphere, which could temporarily help prevent the climate from heating to dangerous levels

GREENHOUSE GASES – gases in the Earth's atmosphere that trap heat and prevent it from leaving the atmosphere. Greenhouse gases include carbon dioxide (CO_2), methane, nitrous oxide, chlorofluorocarbons, ozone and water vapour, but CO_2 is the biggest issue

AEROSOLS – tiny solid particles or liquid droplets that can be suspended in the air, where they can interact with the Sun's light

CLIMATE MODEL – computer programs that can simulate how the many different elements of Earth's climate interact with each other

Climate change is perhaps the single most urgent challenge our planet faces. To prevent dangerous levels of atmospheric warming, we not only need to reduce our greenhouse gas emissions to zero, we must also remove some of these gases from our atmosphere. Measures to reduce the impact of climate change are being taken, but much more needs to be done – and quickly – to avoid catastrophic changes to Earth's climate.

In light of this, scientists are investigating the use of geoengineering to temporarily offset global warming. Geoengineering can include many techniques but, overall, it is a deliberate, large-scale intervention in the Earth's natural systems to counteract climate change.

Dr Ben Kravitz is a climate modeller based at Indiana University Bloomington. Ben and his team use climate models to understand the risks associated with geoengineering. They want to provide policy makers with as much information about geoengineering as they can so that the decision on whether to use this technique or not is as well informed as possible.

WHY ARE SCIENTISTS CONSIDERING THE USE OF GEOENGINEERING?

As mentioned, geoengineering is a large-scale intervention that can involve many different techniques and technologies (see About Geoengineering). One such scheme is adding aerosols to the stratosphere.

In nature, erupting volcanoes throw out, among many other things, sulphur dioxide. If ejected with enough force, the sulphur dioxide can make it to the stratosphere, where it gets converted into sulphate aerosols. Up in the stratosphere, these sulphate aerosols can last a few years and reflect radiation from the Sun back into space, cooling the Earth's lower atmosphere or troposphere.

By mimicking erupting volcanoes – in other words, dispensing sulphur dioxide into the stratosphere using aeroplanes – geoengineering could buy us the time we need to put other, more long-term measures in place.

WHY DO WE NEED CLIMATE MODELS TO STUDY THE EFFECTS OF GEOENGINEERING?

Earth's climate is a deeply interconnected web of systems; storms, ice sheets, ocean

currents and much more affect our climate's behaviour. Because of this, it is crucial for scientists to study the possible impacts of geoengineering on these systems. Computer models – also known as climate models – can help predict the outcomes of numerous possible geoengineering scenarios. For example, how the climate might respond to aerosols released at different altitudes, latitudes, or times of year.

"Climate models are run on supercomputers. They have an atmosphere, an ocean, a land surface, sea ice, and many other things, and all those different components talk to each other," says Ben. "Air and water move around inside the model and interact with energy from the Sun. Computer models are a great way for us to model something we can't do in the real world. We don't want to just "try" geoengineering to see what would happen because we don't get do-overs in case anything goes wrong."

As Ben says, climate models are a simulation of the real world and many research teams are working to make their models as accurate and close to reality as possible. But, in the real climate system, there are many processes that are either too complex or not understood well enough to fully simulate. This means that different climate models from different research groups produce slightly different predictions.

Ben's team is comparing the results of geoengineering simulations from multiple climate models. In this way, it can find the points where models widely agree, enabling them to make better predictions about how the climate will be altered when particular changes are made to the atmosphere.

WHAT WILL HAPPEN IF WE PUT GEOENGINEERING INTO ACTION?

If we simply release vast amounts of aerosols into the atmosphere without understanding some of the consequences, their effects could ripple out in unpredictable ways. Many climate scientists are strongly opposed to geoengineering. As Ben says, "Geoengineering may be risky, and we only have one planet. We don't want to just try geoengineering, because if something bad happens, it could harm a lot of people."

Given that the impact of geoengineering is uncertain, with so many variables involved, it is very difficult to predict what will happen if we geoengineer our climate. Therefore, Ben and his team are asking a different question: 'Can geoengineering achieve certain goals?' Starting with a goal in mind (for example, a particular global temperature), the team is working backwards to determine which techniques would enable us to reach this goal. Indeed, there are many other possible goals, which the researchers are exploring to find out whether these can be met or not.

Ben explains, "When people go to drive their cars, they don't plan where each curve in the road or each pothole is, nor do they plan where everyone else's car is going to be at any given time. Instead, they respond to their environments." This same idea can be applied to geoengineering. If the goal is to keep below a particular global temperature, a certain amount of reflective aerosols could be released into the atmosphere. If the global temperature is still too high, this amount could be increased. But if the global temperature falls too much, the amount would be reduced. "This process of feedback can help us meet our goals, even in such a complicated system like Earth's climate," says Ben.

DR BEN KRAVITZ

Assistant Professor,
Indiana University Bloomington, USA

FIELDS OF RESEARCH

Geoengineering, Climate Modelling

RESEARCH PROJECT

Using climate models to examine the possible impacts of geoengineering, and assessing whether it should be used as a method to prevent climate change

FUNDERS

US National Science Foundation (NSF), Indiana University Prepared for Environmental Change Grand Challenge Initiative

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WHAT HAS THE TEAM DISCOVERED ABOUT GEOENGINEERING SO FAR?

Ben's team has made lots of discoveries, namely that:

- Models tend to agree about a lot of the climate effects of geoengineering
- For many regions around the globe, even a little bit of geoengineering can reduce the harmful effects of climate change. But a few regions could be worse-off.
- There is no single global "thermostat". That is, it is possible to affect multiple things in the climate system simultaneously by injecting aerosols at different locations or in different seasons.
- There is still a lot we do not know!

ABOUT GEOENGINEERING

Climate scientists are studying a wide variety of geoengineering technologies. The most widely researched techniques include injecting sulphur-based molecules into the stratosphere; brightening marine clouds to make them more reflective; and thinning out heat-trapping cirrus clouds.

Despite this research, no geoengineering techniques are close to being ready. There is still much to learn about their impacts and how they will each affect the Earth's climate as a whole.

Britannica has an up-to-date description of many of the geoengineering techniques being proposed: **www.britannica.com/science/geoengineering**

IS GEOENGINEERING A SOLUTION TO CLIMATE CHANGE?

No. If geoengineering techniques are researched extensively enough, they could one day be used to temporarily reduce the effects of climate change – providing us with a few more years to ramp up efforts to reduce our greenhouse gas emissions. All the same, they are not a permanent solution to climate change.

If we keep on emitting greenhouse gases, and then suddenly stop using geoengineering techniques due to unwanted side-effects, the climate would heat up very quickly. This would quickly undo any of the benefits, making the situation even more dangerous than it would have been without geoengineering.

ABOUT CLIMATE MODELLING

Climate models are a key part of geoengineering research and enable climate scientists to accurately recreate the atmosphere within supercomputers. These models help researchers better understand how Earth's climate will change over time.

"Climate models are pretty amazing," says Ben. "We program into them our best understanding of physics, and we feed it some inputs like the Sun, greenhouse gases and a few other things, and it reproduces Earth's climate. We can run experiments that we would never want to run in the real world, or understand what the future might look like with climate change."

Climate models are not perfect, however. As Ben explains, "No matter how well we create them, we're still going to miss some things, so there will always be uncertainties."

PATHWAY FROM SCHOOL TO GEOENGINEERING AND CLIMATE MODELLING

Many different university courses can prepare you for a career in geoengineering and climate modelling, including geography, chemistry, physics, biology, maths, oceanography, meteorology and computer science. "Climate modelling needs everyone it can get," says Ben, "because the climate system has everything in it!"

EXPLORE A CAREER IN GEOENGINEERING AND CLIMATE MODELLING

"Geoengineering has been a fascinating field to work in," says Ben. "It's a privilege to do research that might inform future decisions about how to address climate change. It has also allowed me to ask questions about the climate system that I never would have thought to ask. Climate modelling is also a great field to work in. I get to work on the fastest supercomputers in the world, and I go home at the end of the day feeling like I've made a difference."

• Geoengineering and climate modelling are just two parts of wider field of climate science, which is also linked to environmental science. Indiana University offers education in atmospheric science, the Earth sciences and environmental science. The university also runs a programme called the Indiana Climate Fellows, where students can work directly with communities around the US state of Indiana, helping them develop plans to adapt to climate change.

• Organisations, including the American Geophysical Union (**www.agu.org**) and the Royal Meteorological Society (**www.rmets.org**), have many different resources for students of all levels, including information about careers:
www.agu.org/Learn-and-Develop/Learn
www.rmets.org/careers

• Environmental Science has a section dedicated to climatology:
www.environmentalscience.org/career/climatologist

HOW DID BEN BECOME A CLIMATE MODELLER?

My interests kind of bounced around a lot. I was originally going to be a mathematician, but I failed my qualifying exams, which turned out to be one of the better things that ever happened to me. When I was re-evaluating what I wanted to do, I started thinking about how I loved weather and geology as a kid – I wanted to know how the world worked. Then, I went over and talked to some folks in an earth and atmospheric sciences department, and it felt like I had found my people.

Climate change does worry me, and it keeps getting worse. What gives me hope is that I go to work every day with a community of really smart people who are all working to solve this giant problem. And I also get to be around students who are just as worried as I am, and they're eager to help the world around them. It's sometimes hard to be optimistic in the face of such a big problem, but I also think that when a lot of people get together, they can do amazing things.

Geoengineering isn't just one thing – it can be a lot of things, depending on what the decision makers want done. I think it will be important for the decision makers to figure out what climate they want, or how much climate change they want to offset with geoengineering. And then scientists like me can help them figure out whether geoengineering can actually do what they want it to do and what the side effects might be. All of that needs to happen before I'd feel comfortable recommending or dismissing geoengineering.

Part of keeping positive about the climate crisis is being around researchers, students, teachers and members of the public. All of them are concerned about climate change and want to do something about it. Part of it is trying to focus on things I can do – it doesn't help anyone, especially myself, if I spend my time wearing myself down. There are better things I can do to take care of my mental and emotional health, like spending time with my family and friends, and getting out and enjoying this amazing world as much as I can.

BEN'S TOP TIPS

01 Meet people who are interested in what you're interested in and explore with them. You could even try sending a professor an email – the worst that will happen is that you get told no, which happens to all of us.

02 The most important thing is to figure out what you want to do. You might be interested in the mathematics of climate engineering, solving problems, communicating climate engineering results, negotiating climate treaties, or something else entirely.

03 You're going to be happiest doing what you love every day. For me, I like computers, math, physics, and solving problems, so climate modelling is a great fit.

CAN A CIRCULAR ECONOMY MAKE THE CONSTRUCTION INDUSTRY SUSTAINABLE?

THE CONSTRUCTION INDUSTRY IS RESPONSIBLE FOR 40% OF THE UK'S GREENHOUSE GAS EMISSIONS. **DR DANIELLE DENSLEY TINGLEY** OF THE **UNIVERSITY OF SHEFFIELD**'S DEPARTMENT OF CIVIL AND STRUCTURAL ENGINEERING IN THE UK IS INVESTIGATING HOW TO MAKE BUILDINGS MORE SUSTAINABLE BY REUSING AND RECYCLING EVERYTHING IN THEM

TALK LIKE A LOW CARBON ENGINEER

BUILDING STOCK – the total number of buildings in a given area and the materials stocked within them

BUILT ENVIRONMENT – everything made, arranged and maintained by humans as the setting for human activities, including homes, commercial buildings, government buildings and roadways

CIRCULAR ECONOMY – an economic system that minimises use of resources and creation of waste by sharing, reusing, recycling, and repairing products instead of manufacturing new ones

DECARBONISE – reduce the amount of carbon emitted from the built environment

EMBODIED CARBON – the greenhouse gases produced when making materials, including the extraction of raw materials from the earth, transportation, processing, manufacturing, installation, maintenance and end of life

RETROFIT – the introduction of new materials or technology into a pre-existing building to make it more energy efficient (retrospectively)

One of the largest sources of the greenhouse gas emissions that drive global warming is the construction industry. Construction accounts for roughly 40% of the UK's greenhouse gas emissions. Some of these emissions are embodied – generated by the manufacturing and transport of materials like steel and concrete, rather than emitted directly by the buildings themselves. Other emissions are produced by building operations like heating and cooling or the use of electricity. Dr Danielle Densley Tingley, at the Department of Civil and Structural Engineering of the University of Sheffield, researches strategies for making construction sustainable by reducing the use of new resources.

Instead of using new steel and concrete, the sustainable construction industry of the future needs to be a circular economy: reusing old buildings for new purposes where possible, and reusing building elements and materials from old buildings when new ones are needed. Danielle is working on a project to collect information about the materials currently locked up in the UK's existing building stock.

CONSTRUCTION AND GLOBAL WARMING

Buildings cause operational emissions – greenhouse gases emitted when using the built environment (for example, by heating and using electricity to run computers and home appliances). Switching to a green electric grid can help reduce operational emissions, as can behavioural changes like opening a window instead of turning on air conditioning or heating homes to 18 degrees instead of 20. Improving a building's energy efficiency by installing modern insulation or double glazing also reduces operational emissions.

But, construction is also a major source of embodied emissions. Many of the materials used in buildings are difficult to decarbonise because producing them creates greenhouse gas emissions inherently. For example, the chemical reactions involved in making cement, a key component of concrete, naturally produce carbon dioxide, so the industry is exploring alternatives to Portland cement, which is the type most typically used. "You can have concrete without emissions," explains Danielle, "but for various reasons, this is not currently done at scale."

DR DANIELLE DENSLEY TINGLEY

Senior Lecturer in Architectural Engineering, Department of Civil and Structural Engineering, University of Sheffield, UK

FIELDS OF RESEARCH

Sustainable Management and Conservation of Resources, Circular Economy

RESEARCH PROJECT

Developing a multi-scale framework to assess the circular economy potential of individual buildings, cities and countries

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

Researchers are looking for alternative building materials instead, including organic ones. The construction industry is also very resource-intensive, using over 400 million tonnes of natural resources every year – a rate that cannot be sustained indefinitely. Both emissions and resource use can be reduced by making fewer fresh materials and reusing existing stocks. This is what the circular economy aims to do.

A CIRCULAR ECONOMY

Our current economic system is linear. We extract natural resources, process and manufacture them into products, and discard the products as waste when we no longer need them. In a circular economy, both resource extraction and waste are kept to a minimum by retaining materials in use as long as possible. A circular economy involves a hierarchy of strategies for using materials over their lifetime. Danielle explains, "For the construction sector, this translates to keeping a building for as long as possible, reusing components and materials as the next option, then remanufacturing, then recycling, downcycling and, finally, incineration or disposal if none of the above can be achieved."

An effective circular economy in the construction industry would require new ways of designing buildings. Danielle describes these as "design for adaptability" and "design for deconstruction and reuse." Designing buildings for adaptability means designing them to accommodate changing user needs and a changing climate. Whole buildings should be able to serve different purposes at different times, with minimal change to their structure. Designing for reuse, on the other hand, means creating buildings in a modular way so that they can be taken apart and individual components can be incorporated into other structures. Instead of being demolished when no longer needed, buildings like these would be deconstructed and put back together in new forms – like LEGO bricks.

MOVING TO A CIRCULAR, LOW-CARBON CONSTRUCTION INDUSTRY

Decarbonising the construction industry and turning it into a circular economy is challenging. Decarbonising the existing building stock requires expensive work, like retrofitting building fabric by replacing insulation and installing double glazing. It also requires switching from gas boilers to renewable energy sources for heating, such as air or ground source heat pumps. Retrofitting the 29 million homes in the UK is an urgent and significant task.

Designing new buildings to promote a circular economy is also not easy. Circular building design is an active area of research, with much information and social infrastructure still missing. There are not yet many incentives for circular building design. Large up-front investments are required to achieve benefits at some point in the future, and little regulation exists to encourage circular design. Builders may not be aware of circular design principles or their importance. However, some progress is being made: the Greater London Authority in the UK now requires large development schemes to submit a circular economy statement as part of their planning applications. The statement requires a plan for waste reduction and the reporting of key metrics such as material intensity (kg of material used per m^2 of floor area) and reused or recycled content.

ADDRESSING THE PROBLEM WITH LOW CARBON ENGINEERING

Danielle's research directly addresses the lack of information needed to design a circular economy in construction. With postdoctoral researcher Maud Lanau, Danielle develops detailed case studies, cataloguing how many bricks, steel beams, and other building components are in a building and how they are connected to each other. The case studies are categorised by the purpose and structural type of the building. They are then used as a basis to estimate material stocks in the UK's built environment as a whole and to assess the circular economy potential of the stock. "This means assessing the adaptability of existing buildings," Danielle explains, "and the reuse and recycling potential within the stock. What steel beams can be salvaged and directly reused again as steel beams? If steel can't be directly reused, it can be melted down to form a different steel product."

With two of her PhD students, Will Mihkelson and Charles Gillott, Danielle has developed a tool called Regenerate to measure the circularity of a building design. Regenerate assesses four core circularity principles: design for deconstruction, design for adaptability, circular material selection, and resource efficiency. The circularity criteria are looked at for five building layers – site, structure, skin, services and space – giving an overall estimate of how well the building plan meets the goals of a circular economy. Regenerate is an interactive web tool and is available for anyone to use for free. "Regenerate is being used by the construction sector to explore the circularity of their building designs, to show where improvements could be made," Danielle says. "Hopefully, this will lead to more circular designs and, ultimately, a more resource-efficient built environment!"

ABOUT LOW CARBON ENGINEERING

Danielle's specialism in low carbon engineering is part of the broader field of architectural engineering – a multi-disciplinary approach to the design, construction and operation of buildings. Architectural engineers consider the design of a building's structure, materials, and environmental systems (lighting, heating, and so on) in an integrated way and are at the forefront of solving problems such as achieving a sustainable, low-carbon construction industry. Architectural engineering is both an art and a science, blending creative design and quantitative analysis.

With her focus on the circular economy and low carbon construction, Danielle is passionate about using her engineering skills to reduce the impact of the built environment on the planet. "My research explores sustainable building design solutions, focusing on material impacts, so we can create a built environment that operates within the carrying capacity of the planet," she explains.

HOW CAN ENGINEERS HELP US ACHIEVE NET ZERO EMISSIONS?

Achieving net zero in the construction industry will require new technologies and huge changes in the design of the built environment. Behavioural change is also key, as people must adapt to using fewer resources. Engineers in industry will be critical to finding creative design solutions to the problems of decarbonisation and sustainability.

In academia, much more research is needed about the circular economy. This research includes understanding our current material building stock and how much of it can be reused or recycled. It will also need to investigate the effectiveness of different building designs for promoting sharing and reuse of buildings or deconstruction and reuse of materials. Finally, the behavioural aspect of how we use buildings must be understood if we want to design buildings to encourage more sustainable ways of interacting with the built environment. All of these approaches are ways young researchers and engineers can contribute to a sustainable, low-carbon construction industry.

ARE THERE ANY EXAMPLES OF CONSTRUCTION COMPANIES ALREADY PARTICIPATING IN THE CIRCULAR ECONOMY TODAY?

Yes! A company called Gamle Mursten ('Old Bricks') salvages old bricks and uses a patented cleaning technology so they can be reused instead of discarded as waste. This saves 95% of the energy that would be used to make new bricks. Saving 2,000 bricks prevents one tonne of CO_2 from being emitted into the atmosphere. In another example, the company RGS90 takes old building insulation and processes, sorts, and recycles it by sending it to partner companies to be turned into new, recyclable insulation. Other companies are working on bioconcrete, eco-friendly concrete alternatives grown from bacteria or fungi. Environmental engineering and the circular economy are wide-open fields for young researchers to make a difference.

EXPLORE A CAREER IN LOW CARBON ENGINEERING

• Low carbon engineering offers many career opportunities outside academia. Architecture firms like Perkins&Will (**perkinswill.com/**) or organicARCHITECT (**organicarchitect.com/home.html**) design eco-friendly buildings in line with circular economy principles. The need for sustainable construction will only grow as the world's economy moves towards net zero carbon.

• Danielle's alma mater, the University of Sheffield, is a top place to study and research low carbon structural engineering, architecture and architectural engineering in the UK: **www.sheffield.ac.uk/undergraduate/courses/2022/architectural-engineering-meng**

PATHWAY FROM SCHOOL TO LOW CARBON ENGINEERING

• Danielle emphasises the interdisciplinary character of low carbon engineering, which combines maths, sciences and art. low carbon engineering is a good career for people who do not want to have to choose between the arts and the sciences.

• Danielle recommends studying maths as the most critical subject for engineering, but science is also very useful.

• There are lots of routes into low carbon engineering, including: structural engineering, architectural engineering and architecture.

• It is possible to do a PhD in fields such as architecture, structural engineering, design, or other subjects that support research in the circular economy. Low carbon engineering can also become chartered by the Chartered Institute of Building, the Institute of Structural Engineers or the Chartered Institute of Building Services Engineers and work in industry on development projects.

HOW DID DANIELLE BECOME A LOW CARBON ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

At school I enjoyed maths, sciences and art – for a while I wanted to be a sculptor! I also considered marine biology to pursue my love of animals and science further. I eventually decided to do a degree in structural engineering and architecture as it combined my interests across maths, science and art. I stayed on to do a PhD after my degree because I wanted to make a difference in the world and felt that the way to do that was to become a built environment sustainability specialist.

WHO OR WHAT INSPIRED YOU TO BECOME AN ENGINEER?

I slightly fell into engineering through an enjoyment of maths, science and art. I was considering studying architecture, but realised that in the UK there's little maths as part of the programme, so I studied a dual degree in structural engineering and architecture. It was during my degree that I fully appreciated (and developed) the problem-solving skills and creativity that you need to be a successful engineer.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS AN ENGINEER?

Hard work and determination have got me a long way. I'm also a reasonably creative thinker and like tackling difficult problems.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

The proudest moment in my career so far was winning the funding for my 'Multi-scale, circular economic potential of non-residential building stock' project. It was the first big project that I had led the application for, so it was a proud moment when the research council told me they were awarding the funding.

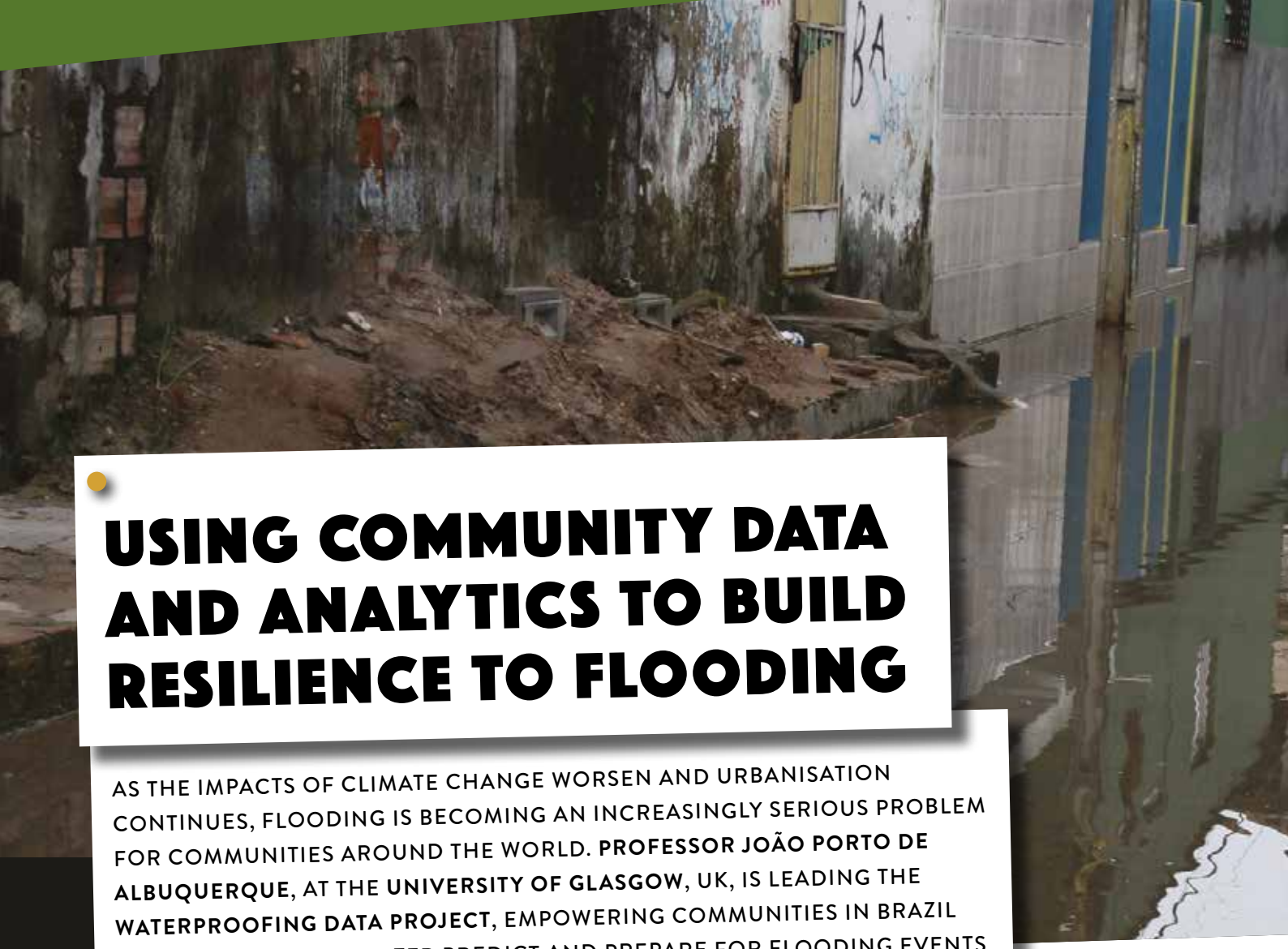
WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

There's lots of other research to do in this space, so going forward my aim is to win more funding in this field to further the research, and to do research that can make a recognisable difference in practice.

DANIELLE'S TOP TIPS

01 Remember that you can achieve almost anything if you set your mind to it and work hard.

02 Pursue something you're genuinely passionate and excited about as this will make the hard work worthwhile, and sometimes it won't even feel like work!



USING COMMUNITY DATA AND ANALYTICS TO BUILD RESILIENCE TO FLOODING

AS THE IMPACTS OF CLIMATE CHANGE WORSEN AND URBANISATION CONTINUES, FLOODING IS BECOMING AN INCREASINGLY SERIOUS PROBLEM FOR COMMUNITIES AROUND THE WORLD. **PROFESSOR JOÃO PORTO DE ALBUQUERQUE**, AT THE **UNIVERSITY OF GLASGOW**, UK, IS LEADING THE **WATERPROOFING DATA PROJECT**, EMPOWERING COMMUNITIES IN BRAZIL AND HELPING THEM BETTER PREDICT AND PREPARE FOR FLOODING EVENTS

TALK LIKE A DATA ANALYST

DIGITAL LITERACY – a person's ability to use digital platforms to find, evaluate and communicate information

EARLY-WARNING SYSTEM – a system that warns communities or decision-making organisations about approaching hazards by analysing environmental data and computational models to calculate the likelihood of an event that can cause socio-environmental impacts

FLASH FLOOD – a flood that occurs very rapidly

MARGINAL COMMUNITIES – a group 'on the edge of society' that is less able to be involved in mainstream activities and decisions

RAIN GAUGE – an instrument that collects and measures the amount of rainfall

RISK MODEL – a mathematical representation that uses data from past events to predict the probability of events happening in the future

Climate change is causing extreme weather events to become more frequent and more severe. This raises serious challenges for many communities, including those vulnerable to flooding. "Extreme rainfall events can be particularly devastating in areas with higher social vulnerability, such as poor neighbourhoods in Brazil," says Professor João Porto de Albuquerque, from the University of Glasgow. He is exploring how to build communities' resilience to flooding, by engaging them in the process of generating the data used to predict when floods will occur.

João's team is working with communities in two very different Brazilian cities. The first, Rio Branco, is a medium-sized city in the heart of the Amazon region and is vulnerable to river flooding. The second, São Paulo, is Brazil's largest city and has a high level of social inequality. Impoverished neighbourhoods have developed in flood-prone areas around São Paulo's edges through unplanned urban growth. The team is working in a neighbourhood called M'Boi Mirim, which frequently suffers from flash flooding during intense rainfall.

In both cities, rapid urbanisation has resulted in the expansion of deprived neighbourhoods, sometimes called 'favelas' or slums, which developed in parallel to official urban planning. Housing in these neighbourhoods is often non-durable and so commonly collapses during flood events. There is a lack of improved water and sanitation infrastructure, and natural drainage through the soil is inhibited by asphalt roads.

In addition, data about the risks and impacts of flooding and other natural hazards are often missing from poor neighbourhoods. "Access to detailed data about a country as huge as Brazil is a big challenge," says João. "Social inequalities are reflected in varying data availability, with data gaps in impoverished marginal urban areas." If there is not sufficient data about rainfall and flooding in an area, then it is very hard to predict when floods may occur. This increases the risk to these communities as they are less likely to have warning before flood events.

COMMUNITY-POWERED DATA

João's team is working closely with communities to generate data to fill these information gaps. "These data will help us improve risk models, which will in turn improve flood early-warning systems," says João. "We can identify how different areas are impacted by varying levels of rainfall and use

this information to generate predictions for when and where flash flooding is likely to hit." Using these models to warn communities in advance has the potential to save lives and livelihoods.

João and the team have developed a school curriculum about flooding which has been implemented in over 20 schools. "Students learn concepts about flooding risk, vulnerability and resilience, and also act as 'citizen scientists' by generating and analysing data about their own neighbourhoods," he says. Students generate data by constructing rain gauges and recording the daily rainfall. João's team has also developed an app, which students use to send their rainfall measurements to Brazil's national agency for flood early-warning, CEMADEN. They also record flooding events in the app, as well as their impacts on the neighbourhood.

"CEMADEN uses these data streams to develop better flood models that incorporate lessons from past rainfall and flood events to improve the accuracy of future warnings," says João. Back in the communities, the app can also be used to access official data on flood risk and weather forecasts, giving residents more accurate information about whether they should anticipate floods. Not only are students empowered by contributing data about rainfall and flooding to the national early-warning system, but by observing the correlations between rainfall intensity and flood events they gain a deeper understanding of flood risk in their communities.

CHANGING LIVES THROUGH CITIZEN SCIENCE

Though the data generated are crucial for early-warning systems, the fact that they are generated by the community means they have greater impacts. "Our research has shown that the act of generating and communicating data leads communities to think differently about rainfall, floods and how they relate to their neighbourhoods," says João. His team also engages with older members of the communities, who share their memories of past floods. These stories become crucial data for informing the flood resilience of the future.

Digital technology provides a means for community data about the local impacts of flooding to be incorporated into national flood early-warning systems, empowering these communities and filling the flood data gaps in marginalised neighbourhoods. "Students gain digital literacy," explains João. "Inspired by the educator Paulo Freire, we propose that by learning how to read and write digital data, students also 'read and write the world', becoming active agents in improving the resilience of their communities."

João believes this philosophy could help empower communities across the world to help prepare and defend themselves against disasters associated with natural hazards. "Recent severe flooding events across the world have made it clear that flooding is a growing global challenge," says João. "We believe that the lessons we learned whilst engaging citizens to generate data as a climate adaptation measure could be applied in other parts of the world."

PROFESSOR JOÃO PORTO DE ALBUQUERQUE

Professor in Urban Analytics, Deputy Director of the Urban Big Data Centre, University of Glasgow, UK

FIELD OF RESEARCH

Urban Analytics

RESEARCH PROJECT

Waterproofing Data: Engaging Stakeholders in Sustainable Flood Risk Governance for Urban Resilience

FUNDERS

The Waterproofing Data project is financially supported by the Belmont Forum and NORFACE Joint Research Programme on Transformations to Sustainability, which is co-funded by DLR/BMBF, ESRC, FAPESP, and the European Commission through Horizon 2020. This research was also supported in part by the UKRI Global Challenges Research Fund and through computational resources provided by The Alan Turing Institute and with the help of a generous gift from Microsoft Corporation.

PARTNERS

University of Glasgow (UK), University of Warwick (UK), Fundacao Getulio Vargas (Brazil), CEMADEN (Brazil), Heidelberg University (Germany)

M'Boi Mirim neighbourhood, São Paulo

ABOUT URBAN ANALYTICS

Urban analytics is a new, interdisciplinary field that has emerged in recent years due to the ever-increasing amount of data available about cities. Traditionally, urban data were generated through censuses and surveys. Today, these are supplemented by 'big data', generated through digital technology. For example, satellite imagery can now capture the details of a city to within a few centimetres, while location apps on mobile phones provide data about the movement of people and vehicles in real-time.

Interpreting the huge volumes of data generated every day, and using them to the benefit of a city and its residents, requires people skilled in urban analytics. "Modern urban data enables a depiction of urban dynamics in much more detail than was possible with traditional data," says João. "An urban analyst must not only have a grounding in urban studies to understand the challenges faced by cities, but also have the skills of a data scientist to process, analyse and visualise urban data. By analysing emerging forms of urban data, we can reimagine cities."

WHAT ARE THE HIGHLIGHTS OF BEING AN URBAN ANALYST?

"What I most enjoy in this interdisciplinary field is that not only do I analyse data and run models on my computer, but I also interact with people in governments, communities and other academic fields to find new approaches to address existing problems," says João. He particularly enjoys doing fieldwork, visiting the communities he is working with and hearing the experiences of people from different cultures and backgrounds. Determining how to connect these experiences to digital technology and data analytics is an enjoyable challenge.

WHAT IS THE FUTURE FOR URBAN ANALYTICS?

Urban analysts are in the exciting position of advancing this new field, which has the potential to revolutionise how cities are studied and understood. "As digital technologies become more and more widespread, we will have ever-increasing amounts of data about cities," says João, "but also an even bigger challenge to make sense of these data."

Urban analysts will have to develop new methods to analyse huge quantities of data, such as using computational techniques from machine learning and artificial intelligence. But the rise of digital technology poses additional ethical questions that must also be addressed, around issues of privacy and accessibility. "Not everyone can access digital technology due to existing social inequalities," explains João. "This means that urban data can be biased and exclude certain social groups, leading to inaccuracies and injustices."

Future urban analysts will help society take advantage of advances in digital technology to improve our urban environments. They will use digital urban data to increase our understanding of cities, in ways that respect people's digital rights while promoting social justice.

PATHWAY FROM SCHOOL TO URBAN ANALYTICS AND DIGITAL GEOGRAPHY

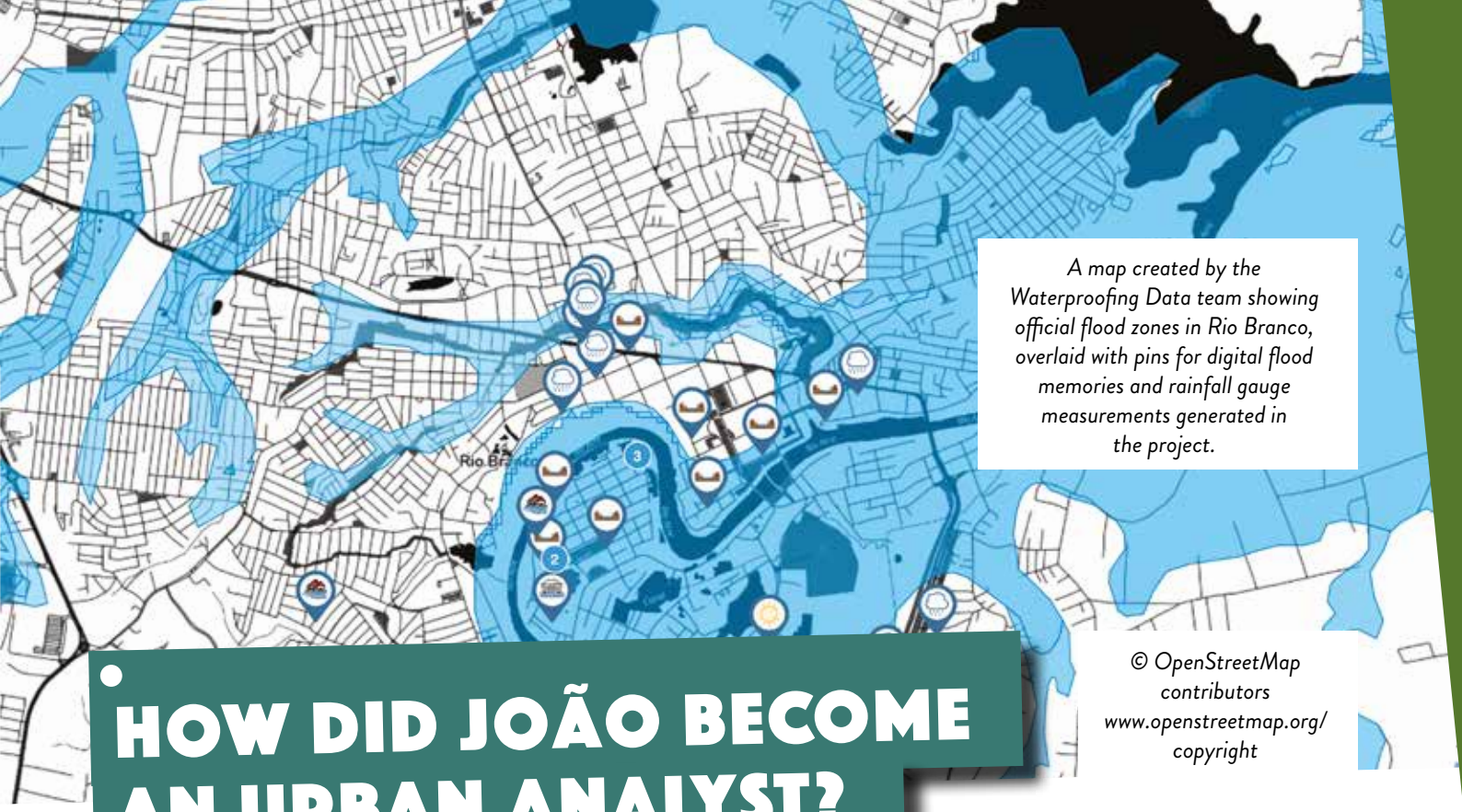
- At school, geography, computing and maths will be useful subjects to study. As an interdisciplinary field, urban analytics can be approached from many different directions. Therefore, degrees in geography, urban studies, computer science, environmental science, statistics or data science could all lead you there. Some universities offer postgraduate degrees in urban analytics.
- João highlights that an urban analyst needs the ability to combine quantitative skills from maths and physics with insights from social science subjects such as geography and history. "For this, an open and curious mind is the most valuable asset!" he says.

EXPLORE A CAREER IN URBAN ANALYTICS

- As the world's cities continue to expand, urban analysts are needed to address the challenges associated with urbanisation. You could apply your skills in urban analytics to ensure neighbourhoods are socially inclusive, to construct infrastructure that can meet the demands of the population, or to protect communities from disasters.
- The University of Glasgow's Urban Big Data Centre (**www.ubdc.ac.uk**), where João works, has videos explaining some of the projects they undertake and many useful resources and training materials for people who are interested in using big data to study urban environments.
- A key skill in urban analytics is the ability to visualise and present spatial data, which is commonly done using geographic information systems (GIS). You can watch this video for an introduction to GIS: **www.youtube.com/watch?v=659CESxEb5U**

JOÃO'S TOP TIP

Follow your interests and don't feel restricted by conventional disciplinary boundaries. Much of the best innovation in research comes from pushing these boundaries and bridging different areas.



A map created by the Waterproofing Data team showing official flood zones in Rio Branco, overlaid with pins for digital flood memories and rainfall gauge measurements generated in the project.

HOW DID JOÃO BECOME AN URBAN ANALYST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I learned programming when I was ten years old and have always been fascinated by computers. I also had a great interest in social justice and environmental issues. Growing up in Brazil, poverty and deforestation of the Amazon Rainforest were very visible to me.

WHAT PATHWAY HAS LED YOU TO YOUR CURRENT ROLE?

I studied computer science at undergraduate level in Brazil and then completed my PhD in computer science in Brazil and Germany, where I maintained a strong interest in the social usage of technology. When I returned to Brazil, I saw first-hand the catastrophic impacts of flooding in impoverished regions. I found a way to incorporate my computer science expertise into solving social challenges, by getting involved in urban analytics and digital geography. I find this intersection helps match my interests in using data science to address urban and social issues.

WHAT HAVE BEEN YOUR HIGHLIGHTS OF THE WATERPROOFING DATA PROJECT?

This project has enabled me to work with researchers from many different fields, including humanities, social sciences, physical science and engineering. I've found it enriching to learn from so many different perspectives. In addition, we worked directly with government agencies in Brazil and also with the communities on the ground. We learned from their lived experiences of flooding, helping us understand the human dimension behind the data we were collecting.

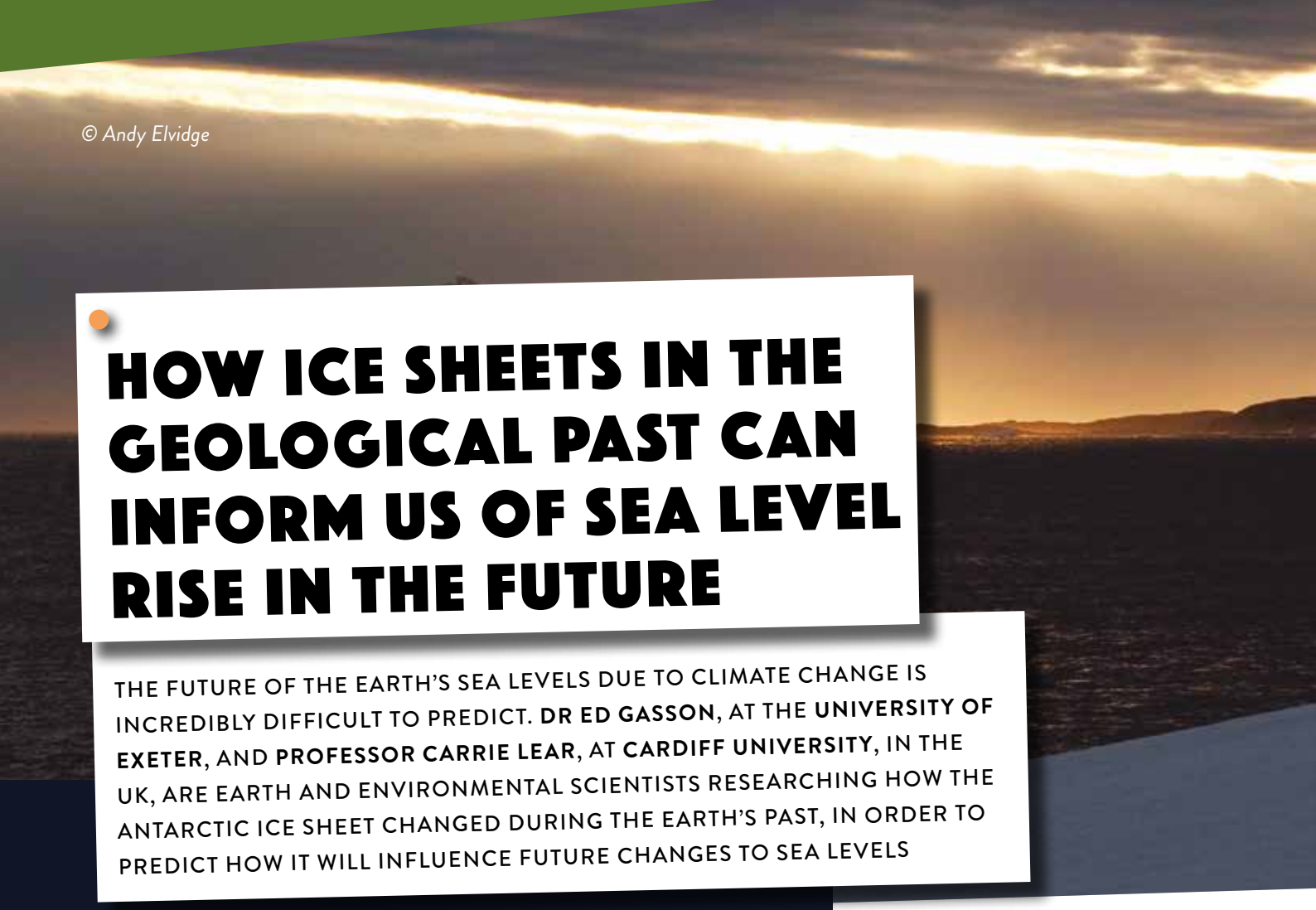
WHAT ARE YOUR OTHER RESEARCH INTERESTS?

My main interest is investigating new methods to include many diverse voices in the collection and usage of data, to help make cities more sustainable and resilient. In recent years, I have developed a group of projects that focus on empowering vulnerable and deprived communities through citizen-generated data. I've had the privilege of working with partners and communities in countries around the world.

WHAT DO YOU ENJOY OUTSIDE OF WORK?

I enjoy spending time with my wife and three kids. I also occasionally play acoustic guitar and am a big fan of running.

The Waterproofing Data team together with community members and stakeholders of governmental agencies in Rio Branco, Acre, Brazil.



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HOW ICE SHEETS IN THE GEOLOGICAL PAST CAN INFORM US OF SEA LEVEL RISE IN THE FUTURE

THE FUTURE OF THE EARTH'S SEA LEVELS DUE TO CLIMATE CHANGE IS INCREDIBLY DIFFICULT TO PREDICT. **DR ED GASSON**, AT THE **UNIVERSITY OF EXETER**, AND **PROFESSOR CARRIE LEAR**, AT **CARDIFF UNIVERSITY**, IN THE UK, ARE EARTH AND ENVIRONMENTAL SCIENTISTS RESEARCHING HOW THE ANTARCTIC ICE SHEET CHANGED DURING THE EARTH'S PAST, IN ORDER TO PREDICT HOW IT WILL INFLUENCE FUTURE CHANGES TO SEA LEVELS

TALK LIKE AN EARTH AND ENVIRONMENTAL SCIENTIST

ANTARCTIC ICE SHEET – the large mass of ice that covers the South Pole and 98% of the Antarctic continent

CLIMATE MODELS – mathematical representations of the Earth's atmosphere and oceans

GLACIAL – an interval of time within an ice age where colder temperatures persist and glaciers advance

INTERGLACIAL – the warmer period of time between ice ages where temperatures rise and glaciers retreat. We have been in an interglacial stage for about 10,000 years

ISOTOPE GEOCHEMISTRY – an area of geology that looks at the relative abundance of different isotopes (such as in the microfossils that Ed and Carrie analyse)

PALAEOCLIMATE – the study of how and why our planet's climate has changed through its history

PLIOCENE – a geological epoch covering the geological timescale between 5.3 and 2.6 million years ago

PROXIES – indirect methods for determining past environmental parameters, such as the temperature of the Earth and the past CO_2 concentration of the atmosphere, using materials preserved within the geological record

SEA LEVEL – commonly meaning the average surface level of the oceans across Earth, affected by many processes on different timescales

The melting of the Antarctic Ice Sheet and subsequent changes to sea levels could have profound impacts on communities all round the world. A billion people live on land less than 10 metres above current high tides and so are particularly vulnerable to the impacts of sea level rise. Loss of land, increased flood risk and disruption to key infrastructure, like power stations, are particular dangers people may face.

Scientists' current projections of how sea levels will change by 2100 and beyond vary significantly. Sea levels could fall slightly due to ice sheet growth from increased snowfall as the Antarctic warms. They could also rise up to 1.4 metres as the ice sheet melts. To improve current projections of sea level rise, Dr Ed Gasson at the University of Exeter and Professor Carrie Lear of Cardiff University are simulating glacial and interglacial conditions in the Earth's past. Modelling changes to the Antarctic Ice Sheet in these times, they hope to understand the extent of sea level change in the future.

RECONTRUCTING THE ENVIRONMENT OF THE PAST

Precise predictions of future climates are hard to achieve as changes to the climate will depend largely on whether we take firm action to reduce greenhouse gas emissions now.

However, Earth scientists can look into the geological past to find out what past climates were like, and how the ice sheets changed during these periods. The Earth's climate has varied from Ice Ages, with mile-thick ice covering much of the land in the northern hemisphere, to periods warmer than today. The last time the atmospheric CO_2 conditions were as high as today was around 3 million years ago in the mid-Pliocene.

To reconstruct past climates, scientists can measure atmospheric CO_2 from gas bubbles trapped in ice cores. These only provide measurements for the past 800,000 years;

to go further into the geological past, a range of indirect techniques, called proxies, are used. If these match the changes measured in the ice cores, scientists can be confident that the proxies are reproducing atmospheric CO_2 levels further back in time.

The warming during the mid-Pliocene was a long-term 'equilibrium' response, rather than the current sharp increase in CO_2. "The rate of CO_2 increase is much faster now than in the past, and we will even exceed the CO_2 concentrations in the mid-Pliocene by 2025," says Ed.

SIMULATING ICE SHEETS IN THE PLIOCENE

Ed and Carrie can calculate ice sheet volume by analysing trace metals and the isotopic composition of microfossils within sediments. This tells them how warm the oceans were in the past and how much CO_2 was dissolved in them. They also use oxygen isotope ratios of fossil plankton which tell them how salty the oceans were. "As the ice sheets grew, more freshwater was stored on land, making the oceans slightly saltier. As the ice sheets melted, that freshwater was put back into the oceans, making them slightly fresher," explains Carrie.

"Although our geochemical records cannot tell us where the ice sheets were, we can work out how large they were, and how quickly they grew and melted," explains Carrie. The team simulates how big the ice sheet got during the cooler 'glacial' stages of the mid-Pliocene, and how small it got during the warmer 'interglacial' stages. "To do this, we have to take into account all of the differences that drove the transition from a cool to a warmer climate," says Ed.

TESTING THE MODELS

"We've been trying for a long time to simulate Antarctic Ice Sheet melt during past warm intervals, and we've often failed," says Ed. The problem is that ice sheet changes inferred from palaeoclimate data are larger than Ed and Carrie can simulate using their models. "Due to the uncertainty of proxy data, it can be difficult to determine whether a model is successful at simulating the past or not," explains Ed. This could result in an underestimation of sea level changes, making predictions for the future misleading.

"If we reduce the palaeoclimate data ranges, we can make a more stringent test for the models. Our future sea level predictions can then be made with more confidence," explains Ed. Currently, team member Amy Thomas-Sparkes has prepared hundreds of fossils for analysis and knows the exact ages of these fossils. "This will be really important as it will help us work out how fast the Antarctic Ice Sheet grew and decayed in the past," says Carrie.

LOOKING TO THE FUTURE

The new sea level records from these fossils will help Ed and Carrie test and calibrate their own ice sheet models. Currently, these models predict faster rates of sea level rise in the future, but there are still modelling issues that need to be addressed. Models must pass the test of matching previous Pliocene sea level estimates. "Because the range of Pliocene sea level estimates are so large, many different models pass this test," explains Ed. This causes a big range in future sea level projections. "We're hoping to narrow the number of models that pass the test, then we can also narrow the range in our future projections," he explains.

The team can do this by adding more and more components of the Earth system to their models, enabling Ed and Carrie to understand how these components interact. "However, this adds to the complexity and makes our models slower to run," says Ed. "It's a fine line between making the models complex, while keeping them usable."

This work focuses on indirectly measuring the retreat of ice sheets and does not indicate which parts of the ice sheet are melting. For this, direct geological records need to be accessed by drilling sediment cores around Antarctica. "We're involved with an upcoming Antarctic drilling campaign that can hopefully resolve some really big outstanding questions in Antarctic science," says Ed.

DR ED GASSON

Royal Society University Research Fellow, University of Exeter, UK

FUNDERS

Natural Environment Research Council (NERC), US National Science Foundation (NSF), The Royal Society

PROFESSOR CARRIE LEAR

Cardiff University, UK

FUNDERS

Natural Environment Research Council (NERC), European Commission

FIELD OF RESEARCH

Earth and Environmental Science

JOINT RESEARCH PROJECT

Using palaeoclimate data from the mid-Pliocene to test and calibrate Antarctic Ice Sheet models in order to estimate the rise in future sea levels

© Andy Elvidge

ABOUT EARTH AND ENVIRONMENTAL SCIENCE

This is an extremely broad field. "In order to understand everything about the Earth system, or even just the climate system, you would have to be an expert in physics, chemistry, maths, biology and Earth sciences!" says Carrie. She finds it very rewarding to work in a diverse team with everyone playing to their strengths, which is essential for making new discoveries. Many of these scientific questions have societal relevance, so it is a very rewarding area to work in.

Ed is finding ways to stay optimistic even though there is a long way to go to reach net zero emissions. He highlights the price of renewables falling year on year, alongside the phasing out of coal in the UK, as big positives. "The UK needs to go further. As the first nation to industrialise, the UK has an obligation to lead the response to climate change," he says. "For example, the UK recently hosted the United Nations Climate Change Conference (COP26) in Glasgow."

"There are incredibly few people working on sea level rise," says Ed. He would like to see many more people working on the issues facing our society. "When it's going to affect hundreds of millions of people, it is fundamental that industries and policy makers support research and the people doing the research," he explains.

Isotope geochemistry lab at Cardiff University

EXPLORE A CAREER IN EARTH AND ENVIRONMENTAL SCIENCES

- Visit the Geological Society website for information on events and training resources: **www.geolsoc.org.uk/Policy-and-Media/Outreach**
- The Environment and Sustainability Institute at the University of Exeter runs an annual Earth and Sustainability day (**www.exeter.ac.uk/esi/community/environmentandsustainabilityday/**) and the university has a scheme for students to learn about university life and research called Exeter Scholars (**www.exeter.ac.uk/exeterscholars/**).
- Cardiff University is involved in several public outreach schemes. The School of Earth and Environmental Sciences hosts public events and has a YouTube channel: **www.youtube.com/user/CardiffEarthSciences/playlists**
- If you are interested in work experience at Cardiff University, you can email **EarthReception@cardiff.ac.uk** explaining your interests and including your CV.

PATHWAY FROM SCHOOL TO EARTH AND ENVIRONMENTAL SCIENCE

- Any of the sciences, including geography, and maths would be great to study in school.
- It is important to remember that a diverse skill set is valuable. If you are passionate about writing, do not feel like you need to drop a subject like English – it is important to be able to communicate the scientific discoveries you make.
- At university, some Earth and environmental science courses will give you an offer if you have one science A-level. If you enjoy a range of sciences, you will find that many of them are used and integrated when studying at university.

THE TEAM'S TOP TIPS

01 Do something you love - work with supportive people who value your contributions and be supportive of others.

02 Don't be afraid to be wrong or to say, "That's an interesting question, but I don't know what the answer is!" Being a scientist is all about asking questions, coming up with new ideas to answer those questions, and testing to see how accurate those new ideas may be.

HOW DID CARRIE BECOME AN EARTH SCIENTIST?

When I was younger, most of my interests involved being outdoors, whether this was fossil hunting or volunteering for local conversation projects. I've always loved learning about the world around me, so doing a degree in Earth sciences seemed a natural way to continue this.

I particularly like this childhood photo of me looking for fossil shark teeth and turtle shells. Although I didn't really appreciate it at the time, I was finding evidence that when CO_2 concentrations were higher in the past, the UK was much warmer than today!

Even though I always enjoyed science, I never really believed I could have a career in research. When I was a student, I didn't meet any established female researchers in my field. Shortly after my PhD, I was lucky to be part of an ocean research expedition, helping to collect sediments from the seafloor. It was really exciting to bring ocean sediments up onto the deck and see evidence of past changes in climate. My eureka moment came on that expedition, after finishing a 12 hour shift with a female colleague and talking with a senior scientist about our future plans. Both of us commented that we didn't feel like we belonged in the world of research, and I will never forget his surprise and dismay. He told us that scientific research would be better with people like us in it, and that really made a difference.

One of my proudest achievements was taking part in fieldwork where we found lots of new plankton fossils. Everyone on the team had a fossil named after them! My fossil is tiny, less than a millimetre in diameter.

The most important attribute to have while doing research is curiosity – wanting to answer puzzles that I see in the Earth's climate system. After that I would say problem solving, collaboration and resilience for when things don't go to plan, which happens very often in science. It's important to focus on the big picture and not get put off by bumps in the road. That's easier to do if you find supportive colleagues to work with.

For the future, if I could achieve one thing, it would be to help make academia a more inclusive environment – we have made progress, but we still have a long way to go.

HOW DID ED BECOME AN ENVIRONMENTAL SCIENTIST?

I have always been interested in the environment, and climate change is the biggest issue that we currently face. The way that climate change was (and sometimes still is) taught in school made me think that the science wasn't settled yet. I wanted to be part of that so I could understand it for myself. However, there is no doubt about the fundamentals of climate change. There are still many areas that we do need to work on so we can make better projections for the future and, more importantly, come up with ways to manage and adapt to climate change.

One of the best aspects of being a scientist is that you drive your own research direction, so an interest and curiosity about what you're working on is essential. However, you can't do everything yourself, so being able to work with others who are experts in different areas is key. This is a great thing about being a scientist.

IN THE LAB

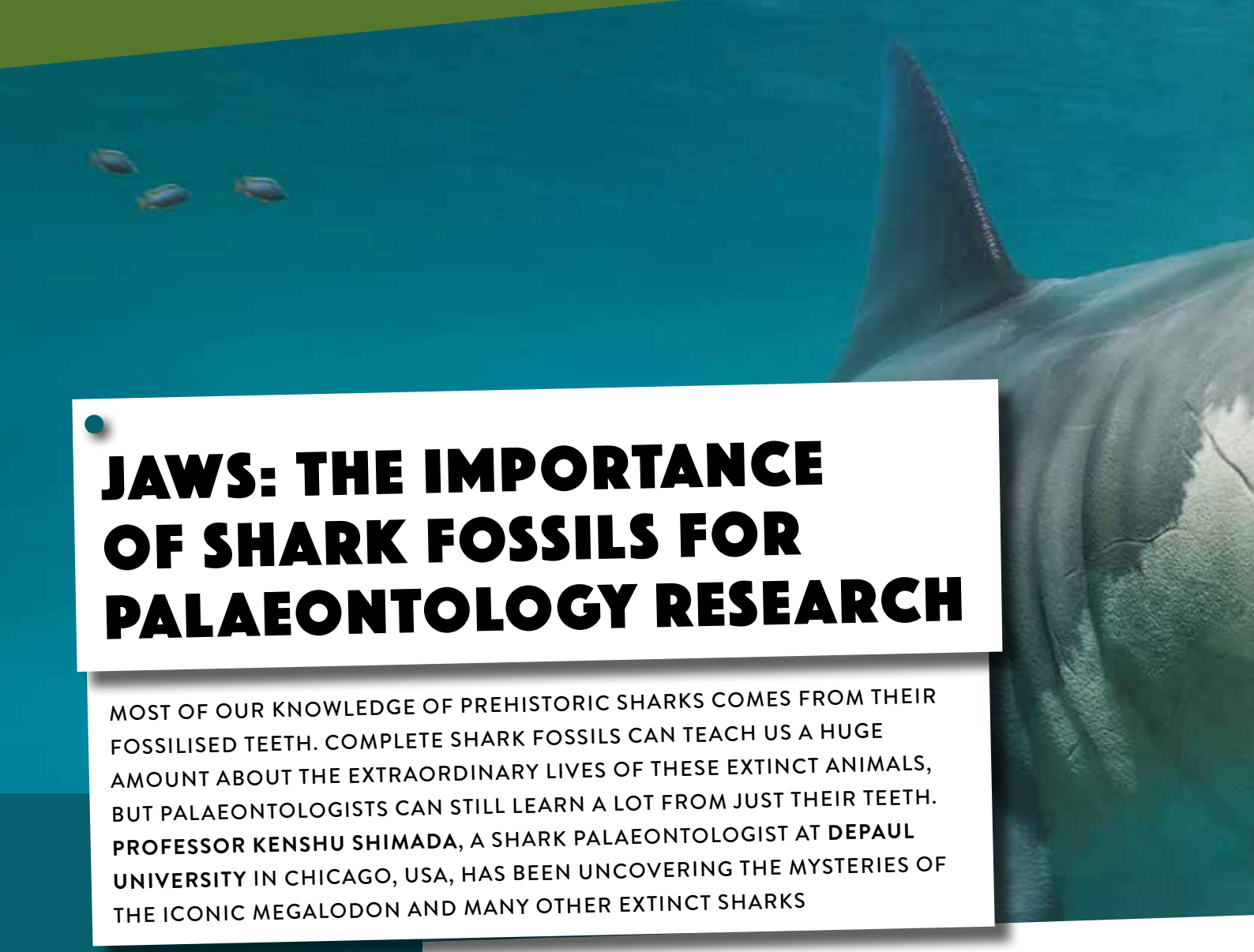
Dr Amy Thomas-Sparkes, Postdoctoral Research Associate at Cardiff University

The deep ocean sediments that we use for our work are retrieved by huge research vessels that drill into the sea floor all over the world's oceans. When we get these ocean sediment samples to the lab, we carefully extract and clean the tiny fossils contained within. These tell us about the temperature and chemistry of the oceans, and the extent of ice sheets, throughout the history of our Earth. In particular, we work with fossilised microorganisms called foraminifera – tiny beings that have shells made of calcium carbonate. The composition of chemical elements in their shells can tell us what the oceans were like when they were alive.

We first separate foraminifera from the rest of the sediment by washing the sample though a small sieve that captures the fossilised shells. We then carefully pick out as many foraminifera of the same species as we can find. There are many species of foraminifera, each with a uniquely shaped shell. My favourite, and the one we are using in our current research project, is called *Melonis barleeanum*.

Once we have those foraminifera, we clean them to make sure the shell surfaces are not contaminated by other chemical elements. We do this in a clean lab wearing lab coats and goggles. We cannot contaminate our samples!

When the shells are clean, we dissolve them in ultra-clean acid and analyse this solution in a mass spectrometer. This machine tells us the amount of certain chemical elements contained in the foraminifera shell. For example, the amount of magnesium can tell us how warm the ocean was in the past!



JAWS: THE IMPORTANCE OF SHARK FOSSILS FOR PALAEONTOLOGY RESEARCH

MOST OF OUR KNOWLEDGE OF PREHISTORIC SHARKS COMES FROM THEIR FOSSILISED TEETH. COMPLETE SHARK FOSSILS CAN TEACH US A HUGE AMOUNT ABOUT THE EXTRAORDINARY LIVES OF THESE EXTINCT ANIMALS, BUT PALAEONTOLOGISTS CAN STILL LEARN A LOT FROM JUST THEIR TEETH. **PROFESSOR KENSHU SHIMADA**, A SHARK PALAEONTOLOGIST AT **DEPAUL UNIVERSITY** IN CHICAGO, USA, HAS BEEN UNCOVERING THE MYSTERIES OF THE ICONIC MEGALODON AND MANY OTHER EXTINCT SHARKS

TALK LIKE A PALAEONTOLOGIST

COMPUTER TOMOGRAPHY (CT) – an imaging technique where multiple X-rays are taken of an object, then compiled to produce a 3D image of the object's interior

ECOSYSTEM – all the organisms in an area, along with the non-living components

FOSSIL – the remains or traces of a prehistoric organism preserved in rock

OOPHAGY – an egg-eating behaviour exhibited by some animals

VERTEBRAE – the series of segmented skeletal supports running through the body axis and containing the spinal cord

VERTEBRATE – an animal that has vertebrae (e.g., fish, amphibians, reptiles and mammals)

It is no wonder that the legendary megalodon has captured our imaginations. Three times longer than a great white shark, this ferocious creature once terrorised the oceans. But today, all that remains of these ancient hunters are their teeth, preserved in stone for millions of years, and questions about their existence. Just how large could they grow? How big were their babies? How long did they live? And what role did they play in prehistoric ecosystems?

By studying fossils of ancient sharks and comparing these to their modern-day relatives, Professor Kenshu Shimada, a shark palaeontologist at DePaul University, is hoping to solve some of the mysteries surrounding megalodon and other extinct sharks.

LAMNIFORM SHARKS

Professor Shimada's research focuses on a diverse group of sharks called lamniforms. Lamniform sharks include plankton-eaters such as the basking shark, as well as meat-eaters like the famous great white shark. "Although only 15 lamniform species live in today's ocean, there are many extinct species in the fossil record, including the iconic megatooth shark, *Otodus megalodon*," Professor Shimada explains.

"There is much more to learn about the biology of each species," he says. "We still don't know about the shape, growth and behaviour of many species, or the roles they played in their ecosystems." The discovery of new fossils, as well as the development of new methods to extract information from these fossils, will help palaeontologists like Professor Shimada to broaden our knowledge of prehistoric sharks.

WHAT CAN SHARK TEETH TELL US?

Sharks are cartilaginous fish, with skeletons made from cartilage rather than bone. Only their teeth are well mineralised, made of calcium phosphate. This means when a shark dies and sinks to the ocean floor, its soft skeleton tends to decay quickly, leaving behind only its hard teeth.

"For this reason, most extinct sharks in the fossil record are represented by isolated teeth," explains Professor Shimada. "Teeth are usually the only clues left for palaeontologists to decipher ancient shark biology." While it is challenging to determine the structure and lifestyle of an entire species based solely on a few dental remains, these teeth do provide a huge amount of evidence about the life of prehistoric sharks.

PROFESSOR KENSHU SHIMADA

Professor of Palaeobiology, DePaul University, USA

Research Associate, Sternberg Museum of Natural History, Fort Hays State University, USA

FIELD OF RESEARCH

Shark Palaeontology

RESEARCH PROJECT

Investigating prehistoric sharks by studying modern sharks and fossils of extinct species

FUNDER

US National Science Foundation (Sedimentary Geology and Paleobiology Award to Kenshu Shimada, NSF grant number 1830858)

The shape of teeth provides clues as to what the shark ate. For example, flat teeth belonged to sharks which crushed shellfish, sharks which ate small fish and squid had pointy needle-like teeth, and sharp triangular teeth belonged to sharks which hunted large prey.

Palaeontologists can examine the chemical elements within fossils. Professor Shimada works with geochemists to determine chemical components preserved in fossilised shark teeth, which can indicate the likely diet and body temperature of extinct shark species, as well as ancient oceanic conditions in which the shark lived.

And the size of the teeth gives an indication of the size of the shark. Professor Shimada has examined the relationship between tooth size and body length in modern sharks. He uses this information to calculate the size of extinct sharks based on the size of their fossilised teeth. "Besides studying prehistoric sharks, I also study their modern relatives," he says. "Without understanding the anatomy of modern sharks, it is practically impossible to figure out the biology of extinct forms."

WHAT HAS PROFESSOR SHIMADA DISCOVERED ABOUT MEGALODON?

Recently, Professor Shimada studied an exceptionally well-preserved specimen of a megalodon that was discovered in Belgium in the 1860s. Unusually, when this shark died 15 million years ago, about 150 of its cartilaginous vertebrae became fossilised, providing a unique opportunity for Professor Shimada to study more than just its teeth.

By comparing the relationship of vertebral size and body length in modern great white sharks, palaeontologists can estimate the length of extinct sharks from the size of their vertebrae. The vertebrae in this megalodon specimen measure up to 15 cm, indicating that this individual was about 9 m long.

Professor Shimada used a technique called computer tomography (CT) to peer inside the fossilised vertebrae, looking for hidden anatomical structures. "The CT images revealed that the vertebrae had 46 growth bands," he says. Much like the way annual growth rings form in trees, a shark's age can be determined by counting the growth rings in its vertebrae. "Therefore, this 9-metre-long megalodon died when it was 46 years old," explains Professor Shimada.

But that is not all that Professor Shimada discovered. "By back-calculating its body length when each growth band formed, my study suggests that the shark's size at birth was about two metres in length," he says. "This result implies that megalodon possibly gave birth to the largest babies in the shark world!"

HOW DID MEGALODON BABIES GROW SO LARGE?

As megalodons were already larger than a human by the time they were born, this suggests they were well-fed before birth. The most likely explanation for this is that the embryonic sharks fed on unhatched eggs of their siblings in the womb, a behaviour known as oophagy. While this might sound sinister, all modern-day lamniform sharks are oophagous, and the practice provides many advantages for the individuals which survive to birth.

"This egg-eating behaviour means that only a few pups will survive and develop," explains Professor Shimada, "but each can grow considerably large before it is born. New-born megalodons would have an advantage in the ocean as they would already be large predators at birth, so they would be less likely to get eaten by other predators."

While Professor Shimada's research is painting a picture of the lives of the ferocious megalodon, there is still so much to discover about the ancient oceans.

ABOUT PALAEONTOLOGY

"The fossil record is a window into the history of life," says Professor Shimada. "It unequivocally shows the Earth's ecosystems have evolved over time." Palaeontologists study ancient life, from microscopic plankton to gigantic sea creatures, from the first trees to the last non-avian dinosaurs, and use their knowledge to investigate past ecosystems.

The fossil record shows that if ecosystems are disrupted, catastrophic changes can occur. Past mass extinction events have been linked to periods of global warming and global cooling, when Earth's climate changed too rapidly and dramatically for organisms to adapt. Understanding ancient ecosystems and their evolution is, therefore, crucial to predicting what may occur to modern ecosystems if current climate and environmental changes continue to occur.

Knowledge of ancient oceans can help modern marine conservation efforts. "Sharks are major carnivores that are vital for maintaining the balance of marine ecosystems," says Professor Shimada. "The extinction of prehistoric sharks, like megalodon, played an important role in shaping marine ecosystems as we know them today. Therefore, the extinction of modern sharks is predicted to have a profound impact on future ecosystems." For this reason, it is important to promote conservation of all organisms within all ecosystems.

To fully understand the ecosystems in which prehistoric sharks lived, Professor Shimada does not just study the sharks themselves. "If I want to understand the evolution of marine ecosystems over time, I need to know about other organisms that existed in the ecosystem as well," he says. "So, I also study other fossil vertebrates that co-occur with fossil sharks, such as bony fish, marine reptiles and sea birds." This allows him to build a more complete picture of what life was like in the ancient oceans.

WHAT DOES PROFESSOR SHIMADA FIND MOST REWARDING ABOUT HIS JOB?

"Studying fossil sharks is my hobby!" says Professor Shimada. "I am very fortunate to have a career that allows me to pursue my passion and share my interests with students, colleagues and the public." Palaeontologists answer questions that have been unresolved for millions of years, and Professor Shimada enjoys discovering and sharing new knowledge about the natural world. "However, the most rewarding part of my job is when I witness a student's 'moment of discovery' by seeing their eyes suddenly light up from learning something new," he says.

WHAT ISSUES WILL FACE THE NEXT GENERATION OF PALAEONTOLOGISTS?

Fossils are priceless non-renewable resources which require careful protection and preservation. Unfortunately, many scientifically significant fossils are sold on the commercial market to private collectors, where they become lost from science and the public. There are also many cases of illegal fossil trading, and occasionally even human rights violations associated with the mining of fossils. "The next generation of palaeontologists must be mindful, global citizens, spreading the joy of palaeontology in a responsible way," says Professor Shimada.

EXPLORE A CAREER IN PALAEONTOLOGY

- Most palaeontologists work as educators, researchers, or technicians at universities or in museums. You could work as a collections manager, exhibit designer or public outreach coordinator. You could be a fossil preparator, revealing the ancient creatures hidden within rocks, or a scientific artist, drawing or building 3D reconstructions of prehistoric organisms for museum exhibits, films or books. Or, you could become a science reporter to inform the public about discoveries palaeontologists make.

- "If you want to be a palaeontologist, you should take initiatives to be an active learner and proactively seek opportunities," says Professor Shimada. Contact local palaeontologists in museums or at universities to learn about their research programme and ask if they can offer you any palaeontology-based experiences.

- Palaeontologists study everything from dinosaur footprints to woolly mammoth tusks. Visit museums, read books and watch documentaries about fossils and natural history to discover which aspects of palaeontology most interest you.

- Go fossil hunting! Are there any geological sites near you where you could look for fossils? Remember to be a responsible palaeontologist. Check whether you need permission before collecting fossils, and do not remove fossils from protected areas.

PATHWAY FROM SCHOOL TO PALAEONTOLOGY

- At school, geology and biology are key subjects to study. Chemistry, physics, statistics and computer science are also useful for palaeontologists.

- As palaeontology requires skills and knowledge from both geology and biology, an undergraduate degree in either subject can lead you into the field. Professor Shimada recommends taking biology classes in anatomy, ecology and evolution, and geology classes in sedimentary geology and field methods.

- With a degree in geology or biology, you can then specialise and study a master's degree in palaeontology. To become an academic researcher like Professor Shimada, you may also want to earn a PhD degree.

Professor Shimada involved with the Lake Nojiri Investigation Team's fossil excavation at age 12.

Professor Shimada at age 13 looking for fossils. This trip turned out to be the day he found his very first shark fossil (a megalodon tooth!) that changed his life forever.

HOW DID PROFESSOR KENSHU SHIMADA BECOME A PALAEONTOLOGIST?

I developed a keen interest in fossils when I was 12 years old. I lived in Japan and frequently visited libraries and bookstores to learn about how and where to collect fossils. I became an avid fossil hunter, spending most of my weekends and holidays looking for fossils. I joined the Lake Nojiri Investigation Team, an organisation that allowed amateur fossil enthusiasts like me to participate in major palaeontological excavations.

When I was 13, I visited a fossil site featured in a geology guidebook, where I discovered a 5-cm-tall megalodon tooth. This incredible and unexpected discovery, combined with the impressive size and mesmerising beauty of the fossilized tooth, had a profound impact on my life. In fact, that was when I became interested in studying fossil sharks, and that discovery has led me to be the scientist I am now.

Many high school teachers and local college professors mentored me through my teenage years, by encouraging and supporting my enthusiasm for fossils. My success as a professional palaeontologist today could not have happened without the kindness and attention they gave me when I was a youngster. My mother also strongly encouraged me to pursue my passion.

I was fortunate to find my interest and passion early on in life. However, one challenge I faced as a consequence of this was struggling to balance my enthusiasm for palaeontology with my regular schoolwork. While I was a 'good' student, I was not academically strong. But my desire to become a palaeontologist drove me to study hard, and my efforts paid off when I was able to go abroad to attend college in the United States to receive formal training in palaeontology.

One highlight of my career was receiving a very competitive grant from the US National Science Foundation to investigate the biology of megalodon. It allowed me to address questions about the size, growth and reproductive strategies of megalodon. This research has also provided me with new opportunities to collaborate with a wide range of other scientists.

I look forward to unlocking more mysteries surrounding the megalodon and other extinct sharks. The fact that most prehistoric sharks are represented only by their teeth in the fossil record gives palaeontologists opportunities to ask many scientific questions. I like to take up nature's challenges.

Outside of my work, I enjoy fishing, including catch-and-release shark fishing. Although this is a hobby, it also feeds back into my research on ancient marine ecosystems by enabling me to observe and experience live modern organisms in their actual habitats.

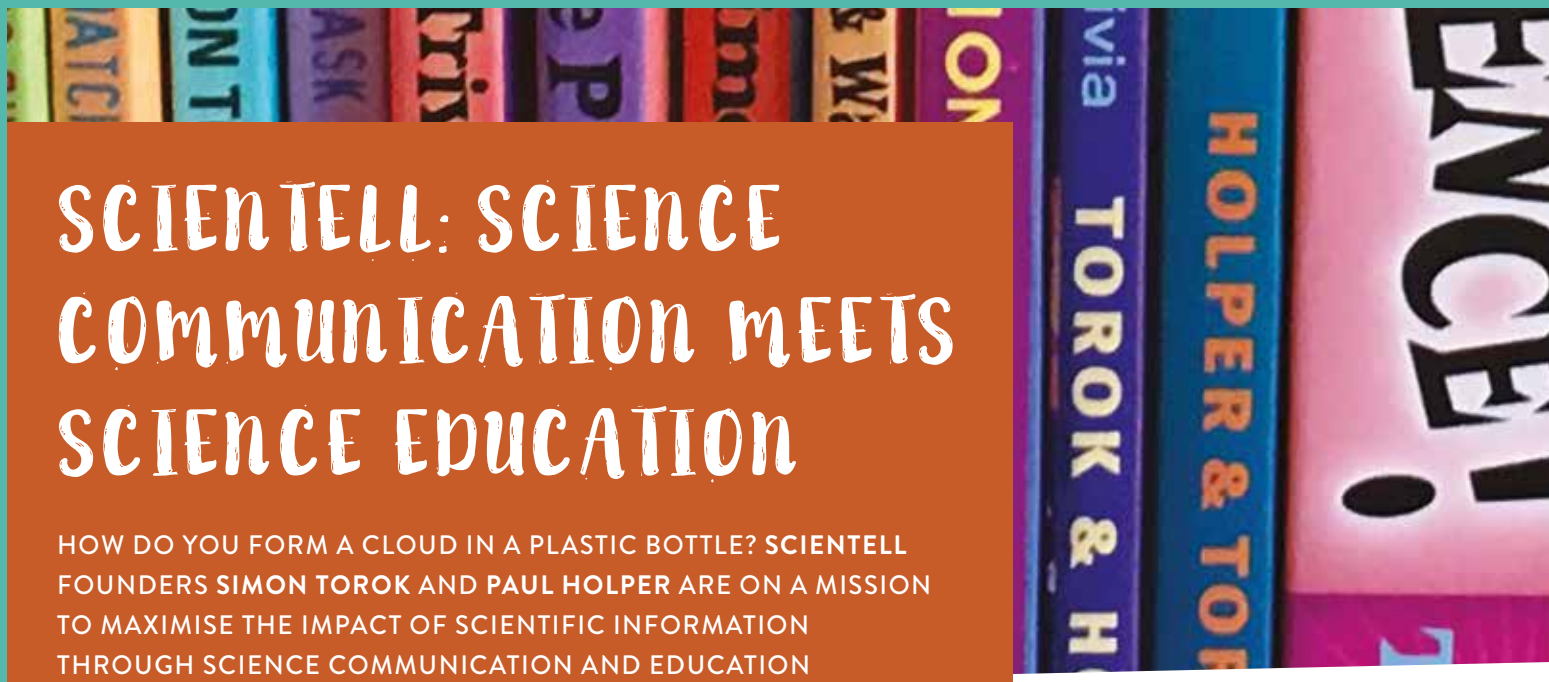
PROFESSOR SHIMADA'S TOP TIPS

01 Follow your passions.

02 Be proactive and search for opportunities.

03 Spend time outdoors in nature as much as you can.

04 Be imaginative and creative. Think 'outside the box' when you face a challenging problem.



SCIENTELL: SCIENCE COMMUNICATION MEETS SCIENCE EDUCATION

HOW DO YOU FORM A CLOUD IN A PLASTIC BOTTLE? **SCIENTELL** FOUNDERS **SIMON TOROK** AND **PAUL HOLPER** ARE ON A MISSION TO MAXIMISE THE IMPACT OF SCIENTIFIC INFORMATION THROUGH SCIENCE COMMUNICATION AND EDUCATION

WHAT INSPIRED YOU TO SET UP SCIENTELL?

We first met at a climate change science conference in 1994, and then worked together when Paul was communication manager for CSIRO Atmospheric Research and Simon was communication manager for CSIRO Environmental Mechanics. A couple of years later, Paul suggested we write a science trivia book together, which was published by ABC Books in 1999. Over the ensuing decade, Paul worked at CSIRO in Melbourne and Simon worked in Canberra, then England, and then also at CSIRO in Melbourne. As we worked in our day jobs, we continued to write together in our spare time, with an average of one book published each year. This efficient, spare-time writing and our collaborative work together at CSIRO laid the foundation for Scientell in 2015. We saw a need for science communicators to help scientists get their research to those who need to use it.

WHY ARE YOU PASSIONATE ABOUT SCIENCE EDUCATION?

Science communication and science education go hand in hand. Science education for young people is especially important, as these are the minds of the future, so it is our job to ensure that they have access to the latest, accurate information and knowledge.

In previous jobs, Paul was a chemistry teacher and Simon worked for CSIRO Education, after spending a year travelling around Australia presenting science shows with a science circus. Experience in both positions helps us communicate effectively for our clients.

SCIENTELL HAS PERFORMED SCIENCE SHOWS FOR CHILDREN IN AUSTRALIA AND ABROAD. WHAT CAN TEACHERS/PARENTS/CHILDREN EXPECT FROM THESE SHOWS?

The shows include hands-on demonstrations using easily accessible, everyday objects to demonstrate important scientific concepts. For example, you can form a cloud in a plastic bottle to demonstrate the indirect cooling effect of aerosols, as follows:

1. Pour a small amount of cold water into a large, clear plastic soft drink bottle. Screw on the cap and shake the bottle. Squeeze and release the bottle a few times. Nothing should happen.
2. Next, open the bottle and drop a lit match into it (the match will go out when it hits the water).
3. Screw on the cap, squeeze the bottle and then again shake it. The bottle will appear to fill up with smoke. But squeeze and release the bottle again a few times, and it will become clear that it is not smoke, but fog (or a cloud in a bottle).

When water condenses, the droplets may form clouds. Particles of dust in the air help the droplets form. In fact, without tiny particles in the air, clouds would not form at all. Here, the drops form on the smoke particles. This activity demonstrates many concepts, such as that high pressure leads to clear skies and low pressure leads to clouds, and also that the addition of small pollutants to the atmosphere can have an impact on cloud formation.

CAN YOU GIVE AN EXAMPLE OF AN EDUCATION STRATEGY SCIENTELL HAS WRITTEN FOR GOVERNMENT ORGANISATIONS?

The Melbourne Water Education Strategy is one example. This strategy included a review of what education activities had been done in the past, what the company could do in the future and how this might be implemented. We produced a series of appendices, which included observations from our interviews with staff and stakeholders, and also trends in education across the state of Victoria.

WHAT IS AUSTRALIA DOING TO MAKE SCIENCE FUN AND ENGAGING FOR YOUNG PEOPLE?

Access to technology is increasingly expanding science education activities across the country through annual events such as National Science Week (for which we produce an annual educational brochure). The aim is to engage students in science as an interesting and fun activity.

ABOUT SCIENTELL

Scientell specialises in synthesising scientific and technical information into clear and usable knowledge. Since its inception, Scientell has completed many projects for governments, universities, private companies and NGOs, nationally and internationally.

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TALKING FROM EXPERIENCE

PAUL HOLPER

Prior to founding Scientell with Simon, Paul was a secondary school teacher, teaching science and chemistry. He also managed CSIRO's involvement in the Australian Climate Change Science Program.

"There's a step-by-step process that I had to go through as a teacher that serves me well today in my science communication work. Firstly, I need to understand the material, and then work through methods and strategies for explaining it to others. Often, it's the process of explaining or communicating science that helps your own understanding.

"Simon and I co-authored three *Amazing Science* textbooks published by Oxford University Press, designed to appeal to a wide spectrum of students and cover the complete Australian science curriculum for Years 7, 8 and 9."

SIMON TOROK

Simon has worked in communication for 25 years, including as communication manager for CSIRO in Canberra and in Melbourne, and as the communication manager for the Tyndall Centre for Climate Change Research in England. He was part of the CSIRO education team and was editor of CSIRO's Helix and Scientriffic magazines.

"These magazines have merged to form a new magazine, *Double Helix*, which contains fun and exciting science articles, activities and competitions to promote an interest in science, technology, engineering and maths: **doublehelixshop.csiro.au**

"CSIRO's education programmes aim to inspire students to pursue STEM education and equip the next generation with the required skills for the future. As well as the Double Helix magazine, their programmes provide ideas and resources for students to do at home and in the classroom, advice and experience to help students plan career pathways, training programmes to help support and develop teachers, and other education programmes.

"Science education should help young people understand the nature of science in the real world, which involves discovering answers to unsolved problems and making the world a better place.

"Education is a lifelong pursuit. This is why Scientell works to communicate clear science not only to children, but also the general public, the scientific community, government and industry."

SCIENTELL RESOURCES FOR TEACHERS AND STUDENTS

STATE OF THE ENVIRONMENT REPORT

Scientell worked with the Australian Capital Territory's Commissioner for the Environment to create two versions of the State of the Environment report, for younger and older students, so that young people can better appreciate and understand their local environment in Canberra, Australia: **www.scientell.com.au/projects/act-state-of-the-environment-report-for-young-people**

AMAZING SCIENCE

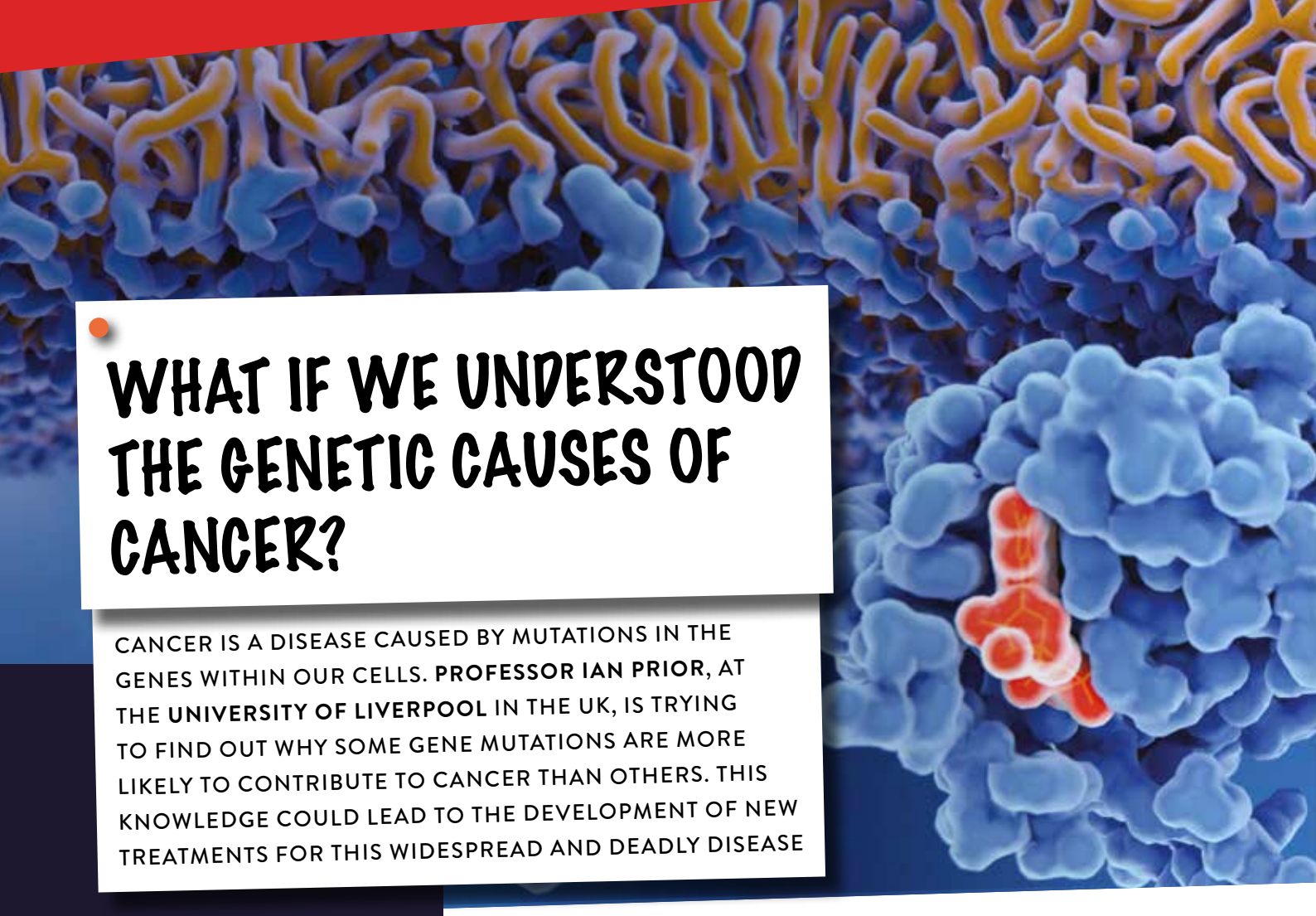
Simon and Paul have written 20 books on science, climate change and environmental matters, some of which are suitable for secondary school students. Published by Oxford University Press, *Amazing Science* covers the complete Australian science curriculum for Years 7, 8 and 9: **www.scientell.com.au/projects/amazing-science-secondary-school-science-textbooks**

CLIMATE CHANGE: WHAT YOU CAN DO ABOUT IT AT WORK, AT HOME, AT SCHOOL

Easy to read, highly accessible, yet full of the latest research and up-to-the-moment science, this book takes you through the simple yet effective things you can do in your home, your workplace, your school and elsewhere to limit your carbon emissions: **books.google.com.au/books/about/Climate_Change.html?id=6XhrOzgqt_gC&redir_esc=y**

IMAGINING THE FUTURE

Published by CSIRO Publishing, this book aims to show young Australians what a possible future could look like, based on current scientific advances. Printed food, talking with animals, designer babies, weather control, and immortality: some concepts are more likely than others, while some are already happening. **www.scientell.com.au/projects/imagining-the-future-popular-childrens-book**



WHAT IF WE UNDERSTOOD THE GENETIC CAUSES OF CANCER?

CANCER IS A DISEASE CAUSED BY MUTATIONS IN THE GENES WITHIN OUR CELLS. **PROFESSOR IAN PRIOR**, AT THE **UNIVERSITY OF LIVERPOOL** IN THE UK, IS TRYING TO FIND OUT WHY SOME GENE MUTATIONS ARE MORE LIKELY TO CONTRIBUTE TO CANCER THAN OTHERS. THIS KNOWLEDGE COULD LEAD TO THE DEVELOPMENT OF NEW TREATMENTS FOR THIS WIDESPREAD AND DEADLY DISEASE

TALK LIKE A MOLECULAR ONCOLOGIST

ONCOLOGY – a branch of medicine relating to the study, prevention, diagnosis and treatment of cancer

ONCOGENIC – able to cause cancer

DNA – the molecule that stores the genetic information in our cells

RAS GENES – a group of genes involved in controlling cell growth and reproduction. The main members of the Ras gene family are KRAS, HRAS and NRAS. Many human cancers, such as colorectal, lung and pancreatic cancers, are driven by mutations in Ras genes

CRISPR – a gene editing technique used to introduce mutations into DNA

PROTEOMICS – the study of the structure, function and interactions of proteins produced by genes of a particular cell, tissue or organism

GENOMICS – the study of an organism's genes (the genome), including interactions of genes with each other and the organism's environment

Around 1,000 people are diagnosed with cancer in the UK every day. This equates to around one person every two minutes. Of these 1,000, around 450 will die from their cancer but the number of deaths from the disease has decreased dramatically over the past 50 years. This is partly due to changes in behaviour. For example, smoking is the largest cause of cancer in the UK, but with fewer people smoking, fewer people are dying from cancer. However, advances in diagnosing and treating cancer have also made a huge difference to the chances of survival.

Ian Prior is a professor of molecular oncology and Head of the Liverpool Shared Research Facilities at the University of Liverpool. He has spent the past 25 years researching the causes of cancer and how this knowledge might be used to find new methods for treatment. His current research focuses on why a certain type of gene, called Ras, seems to contribute to a large percentage of cancer cases, and how defects in this gene could be corrected in order to slow or reverse the onset of disease.

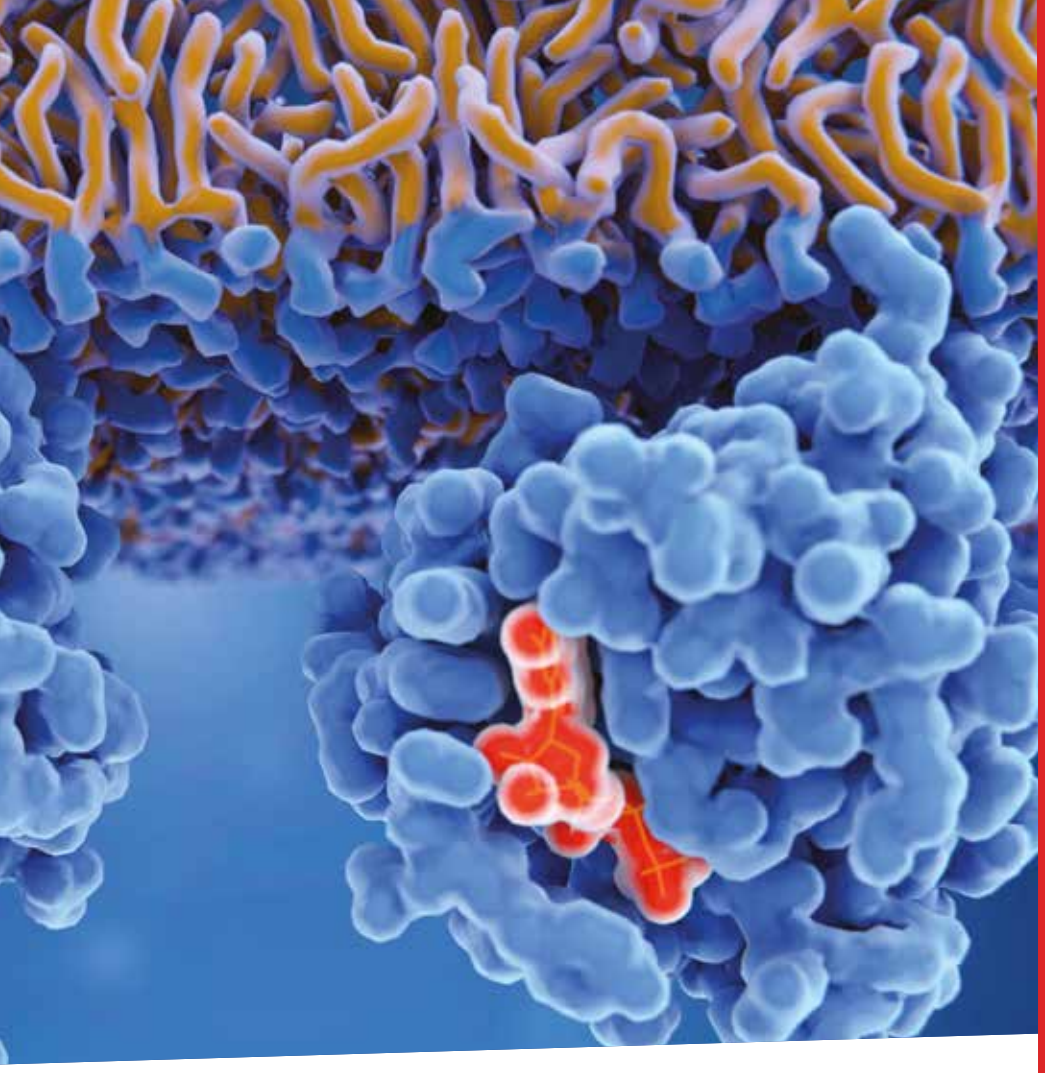
WHAT CAUSES CANCER?

The DNA stored within cells carries the instructions for them to function, grow and reproduce. Cells reproduce by dividing into two new (daughter) cells. During division, the cell copies its DNA and passes it on to the daughter cells. "DNA is constantly being damaged by stresses that cells experience," explains Ian. This damage causes mistakes to be made when the DNA is copied, creating mutations. For example, tobacco smoke contains chemicals that attach themselves to DNA, causing a mutation in the DNA when it is copied.

Usually, these mutations are corrected by the cell's repair mechanisms, but sometimes errors slip through. Most of these mutations have no effect on the cell's function, but mutations in genes that control cell division and growth can cause cancer. If a mutation causes these genes to become too active, it leads to uncontrolled cell growth and, therefore, a tumour will form.

HOW ARE RAS GENES LINKED TO CANCER?

Ras genes control the activation of many other genes involved in cell division, growth and survival. Mutations in Ras genes can cause them to be permanently switched on, which means that they are constantly instructing the cell to divide and grow. Ras gene mutations are found in around 20% of all cancer patients, but are especially common in pancreatic (90%), colon (45%) and lung cancer (30%). There are three main Ras genes: HRAS, KRAS and NRAS. KRAS is the most important for human development and is also the most



PROFESSOR IAN PRIOR

Professor of Molecular Oncology, Head of the Liverpool Shared Research Facilities, University of Liverpool, UK

FIELD OF RESEARCH

Molecular Oncology

RESEARCH PROJECT

Investigating Ras genes' link to cancer and how defects in this family of genes could be corrected to slow or reverse the onset of disease

FUNDERS

Biotechnology and Biological Sciences Research Council (BBSRC), North West Cancer Research

frequently mutated. KRAS is the main focus of Ian's research.

WHAT METHODS DOES IAN USE TO STUDY RAS GENES?

Ian's team uses cell models and mice in its studies. The researchers use a gene editing technique called CRISPR to introduce various combinations of Ras mutations in mice, which, in turn, enables the researchers to find the mutations that are responsible for causing cancer. In traditional mouse-based studies, different mouse bloodlines would be created, each with a different mutation. Using CRISPR, Ian's team can introduce multiple mutations into one mouse. "It means we can significantly reduce the number of mice that we use whilst at the same time increasing our ability to directly compare panels of cancer gene mutations," says Ian.

The researchers also use genomics to study genes that are activated or deactivated by different mutations, and proteomics to study proteins regulated by Ras genes and how they are affected by different Ras mutations.

WHY IS CANCER SO DIFFICULT TO TREAT?

Most drugs work by binding to a specific location within a protein molecule that controls the protein's interactions with other molecules. When the drug binds to the protein, it blocks the active site and prevents the protein from carrying out its functions in the cell. Kinases are a type of enzyme that are involved in controlling major cancer-causing cell processes and many successful cancer drugs have been developed that bind to kinases.

Ras genes are not kinases, however, and the drugs that have been used to target kinases will not affect Ras-controlled processes. Ian explains: "Most successful drugs have been designed to bind to a pocket in a protein (like a key in a lock). To inhibit Ras, it needs to be prevented from interacting with partner proteins i.e., a drug needs to bind to the surface of Ras in a specific location. Instead of trying to find a key for a well-understood lock, chemists have had to try to create drugs that can selectively bind to the smooth surface of Ras – it's a very tough challenge."

Recently, drugs that target a mutation (known as G12C) in KRAS, which is commonly found in lung cancer, have been developed and are currently being tested in clinical trials. Although these drugs are showing signs of being successful, one of Ian's concerns is that cancers will become resistant to these new drugs. His team is testing different KRAS G12C inhibitors in lung cancer cells and investigating the mechanisms of resistance associated with each drug. The researchers have discovered that cells treated with these new inhibitors become resistant to some existing cancer drugs, but they have also identified combinations of drugs that could slow the onset of resistance.

HOW WILL IAN'S WORK LEAD TO IMPROVEMENTS FOR CANCER PATIENTS AND BENEFIT THE WIDER RESEARCH COMMUNITY?

"Ras controls a network of cancer-relevant genes. Understanding how the network operates and responds to therapies is important for treating cancer," says Ian. "I want to understand what makes KRAS so oncogenic and why different Ras mutants are not all equally bad. Improved understanding will help therapeutic decision making and hopefully lead to the development of better treatments."

Part of Ian's role has been to establish a new centre known as the Liverpool Shared Research Facilities, which houses a wide range of imaging facilities and proteomics and genomics labs. Solving major scientific questions is no longer a solo endeavour so having all these facilities in one place has made it much easier for researchers with a diverse range of expertise to collaborate. Through these collaborative efforts involving a range of new technologies, cancer diagnosis and treatment will go from strength to strength.

ABOUT MOLECULAR ONCOLOGY

Molecular oncology is the study of cancer causes and treatments at the molecular scale. The aim is to identify the genes responsible for causing cancer and the mechanisms through which gene defects are translated into disease. This involves studying the chemical pathways in the cell that translate the genetic information of genes into cell processes, and why these go wrong in cancer cells. By understanding what goes wrong, we can develop new targets for cancer drugs or other treatments. Molecular oncology is a field which has advanced rapidly in recent years, as Ian explains:

Our understanding of cancer genetics via large-scale sequencing of cancer samples (exemplified by The Cancer Genome Atlas Program) has turbocharged our ability to identify the causes of cancer and how it evolves over time, new therapeutic targets and mechanisms of resistance to therapies. New clinical approaches are starting to include regular sequencing to get real time data on tumour responses to therapy. These provide the foundations for a future where each patient can be offered personalised therapies that are continuously optimised to keep the disease at bay.

I would definitely recommend a career in molecular oncology. I'd love to be at the start of my career again! It's a very exciting time to be working in biomedical research and especially cancer research. There have already been significant advances in cancer treatment and, as a result, more than 50% of people diagnosed with cancer now survive. We are entering a new era where personalised medicine will become increasingly common and there are many opportunities in industry and academia to contribute to developing these treatments.

I have enormous respect for all of the people who have contributed to our understanding of cancer biology. It has been a huge team effort. A good book to read to find out about many of these achievements is *The Emperor of All Maladies* by Siddhartha Mukherjee. I am also grateful for the funding that has been invested to make this possible. My own research, in part, relies on funding from a local cancer charity (North West Cancer Research) and it's always humbling when I meet the fundraisers who work so hard to make this possible.

EXPLORE A CAREER IN MOLECULAR ONCOLOGY

- The Institute of Cancer Research runs an internship scheme for undergraduate students every summer: **www.icr.ac.uk/studying-and-training/undergraduate-vacation-scholarship-scheme**.
- "Don't be afraid to contact people to ask for advice or an opportunity," says Ian. Contact universities and laboratories near you to find out whether they offer tours, talks or internship opportunities.
- The American Society for Biochemistry and Molecular Biology has a useful resource for students that provides information on careers in these fields: **www.asbmb.org/getmedia/f7c551d5-682e-44b1-a7a3-0cb3bcef9eac/asbmb-career-brochure-2017.pdf**
- The average salary for an oncologist in the UK is £39,000 according to PayScale.com but this can be considerably higher for experienced researchers.

IAN'S TOP TIPS

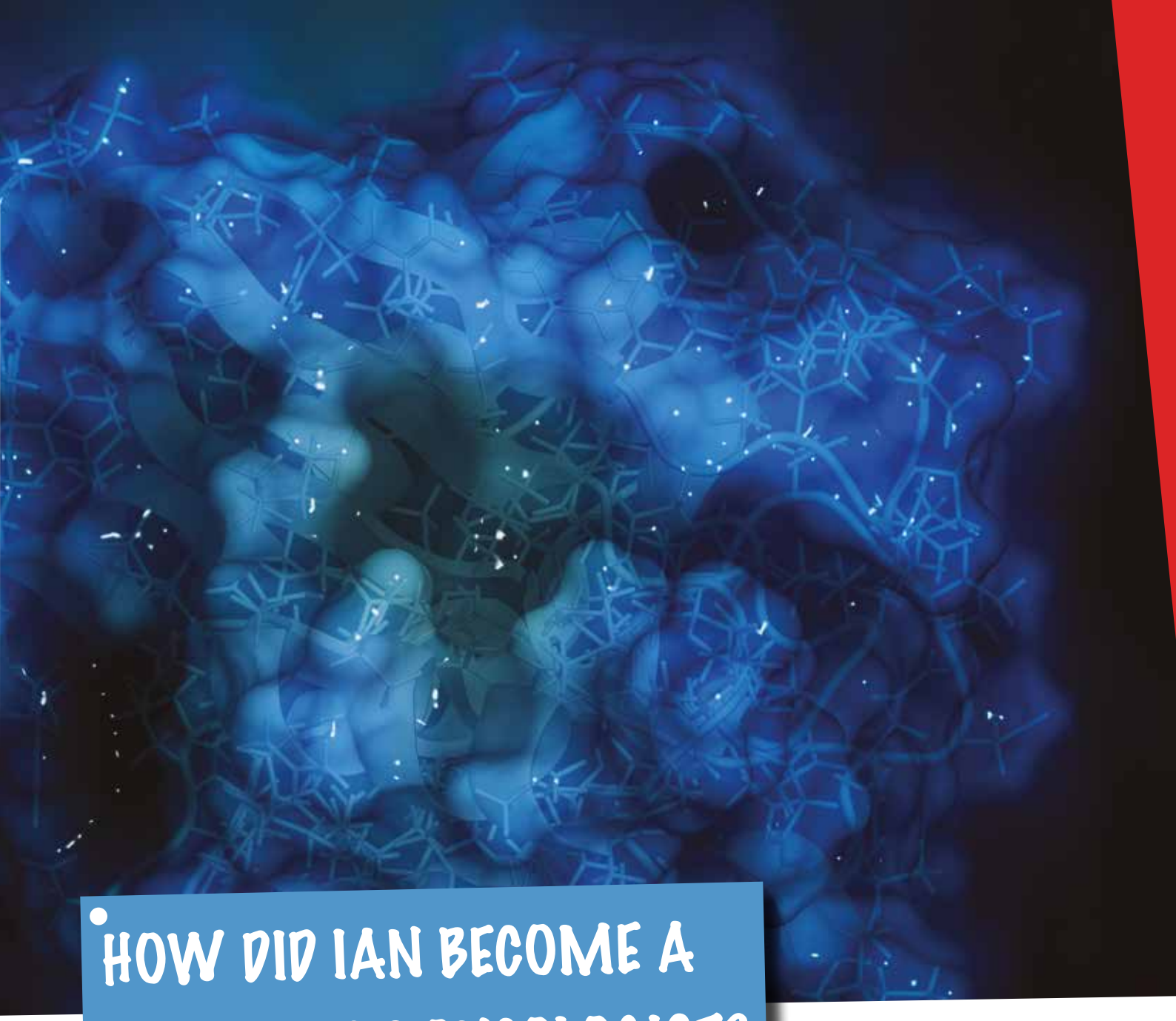
01 Be flexible. There are many routes to a career in science, but it is much harder if you are only prepared to consider one route.

02 Qualifications are important but also look for work experience, e.g. summer projects during your undergraduate degree. This will help you to decide if you like working in a lab.

03 Be open, share your ideas and work with the best people you can find. Science is a team activity.

PATHWAY FROM SCHOOL TO MOLECULAR ONCOLOGIST

- A strong background in science subjects is important, in particular chemistry and biology.
- Many medical research projects involve analysing large datasets using computational techniques, so having some programming and statistics knowledge is useful. Most undergraduate science degrees now offer some form of training in these skills.
- Career Explorer offers an overview of oncology and cancer biology degree options: **www.careerexplorer.com/degrees/oncology-and-cancer-biology-degree/**



HOW DID IAN BECOME A MOLECULAR ONCOLOGIST?

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I liked most subjects at school, but the sciences were the most interesting. I didn't have a clear idea of the range of careers that you could have in those areas; it always seemed like a good idea to keep focusing on the things that I enjoyed the most.

YOU HAVE A BSC IN ZOOLOGY, AN MSC IN TOXICOLOGY AND A PHD IN MOLECULAR CELL BIOLOGY. WHY DID YOU TRANSITION FROM ZOOLOGY TO MOLECULAR CELL BIOLOGY?

Zoology was a very enjoyable degree, but it became obvious to me that there were many more lab-based jobs available if I wanted to have a career in scientific research. I had no fixed idea of the type of lab science I wanted to do, but that flexibility was an advantage when making the transition.

THINKING ABOUT STUDENTS WHO MAY NOT HAVE A CLEAR IDEA OF WHAT THEY WOULD LIKE TO DO CAREER-WISE, HOW EASY IS IT TO SWITCH BETWEEN DISCIPLINES?

Biomedical research requires a wide range of expertise to deliver big results and it's not unusual to find people with chemistry, physical science, mathematics and computing backgrounds. Switching disciplines often involves retraining (e.g. via a postgraduate degree). Alternatively, take your specialised experience to a new discipline that needs it - such as programmers who help with big data analysis of cancer genetics patterns.

OF ALL YOUR PROFESSIONAL ACHIEVEMENTS, WHAT HAS BEEN YOUR PROUDEST MOMENT SO FAR?

I really value the opportunities that I have had to help my students and lab members to develop as scientists and then go on to achieve their career goals.

WHAT DO YOU LIKE TO DO IN YOUR SPARE TIME?

I like to draw. Research can be frustrating at times, not every idea works out and sometimes you work really hard and have nothing to show for it. Drawing always results in an end product and it's a nice way to switch off.

CAN WE VACCINATE AGAINST THE VIRUSES HIDING IN OUR CELLS?

MANY OF US HAVE VIRUSES LYING DORMANT WITHIN OUR CELLS. WHILE OUR IMMUNE SYSTEM CONTROLS THESE TO KEEP US HEALTHY, PROBLEMS ARISE IF OUR IMMUNE SYSTEM BECOMES WEAKENED. **DR MATTHEW REEVES** IS A MOLECULAR VIROLOGIST AT **UNIVERSITY COLLEGE LONDON**, IN THE UK. HE IS DEVELOPING A VACCINE AGAINST HUMAN CYTOMEGALOVIRUS, A VIRUS THAT INFECTS 70% OF THE WORLD'S POPULATION AND CAN HAVE DEVASTATING CONSEQUENCES FOR UNBORN BABIES AND ORGAN TRANSPLANT PATIENTS

TALK LIKE A VIROLOGIST

ADAPTIVE IMMUNITY – an immune response that is directed against a specific virus

ANTIBODIES – proteins in the immune system which can recognise specific viral proteins to combat disease

HOST – a cell or organism within which a virus replicates itself

IMMUNE SYSTEM – our body's defence system against infection

VIRUS – an infectious agent that causes disease by replicating within the cells of an organism

VIRUS LATENCY – the ability of a virus to exist indefinitely within its host in a dormant state

"It is estimated that over 70% of the world's population is infected with human cytomegalovirus (HCMV)," says Dr Matthew Reeves, a molecular virologist at University College London. In some countries, prevalence is approaching 100%, meaning that almost every individual is infected. Yet most people will carry HCMV throughout their lives without ever noticing.

HCMV is a herpes virus, which usually causes mild symptoms that feel like a bad cold. It is one of nine herpes viruses that infect humans, with others causing chickenpox, glandular fever and cold sores.

WHAT HAPPENS WHEN A VIRUS ENTERS OUR BODY?

"Viruses are parasitic," explains Matt. "They need cells, and all the wonderful things in them, to make copies of themselves." Each virus particle contains the genetic instructions needed to replicate itself. Once the virus has replicated within a cell, the new copies infect other cells where they then replicate themselves. In this way, the infection spreads throughout the body, and hopefully (from the virus's point of view) into other individuals. "The primary success criterion for any virus is transmission," says Matt. "If a virus can infect a host, make copies, and then infect a new host, then it is successful."

If a virus enters our body, our immune system leaps into action to defend us. "The adaptive immune response targets viruses in two ways," explains Matt. "B cells make antibodies that can neutralise viruses to stop them from infecting cells, while T cells can recognise cells that have been infected with a virus and can destroy the cell and therefore the virus."

VIRUS LATENCY

Sometimes, the immune system is successful in preventing a virus from replicating, but not in eliminating all the viral particles from the body. A virus remaining in the body in this state is said to be latent. "A latent virus can still deliver its genetic material to the host cell. Once there, the material is silenced but not eliminated," Matt explains. "Importantly, the silencing is reversible – this genetic material can become active again and resume making new viruses."

But even when a latent virus is reactivated, the infection doesn't usually progress far before the immune system brings it under control.

"Problems arise when your immune system is not working as well as normal," says Matt. "A weakened immune system may allow the virus to escape, replicate extensively and ultimately cause disease."

Once a person is infected with a herpes virus, they are infected for life, as herpes viruses have evolved to evade immune detection, allowing them to latently reside within us. As the latent virus does not cause harm, this is not a major problem, although it means the immune system must constantly work to control the virus. If a person has latent HCMV, more than 20% of their T cells may be dedicated to controlling just this one virus!

But if someone's immune system becomes weakened, then they will no longer be able to supress latent viruses. This is why some people suffer from repeated bouts of glandular fever each time they become overly tired and run down, why people develop cold sores if they become stressed, and why adults can develop shingles decades after they had chickenpox as a child. In each case, the latent herpes virus is reactivating due to a weakening of the immune system.

GROUPS AT RISK FROM SERIOUS HCMV

While HCMV only causes cold-like symptoms in most people, it is serious in those without a functioning immune system. If a pregnant woman becomes infected with HCMV, her immune system will fight the virus, but the virus can be passed to the foetus (which has no immune system) across the placenta. This can result in blindness, deafness or developmental issues when the baby is born.

Organ transplant patients are also at risk of serious harm from HCMV. When a patient receives an organ transplant, there is a strong chance their immune system will attack the donated organ because it sees it as 'foreign' in the same way it recognises infections. Before the transplant takes place, doctors must therefore give the patient drugs to temporarily suppress their immune system. But this then provides any latent viruses with the opportunity to flourish.

"A good analogy of this medical dilemma is of a dog (HCMV) straining on a leash (being controlled by the immune system)," says Matt. "If we let go of the leash (immune suppression), the dog can run wild (HCMV replication and disease)." Doctors must balance the patient's immune system by ensuring that it is not strong enough to reject the new organ but is strong enough to suppress any latent viruses.

DEVELOPING AN HCMV VACCINE

Matt and his team are investigating how the virus avoids immune detection with the aim of developing a vaccine to protect those most at risk of HCMV. If transplant patients could be vaccinated against HCMV, this would reduce the risks associated with immune suppression during and after the operation. Vaccinating women of child-bearing age could protect unborn babies from contracting HCMV in the womb. And vaccinating children could stop them spreading the virus. "Children are prodigious shedders of HCMV in urine and saliva," says Matt. "As such, we often acquire the virus in childhood or through contact with children."

Developing a vaccine for HCMV presents challenges, as much of the world's population is already infected with the virus. This means the conventional approach of training the immune system before it encounters the virus may not work unless we can 're-educate' the immune system effectively.

Additionally, HCMV has evolved to exist, and even to thrive, in the face of immune responses. To avoid antibodies, HCMV limits the amount of time it spends outside our cells, and it expresses proteins to prevent infected cells alerting T cells to the presence of infection. So, Matt and his team are trying a new approach, to modify the way in which the immune system operates. "We are searching for the Achilles heel of the virus," says Matt. "We want to find an immune response that the virus cannot evade, which we can enhance via use of a vaccine."

Clinical trials have been conducted by other research groups attempting to develop an HCMV vaccine. While no suitable vaccine has yet been produced, some have been partially effective. By studying data from past trials, Matt is trying to distinguish which aspects within vaccines produced good immune responses in patients and which did not. "With this knowledge, we aim to devise strategies to enhance the good responses whilst limiting the less beneficial ones," he says.

The team has found a potential Achilles heel of the HCMV virus, a vaccine-specific response that controls the virus. Next, they hope to develop a vaccine that takes advantage of this, enabling vaccinated people to make this immune response more effectively.

If you want to combine cutting-edge science with real-world impact, a career in virology could be for you!

DR MATTHEW REEVES

Associate Professor of Molecular Virology, Institute of Immunity and Transplantation, University College London, UK

FIELD OF RESEARCH

Molecular Virology

RESEARCH PROJECT

Developing a vaccine against human cytomegalovirus

FUNDERS

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(The contents are solely the responsibility of the authors and do not necessarily reflect the views of the Funding Agencies above.)

ABOUT VIROLOGY

Virology is the study of viruses and the diseases they cause. But virology can also help answer other biological questions. Matt's primary interest lies in understanding how our cells work and what goes wrong in them to cause disease, and he uses virology as a means to investigate this.

"If you want to understand how something works then ask an expert," he says. "In the case of human cells, the viruses are the experts! They have been evolving to use our cells to their own advantage for millions of years." This is why studying viruses is the best method we have for understanding our own cells. The first oncogene (a gene that causes cancer) was found in a virus.

And in this long relationship between humans and viruses, it's not only the viruses that have been evolving. "A lot of our own DNA is the result of infection with a family of viruses that inserted their genome into our DNA earlier in the human story," Matt explains. "For instance, the protein that is crucial for the formation of the placenta (syncitin) first came from a virus that infected our ancestors many years ago!"

WHAT IS A TYPICAL DAY FOR A MOLECULAR VIROLOGIST?

"There isn't a typical day!" says Matt. "I think that is the fun of it!" Matt spends some days in the lab doing experiments, some days going to meetings to talk about his research, and some days reading about the research conducted by other scientists around the world. This means that he is always learning new things about viruses, diseases and cells. An important part of his job is teaching the next generation of scientists in the lecture theatre and laboratory.

HOW CAN VIRUSES INFECT NEW SPECIES?

"The process of co-evolution between a virus and its host means viruses end up being highly adapted to growing in a particular species," explains Matt. "They need to be able to recognise specific host proteins in order to infect and replicate, whilst also avoiding recognition by other host proteins that would stop them replicating."

It's a bit like navigating a new and stressful social event! Being in an unfamiliar social environment can be difficult when you lack the cues that let you know what is expected of you and how you should behave. Similarly, when a virus finds itself within the cells of an unfamiliar species, it is less effective at recognising which proteins it needs and which it must avoid.

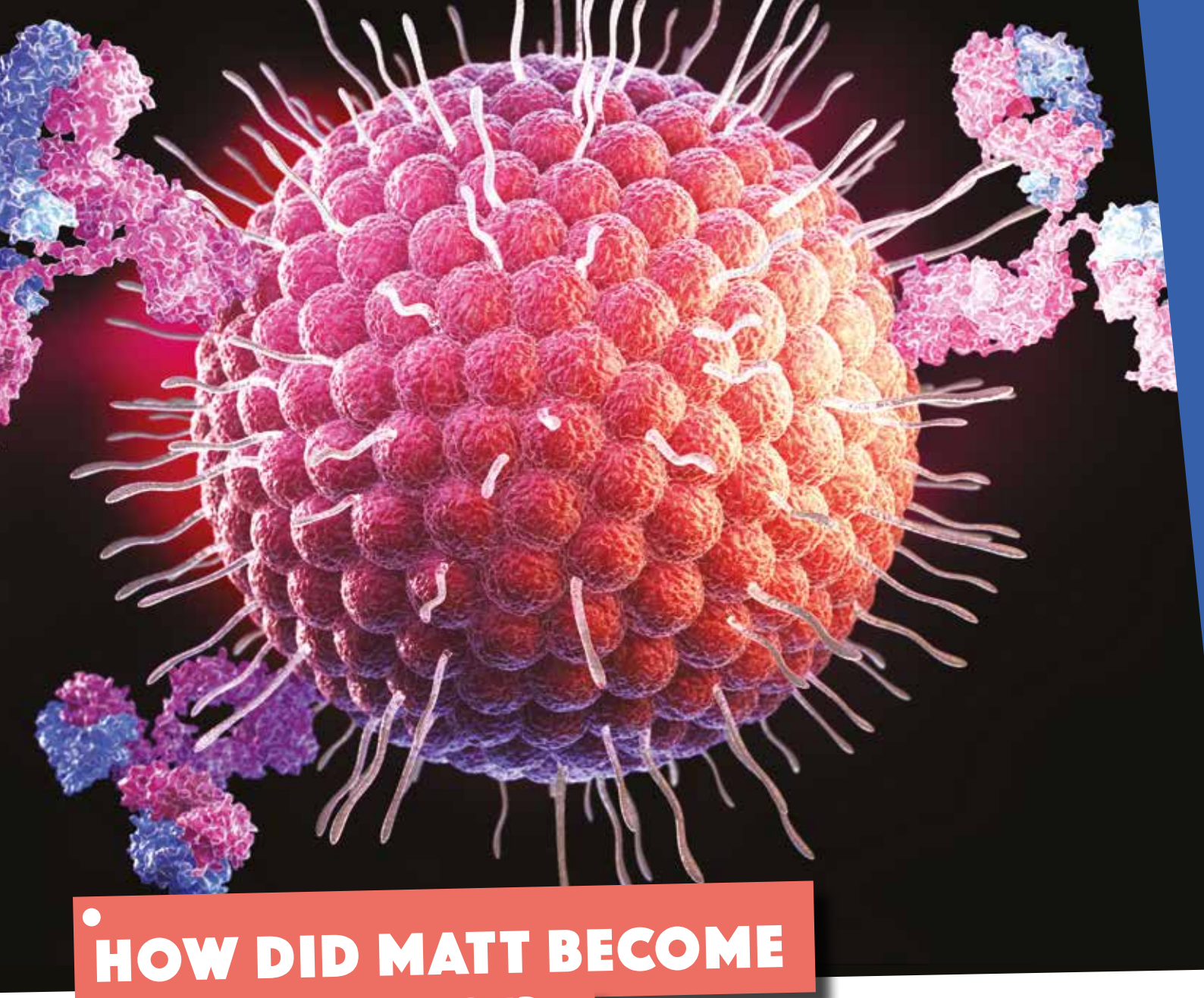
But sometimes, a virus can overcome this barrier and infect a new species. "When a virus is successful in infecting a new host species, it is usually as a result of a mutation which makes it better able to infect and grow in the new host. Scientists call this a zoonotic event," Matt explains. The viruses that cause COVID-19, Ebola and AIDS all began in animals, but mutations enabled them to infect humans. And as we encroach on greater portions of natural habitat and therefore come into closer contact with wild species, opportunities for viruses to attempt the jump into humans will increase.

EXPLORE A CAREER IN VIROLOGY

- The ever-present threat of viruses means that virologists are in demand in many places. You may find yourself working on a hospital ward with patients, in a research lab studying viruses, in a biotechnology lab developing vaccines, or advising the government during a viral outbreak.
- It can be valuable to obtain experience in a research lab while still at school. Matt recommends the schemes run by the Nuffield Foundation (**www.nuffieldfoundation.org/students-teachers/nuffield-research-placements**) and In2Science (**www.in2scienceuk.org/about**), both of which enable school students to undertake science research placements.
- The Royal College of Pathologists provides information about how to become a virologist: **www.rcpath.org/discover-pathology/careers-in-pathology/careers-in-medicine/become-a-virologist.html**
- The Microbiology Society (**www.microbiologysociety.org/members-outreach-resources.html**) and the British Society for Immunology (**www.immunology.org/public-information/immunology-related-activities-and-resources**) both have resources and activities for aspiring virologists.

PATHWAY FROM SCHOOL TO VIROLOGY

- Study maths and science subjects at school. Biology and chemistry A-levels are likely to be requirements for studying a virology-related degree.
- Matt also recommends gaining computing skills, as these will be essential for handling the large volumes of data generated in all fields of science.
- Many universities will offer undergraduate degrees in virology and/or immunology, or postgraduate degrees in infection and immunity. Other degrees, such as biochemistry or biomedical science, could also lead to a career in virology. You don't have to start out as a virologist. Matt trained as a molecular biologist and specialised in virology when he began his PhD.



HOW DID MATT BECOME A VIROLOGIST?

WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was interested in detective stories as a child – the Sherlock Holmes stories were my favourites! I also enjoyed problem solving, so a career in science seemed like a natural fit. Another reason for wanting to become a scientist was that I liked the noble idea of doing something for the 'common good'.

WHAT DO YOU MOST ENJOY ABOUT YOUR JOB?

I always love the thrill of finding new knowledge. When you make a scientific discovery, you are the first person in the world to know it! However, the part of my job that gives me the greatest pleasure now is seeing people I have trained in my lab go onto the next steps in their career and be successful.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS?

My two proudest achievements came when I obtained my PhD from Cambridge, and when I won the Medical Research Council Fellowship which allowed me to start my own lab studying HCMV.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I hope to identify a vaccine against HCMV – though this could put me out of a job!

WHAT DO YOU ENJOY OUTSIDE WORK?

Sport is my major interest – I suffer supporting Sheffield United, my hometown club.

MATT'S TOP TIPS

01 Remember that science is simply about finding stuff out and then telling people about it!

02 Never forget that the most important question is "Why?" Always ask, "Why does that happen?" Then the next question is "How? How does this happen?"

03 Learn not to be disheartened by rejection! Unfortunately, all scientists suffer rejection of papers they wanted to publish or grants they wanted to have funded. It is important to bounce back from this.

HOW RESEARCH FIELDS ARE JOINING FORCES TO PROTECT HEALTHCARE SYSTEMS

HEALTHCARE-ASSOCIATED INFECTIONS AND ANTIMICROBIAL RESISTANCE ARE TWO OF THE GREATEST THREATS TO GLOBAL HEALTHCARE SYSTEMS. DEALING WITH THEM CANNOT RELY UPON MEDICINE ALONE. INSTEAD, SOCIAL, TECHNOLOGICAL AND COMPUTATIONAL INNOVATIONS NEED TO BE INTEGRATED. AN INTERDISCIPLINARY TEAM OF RESEARCHERS FROM **IMPERIAL COLLEGE LONDON**, UK, AND THE **UK HEALTH SECURITY AGENCY** IS RISING TO THIS CHALLENGE

GLOSSARY

MICROBE – a single-celled organism

PATHOGEN – a microbe that causes disease, such as some bacteria

ANTIMICROBIAL – an agent that destroys or inhibits microbes, including bacteria, fungi and viruses

ANTIBIOTIC – an agent used to combat bacteria

ARTIFICIAL INTELLIGENCE – computer systems that can 'learn' to perform tasks

BIOSENSOR – a device that senses or measures a particular biological trait

EPIDEMIOLOGY – the study of diseases

PROTEOMICS – the large-scale study of proteins

Although hospitals and healthcare facilities are the best tools we have for combating illness, they can also be hotbeds for infectious diseases, including drug resistant ones. To address the problem, a diverse team of scientists has been assembled to investigate this issue from fields such as medicine, biology, social sciences and technology.

Professor Alison Holmes at Imperial College London and Dr Matt Ellington at the UK Health Security Agency (formerly Public Health England) lead a Health Protection Research Unit (HPRU) focused on two of the greatest threats to healthcare systems around the world – healthcare-associated infections and antimicrobial resistance. The HPRU brings together academic researchers and clinical practitioners to build a more effective healthcare system.

HCAIS AND AMR

Healthcare-associated infections (HCAIs) occur when a patient in the health system for one treatment then becomes infected by another disease. "Interactions with healthcare should make people better, not worse, so HCAIs are a real problem," says Alison.

Antimicrobial resistance (AMR) occurs when pathogens evolve to no longer be affected by a particular antimicrobial drug, making disease harder to treat. "So much of modern medicine depends on working antimicrobials," Alison explains. "If antibiotics cease to work, medicine could go back to the Dark Ages."

AMR is not an emerging issue; it is already a global problem, referred to as the 'silent pandemic' as the public rarely hears about it. If one pathogen becomes resistant to one antibiotic in one country, the resistant strain will soon spread around the globe. And many pathogens have evolved to become resistant to multiple drugs. "We now see resistance in a wide range of bacteria, against a wide range of antibiotics, throughout the world," says Alison.

ANTIMICROBIAL STEWARDSHIP

Alison advocates for the concept of 'antimicrobial stewardship', which means only using antimicrobial drugs when they are necessary. "Antimicrobial resistance is natural, and we can't stop it," she says, "but we can slow it down." We should all take responsibility for antimicrobial stewardship. Only use antibiotics if they are essential and follow the advice of healthcare professionals. Practice

THE NIHR HEALTH PROTECTION RESEARCH UNIT IN HEALTHCARE-ASSOCIATED INFECTIONS AND ANTIMICROBIAL RESISTANCE

INSTITUTIONS

Imperial College London and the UK Health Security Agency (formerly Public Health England)

FIELD OF RESEARCH

Healthcare-Associated Infections, Antimicrobial Resistance

FUNDER

National Institute for Health Research (NIHR)

good hygiene, as regular handwashing will stop transmission. And have vaccinations to reduce your chances of getting infections in the first place.

THE HPRU

"Research into AMR has to be collaborative to be successful," says Alison. This is why the HPRU is an interdisciplinary partnership between Imperial College London and the UK Health Security Agency. "This partnership means that our research is grounded in public health priorities, not just academic interest," she explains. "We provide an evidence base which has already influenced government guidelines on controlling infections."

Using expertise from a variety of fields, the HPRU is addressing HCAIs and AMR via four complementary research themes: 1) Priority pathogens, 2) Precision prescribing, 3) Practice, design and engineering, and 4) Population health and policy.

PRIORITY PATHOGENS

To assess the risks of AMR, it is important to know how different microbe species behave and adapt. Dr Elita Jauneikaite works on identifying priority pathogens – those most likely to develop antimicrobial resistance and cause issues for public health. Many of these pathogens can cause severe infections and are especially dangerous to people with compromised immune systems.

Elita's team is very diverse, to ensure the project is approached from multiple angles. "We have experts in bacterial pathogenesis, proteomics and molecular biology, alongside clinicians, epidemiologists, mathematical modellers and data analysts," she says. "This diversity gives us a much better overall picture of how different aspects of priority pathogens interact and influence each other."

This variety in research expertise results in a wide range of scientific techniques being used, to understand how bacterial populations change over time and how this affects patients. Bioinformatics (a field which involves the processing of large quantities of biological data) methods are used to detect antimicrobial resistance genes and how they mutate over time. Molecular biology techniques can test these mutations in the lab to see which are the most effective at resisting antimicrobials. "As well as lab studies, we also analyse anonymised patient data to better understand if particular patient populations are especially at risk to specific bacteria strains," says Elita.

Elita hopes that her team's method of combining patient data with biological research into specific pathogens can set a framework for further investigation into how antimicrobial resistance is transmitted between pathogens and between patients.

PRACTICE, DESIGN AND ENGINEERING

Though an understanding of the biological science behind HCAIs and AMR is fundamental, it doesn't capture every aspect of transmission. Dr Esmita Charani is focusing on the social and physical environment of the healthcare network and assessing how it could be improved to lower risks of infection and transmission.

The behaviours of healthcare professionals, patients and the public depend upon attitudes towards infection and antibiotic use. "Ever since their discovery in World War II, antibiotics have been heralded as 'miracle drugs'," says Esmita. This has resulted in their wide-spread use as the simplest way to cure most illnesses.

Before attempting to change these behaviours, Esmita and her team are hoping to understand

the motivations behind them. "We have to create the right environment to support individuals to make the right decisions," she says. This can involve simple measures such as promoting hand washing in hospitals, as well as more complex measures such as the development of bespoke prescription charts or apps to help doctors prescribe antibiotics appropriately. "We also need to communicate the risks of AMR to the public, including the importance of using antibiotics only when necessary and when prescribed," says Esmita.

The physical environment of hospitals is also important. Esmita advocates the use of 'smart engineering' to reduce infection risk, such as improving ventilation, reducing 'touch surfaces' (e.g. door handles and taps) and constructing clinical surfaces from materials that do not harbour microbes.

PRECISION PRESCRIBING

More advanced healthcare techniques rely on sophisticated data collection. Dr Tim Rawson is exploring how technologies such as artificial intelligence and biosensors can help combat HCAIs and AMR. "A huge amount of data is generated for every patient within a healthcare system," says Tim. "However, much of this data will not be integrated into larger datasets, due to difficulties in processing and interpreting it."

Tim believes that addressing this could help doctors prescribe antimicrobials more appropriately and precisely. "Antimicrobial prescribing is complex," he explains. "By using data that incorporates this complexity for individual patients, prescribers will be able to make more accurate decisions about which antibiotic to use and how long it should be used for." These data-supported decisions would be better for the individual patient and would also reduce the risk of AMR.

The sophistication of these decisions can be taken a step further with artificial intelligence. "An algorithm could analyse hundreds of variables and summarise them into a single probability score for 'risk of bacterial infection', which allows the prescriber to decide on the appropriateness of antibiotic prescription," says Tim.

Technology can also encourage optimal antibiotic prescription through the use of biosensors, which measure the concentration of microbes and antimicrobials in a patient's blood. This allows doctors to track how the antibiotic is faring within the body after administering it and rapidly adjust the dosage to ensure optimal efficiency. Tim believes that integrating these technologies into standard healthcare routines could lead to a much more precise approach to treating microbial infections.

POPULATION HEALTH AND POLICY

Dr Nina Zhu is working on maximising the usefulness of data collected within healthcare systems, through data linkage, systems modelling and dynamics, and network analysis. "Rather than tracking diseases, we are tracking patients, by linking data generated from different sources," she says. "This involves assessing policy environments and mapping patient movement and networks, to inform the design of health interventions."

Nina works with 'whole systems integrated care', which links multiple health sectors across north-west London. "This integration has helped us study how infections emerge in the community, how they are managed, and whether treatment succeeds or fails," says Nina. "It also provides evidence for whether infections are associated with movement of patients within or between hospitals."

This system came into its own during the COVID-19 pandemic. "The first challenge was to ascertain which COVID cases were HCAIs," says Nina. "We developed a system to automatically flag any patients whose virology test results confirmed they had caught the virus within hospital and modelled their movements within the hospital to identify which wards saw the most transmission events." The team also reviewed existing literature of previous pandemics and developed a holistic instrument to guide future pandemic response, incorporating social, political and technological considerations.

EXPLORE A CAREER IN ANTIMICROBIAL RESISTANCE RESEARCH

- AMR is a serious threat to global healthcare systems that needs to be tackled from a diverse range of perspectives. You could address the issue clinically, working as a doctor or pharmacist. You could study the biological processes of AMR as a microbiologist or epidemiologist. You could develop new technologies to monitor AMR as a bioengineer or analyse the results of AMR studies as a data scientist. You could investigate our relationship with antimicrobial drugs from a social science point of view as an anthropologist or economist. Or you could work in public health to influence government policy.
- The HPRU recognises the importance of encouraging people from all walks of life to get involved in AMR research. They welcome people to get in touch and find out more: **www.imperial.ac.uk/medicine/hpru-amr**

PATHWAY FROM SCHOOL TO ANTIMICROBIAL RESISTANCE RESEARCH

- As highlighted by the researchers in the HPRU, there are many different pathways into AMR research.
- At school, STEM subjects will be valuable for following any route into AMR research. Most scientific research requires computer coding skills for analysing data, so the team advise learning to code. Biology and/or chemistry will be essential for many university courses that could lead to AMR research. Maths will be beneficial if you will be dealing with data. English or foreign languages will provide useful communication skills, but these are not typically requirements for STEM university courses.
- At university, courses such as medicine, molecular biology, epidemiology, pharmacology, bioengineering, mathematics and anthropology could all lead to a career in AMR research.
- Alison highlights that effective communication is needed to change public attitudes to antimicrobials. Subjects such as public health, journalism and politics are therefore all relevant to addressing the increasing global threat of AMR.

MEET THE TEAM

PROFESSOR ALISON HOLMES

PROFESSOR OF INFECTIOUS DISEASES, IMPERIAL COLLEGE LONDON
DIRECTOR OF THE HPRU

I have always found infectious diseases the most interesting area of medicine. It links diseases to the environment, and as a doctor of infectious diseases you have to be interested in transmission, vectors and epidemiology as well as the disease itself. I find this whole-system approach produces some of the best doctors.

Being the Director of the HPRU is just one of my roles, all of which involve talking to a wide range of people, from international leaders to NHS colleagues on the wards, to researchers at every stage of their academic career. Sharing ideas with these people is one of the joys of my work.

Every day of work is varied. I always have meetings with my research team and other colleagues to attend. I also spend a lot of time reading – draft manuscripts summarising our work, grant applications for new funding, PhD theses that I am examining... There are a lot of demands on my time, so the support of my core team has been really important.

I love being surrounded by incredibly talented colleagues and seeing them grow and flourish. It is fantastic to collaborate with so many brilliant experts in different fields, and including behavioural research and bioengineering research into our group has been wonderful.

Initially, it was very challenging to raise the profile of AMR and the need to address how we use antibiotics. It was apparent to me that we needed greater focus and leadership, and much more research into the issue. Finally, it is becoming a national and global research priority.

I lived in many different places growing up. In every environment, my father shared his interest in natural history and his extraordinary knowledge and sharp observation skills, which inspired me to become a scientist.

Enthusiasm, genuine interest and persistence have made me a successful scientist. I have made the most of opportunities and have learnt from those around me. I have also helped support others through collaborations and advancing their interests and careers.

DR MATT ELLINGTON

UK HEALTH SECURITY AGENCY LEAD FOR THE HPRU

At school I enjoyed biology and biochemistry, so I chose a degree with flexible core modules in life sciences. At university, my imagination was caught by a lecture on microbial bioenergetics. I completed a summer placement project with the lecturer, Professor David Richardson, and subsequently a final-year practical project in his lab. As well as building my technical skills, David inspired my inquisitiveness through discussing ideas and theories and finding ways to test them.

I then completed a PhD in microbial bioenergetics and molecular biology, after which I was recruited to investigate antimicrobial resistant bacteria. This role opened my eyes to the scale and breadth of research activity taking place around AMR.

I became qualified as a clinical scientist and developed my bioinformatics and computer coding skills so I could analyse whole genome sequence data. As my work became more managerial, it cemented my belief in the importance of having a wider public health science workforce partnering closely with the UK Health Security Agency.

In the national AMR reference laboratory we receive samples of bacteria from hospitalised patients and test them for unusual antimicrobial resistances, while conducting research into how to detect new forms of resistance. We also investigate infectious outbreaks and analyse how bacteria spread between individuals, and we examine new antimicrobial drugs to determine how microbes may develop resistance to them.

I think that interpreting our results is the most interesting part of my research, trying to determine 'what does it mean?' My work involves lots of meetings with colleagues to analyse data, discuss our results or plan our next steps. There are also always technical problems to solve when conducting research.

I think my interest in the 'technical details' and my desire to understand things have helped my success. I have always wanted to do something helpful for society and future generations.

As a pre-teen I was very into building things from LEGO and Meccano and building remote-controlled cars. As a teenager I loved music, as well as football, cycling and other outdoor pursuits.

MEET THE TEAM

MICROBIOLOGIST
PRIORITY PATHOGENS RESEARCH LEAD

DR ELITA JAUNEIKAITE

My undergraduate degree was in microbiology, with a year of professional training in industry. I then gained further laboratory research experience in molecular epidemiology at Public Health England. This helped me to see how useful such research can be, which encouraged me to pursue a PhD.

My previous studies and research prepared me for my current role leading the Priority Pathogens team. They provided opportunities to learn new techniques, work with researchers from different backgrounds, manage multiple multi-disciplinarity projects and pursue my research interests.

Being a research scientist involves many roles, which often all come at once. Though this can be challenging, it is also what makes scientific research so engaging. As a senior researcher, I manage other researchers and students as well as collaborating with clinicians who work on the front lines of microbial outbreaks in hospitals.

A typical day for a researcher is a busy one! I specialise in bacterial genomic analysis, so when I'm not talking to colleagues or writing up research, I'm linking to the university's supercomputer to analyse data for new discoveries.

A scientist must be curious and driven to ask 'why?' The ability to absorb and process large amounts of information and to find patterns and answers, and the tenacity to not give up are also useful. And they must be able to work with other researchers.

I loved reading books as a child, especially books about nature. I loved observing and learning things, organising events and going on nature walks. I think it was my love of solving puzzles and interest in the natural world that led me to become a scientist.

Outside of work, I enjoy spending time with my family, travelling and meeting new people. I still retain my love for nature and animals.

CLINICAL PHARMACIST PRACTICE, DESIGN AND ENGINEERING RESEARCH LEAD

DR ESMITA CHARANI

I meandered my way into research and science. I always wanted to be a journalist or author but became inspired by the people interested in sharing the knowledge and skills they have gained through research.

I studied pharmacy and then completed an MSc in Infectious Diseases. After a few years working in antimicrobial stewardship and medicines information, I applied for a research job even though I had no research experience. Over the last ten years I have developed my research career and completed a PhD, which focused on applying social science research to understand how and why people use antibiotics, and implications for their long-term effectiveness.

I love my research role as there is never a dull day. I get to feed my curiosity and follow ideas and questions that interest me. I have developed fantastic collaborations with colleagues around the world from different professions – when it comes to infectious diseases, it is important to work across geographic and cultural boundaries. It is extremely rewarding to contribute to positive outcomes in healthcare.

Early in the pandemic I volunteered in our vaccination clinics for staff, which was very rewarding. I also supported the research teams in the hospital conducting studies about diagnosis and management of COVID-19.

Curiosity, patience and tenacity are important skills for a scientist. It is also vital to build strong relationships with colleagues, to work together and learn from each other.

As a child, I loved reading. My family also travelled a lot, which was great as I enjoy being on the road in search of adventure, but meant I frequently had to change schools. I even missed out on school for a year!

As well as travelling, I enjoy cooking and baking for my friends and family. When I was on-call as a pharmacist, I taught myself to make jewellery to keep me awake on night shifts. I have made lots of pieces from silver and semi-precious stones for myself, relatives and friends.

CLINICAL DOCTOR IN INFECTIOUS DISEASES AND MEDICAL MICROBIOLOGY PRECISION PRESCRIBING RESEARCH LEAD

DR TIM RAWSON

I have wanted to pursue a career in infectious diseases since my first year of medical school. During my undergraduate training I found that I enjoyed academic writing and research, which cemented my desire to explore ways of linking clinical practice with academia. As part of my PhD, I explored the role of artificial intelligence and biosensor technologies in delivering precision antimicrobial therapy.

I am currently completing clinical training alongside academic research. It can be challenging to balance my time between increasing clinical and academic commitments as I progress in my career, but fortunately the HPRU supports me in this.

Research-focused days can be incredibly varied. We work on a broad range of subjects, from clinical trials of medical devices to the development of new technologies. Leading the Precision Prescribing team, a lot of my time is dedicated to developing research ideas and supporting members of the team.

I love identifying clinically important challenges and addressing them through academic research. It's satisfying to see a study develop from an initial idea to meaningful results. I also feel very fortunate to work with such a friendly group of people, which fosters a culture of collaboration.

I am lucky in that I really enjoy what I do. Scientists need enthusiasm to learn new skills and think differently about things. They also need to have fairly thick skin, as you will inevitably face criticism of your work and the methods you chose, but it is important to learn from this feedback.

I was always interested in science and making things when I was growing up. My father is a joiner and I worked as a labourer during my summer holidays. Although I'm not very good at carpentry, I enjoyed the practical aspect of making things and this has translated to some of the technology development work I have been involved in over the years.

Outside of work, I aim to enjoy the outdoors as much as possible. I play golf (socially, not competitively) and scuba dive. In recent years I have been learning to rock climb, travelling around the UK to Portland and the Peak District to test my skills.

EPIDEMIOLOGIST POPULATION HEALTH AND POLICY RESEARCH LEAD

DR NINA ZHU

My background is in biomedical engineering, which set the foundation for me to become a quantitative researcher. Prior to joining the HPRU, I explored different fields of public health, and completed a PhD that combined systems theory with research into infectious disease. I was attracted to the HPRU's multidisciplinary team and the fact that it is a fast track to real-life health data.

A typical day involves number crunching as I analyse data and a lot of meetings with clinicians and researchers. I work with scientists from various fields – doctors, pharmacists, microbiologists…

I enjoy the process of answering questions using real-life data – I like solving puzzles. The challenge lies in ensuring that I interpret my findings appropriately as it is important to understand the limitations and the wider context of the data.

Curiosity drove me to become a scientist. I loved detective novels when I was younger, and have always been intrigued by unanswered questions. I am always determined to find out 'why'. I still enjoy reading in my spare time, as well as going to the gym.

THE TEAM'S TOP TIPS

01 Find what feeds your curiosity and passion – do what inspires and fascinates you. You should enjoy what you do!

02 Try hard, be flexible and work with great people.

03 Don't try to walk in the shoes of others. Do what is right for you. If something interests you, pursue it. But if you lose the interest, shift your focus elsewhere and don't punish yourself for making mistakes.

REACHING OUT TO OVERCOME DIABETIC EYE DISEASE IN THE PHILIPPINES

THE **REACH-DR** PROJECT, LED BY **PROFESSOR TUNDE PETO** AT **QUEEN'S UNIVERSITY BELFAST** IN THE UK IN COLLABORATION WITH THE PHILIPPINES TEAM, HAS BEEN ESTABLISHED TO SHARE UK EXPERTISE AND ENABLE SUSTAINABLE DIABETIC EYE SCREENING PROGRAMMES IN THE PHILIPPINES

TALK LIKE AN OPHTHALMOLOGIST

DIABETES – a condition that causes an individual's blood sugar levels to become too high

DIABETIC MACULOPATHY – an eye complication resulting from diabetes that causes the central part of the retina to become swollen because of the leakage of fluid from the blood vessels

RETINA – light-sensitive layer of tissue at the back of the eye

RETINOPATHY – disease or damage to the retina, causing loss of vision or visual impairment

TELEOPHTHALMOLOGY – eye care delivered through digital medical equipment and telecommunications

One of the amazing things about research is that it not only tackles academic challenges and adds to human knowledge, but it also has the power to improve people's lives – an impact even more significant when researchers share their skills and successes with others. Which is exactly what the Philippine Eye Research Institute, Professor Tunde Peto and a team of researchers based at Queen's University Belfast (QUB) in the UK are doing with the UK-Philippines Remote Retinal Evaluation Collaboration in Health: Diabetic Retinopathy (REACH-DR) project.

Diabetes can lead to a wide range of complications, many of which affect blood vessels around the body. For instance, retinopathy happens when diabetes damages the blood vessels inside the eyes. This can subsequently lead to diabetic maculopathy, a severe condition where patients may experience impaired vision such as blurring and image distortion.

However, in the majority of instances, there are no visual symptoms until it is too late. It is for this reason that diabetic eye screening is of great importance – the earlier that changes are identified, the better the chance of saving a person's sight.

Diabetic eye screening programmes (DESP) in the UK are among the most successful in the world, particularly with the advent of teleophthalmology eye evaluations, and Tunde and her team want to ensure the REACH-DR project enables the Philippines to achieve a similar level of care. "Advances in telemedicine using remote retinal cameras mean that we now have the technology to transfer our knowledge to developing nations with limited resources and challenging infrastructure," says Tunde.

THE CHALLENGES

The Philippines has 7,641 islands and more than 100 million people which makes evaluation of diabetic eye disease very challenging. "Not all areas have the necessary equipment for eye examinations and the transportation of machines and specialists is challenging if a DESP it to be deployed on a national scale," says Tunde. "Then there is the lack of trained eye health professionals; there are only about 1,600 ophthalmologists in the country where around 4 to 5 million people are estimated to have diabetes."

THE SOLUTION

A teleophthalmology eye evaluation involves taking photographs of the patient's eyes in

different community-based locations and sending these images to a central database. The images are evaluated remotely at a reading centre by trained image graders who send the results back to the patient and their doctors. Thus, if the team can establish a means of performing teleophthalmology eye evaluations using mobile retinal cameras, they can overcome the geographical and practical challenges that exist in the Philippines.

COLLABORATION

The UK national DESP is one of the most successful globally – since 2014, diabetic eye disease is no longer the leading cause of severe sight impairment in England and Wales. The UK team is therefore translating this to the Philippines. "Having properly trained personnel is crucial in deploying a DESP. The REACH-DR project, through the UK partners, supported the retinal imager and grader training and certifications. Aside from training, the framework for the pilot DESP in the Philippines was developed using UK standards and best practices," explains Tunde. "The UK partner also provides continuous programme quality assurance to ensure that the DESP operates at the highest standards. The exchange of personnel will help with training."

The UK team's colleagues from the Philippine Eye Research Institute are involved in the planning and delivery of all aspects of the project from the very beginning. The two teams have been working together on the design of the programme, the delivery of the training and quality assurance, and thinking about how to include artificial intelligence in the screening programme.

THE LONG-TERM

The goal of the REACH-DR project is that relevant decision makers and government institutions in the Philippines will have specific policies in place to enable long-term funding that sustains DESP appropriately. The Philippines is aiming to achieve a reduction of blindness from diabetic eye disease, mirroring the UK results.

The next steps of the project include presenting the results to the relevant stakeholders, including patient groups, applying for further funding and expansion of the pilot programme to involve more regions in the Philippines. For the programme to be successful in the long term the team will also need to train administrators, policymakers, AI-specialists and quality assurance personnel, so a DESP can support a cadre of professionals, rather than just those with a clinical background.

PROFESSOR TUNDE PETO

Clinical Ophthalmology, School of Medicine, Dentistry and Biomedical Sciences, Centre for Public Health, Queen's University Belfast, UK

FIELD OF RESEARCH

Ophthalmology

RESEARCH PROJECT

Establishing a sustainable model for diabetic retinopathy screening programmes in the Philippines

FUNDER

UK Research and Innovation (UKRI), Medical Research Council (MRC)

EXPLORE CAREERS IN OPHTHALMOLOGY

- Tunde suggests that young people looking to pursue a career in the field of ophthalmology reach out to their local eye care professionals so they can personally discuss their ideas or questions about the field. It can also be very helpful to volunteer at an eye clinic to get a glimpse of what working in this field entails.
- The Royal College of Ophthalmologists' website is an excellent resource for those interested in learning more about the subject: **www.rcophth.ac.uk**
- The basic starting salary for junior hospital doctor trainees at foundation training level is £27,000 in the first year, rising to £32,000 in the second year: **www.prospects.ac.uk/job-profiles/ophthalmologist**

ABOUT OPHTHALMOLOGY

Ophthalmology is a branch of medicine concerned with the diagnosis, treatment and prevention of diseases that affect the eyes and vision. There are a vast number of people from medical and non-medical backgrounds working in the field of ophthalmology and it is a diverse field that offers job opportunities for people with varying interests and capabilities.

For instance, clinical professionals are involved in detecting and managing ocular disease, while non-medical staff may be involved in screening for ocular pathology, capturing ocular images using different imaging modalities, working with people with visual loss, quality assurance, health-economics and eye care research.

As the REACH-DR project shows, there are a range of opportunities within the field that can benefit countries around the world. This is a field where you can make a real difference to the quality of people's lives.

The next generation of ophthalmologists will face the challenge of examining and treating a huge wave of people with not only diabetic eye disease but other conditions such as age-related macular degeneration and refractive errors such as short and long-sightedness.

Good communication and interaction with patients are crucial in the field of ophthalmology, however the ever-changing technological landscape, including virtual clinics and artificial intelligence, may mean that there is less in-person contact. Consequently, another challenge will be how to use these technological advances while remaining empathic and communicating well with patients.

The teams involved in ophthalmology are varied – from administrators to IT personnel and technicians, and optometrists, nurses and doctors. Being a good team-player will be a crucial characteristic of any successful entrant into the field.

PATHWAY FROM SCHOOL TO OPHTHALMOLOGY

Tunde recommends biomedical sciences for those interested in pursuing a career in ophthalmology, as well as mathematics, statistics and data science. "In the era of computerisation, big data and artificial intelligence, these subjects are very important," she says. "However, we cannot forget that we work closely with people, many of them elderly and visually impaired, so being a good communicator is vitally important." So, you will find people with backgrounds in social sciences, psychology and languages working in ophthalmology teams.

MEET THE REACH-DR TEAM

PROFESSOR TUNDE PETO
PRINCIPAL INVESTIGATOR

TUNDE'S TOP TIPS

01 Always listen, know yourself and your limitations but use your skills to the best of your ability.

02 Sometimes life presents opportunities you never knew existed, so keep your eyes open!

03 Be pro-active in learning and work in different teams and cultures if you can, these experiences will always teach you something new.

My role is to lead and manage the programme, enabling the Philippines to set up a sustainable model for diabetic eye screening programmes (DESPs). This will ensure knowledge transfer on all levels: from administration to the screening process, to providing treatment.

I have been committed to studying and treating chronic eye disease since completing my medical degree. After finishing my PhD and ophthalmology training, I moved to Moorfields Eye Hospital in London, focusing on diabetes-related complications. I am now Professor of Clinical Ophthalmology at Queen's University Belfast (QUB) and have worked on many large population studies and multi-centre clinical trials while remaining a practicing ophthalmologist.

As the clinical lead for the Diabetic Eye Screening Programme in Northern Ireland, I have been involved with the UK's National Diabetic Retinopathy Screening Programme. Finding and treating patients early in the disease process reduces the rate of diabetes-related visual loss, but is expensive, which is where telemedicine can step in.

I always wanted to pursue science and I loved both the regular human contact and long-term relationships with patients with chronic diseases. This, along with the surgical challenge, makes ophthalmology perfect for me. I love that it involves maths, science, technology, statistics, surgery and lots of communication with patients, their family and their carers.

One of my main motivations is the importance of collaboration and a joined-up approach to research. I work with large teams involving not only those working in eye-care, but also in healthy ageing and dementia care. These are new frontiers and I never stop learning.

Not giving up and being open minded have made me successful. It is important to never look down on anyone and to be appreciative of help.

I have been involved in a number of international developmental activities, such as being part of the team for the Queen's Diamond Jubilee Trust Fund's Diabetic Eye Screening in the Commonwealth. Our work will leave a lasting legacy in the countries involved.

DR KATIE CURRAN
RESEARCH OPTOMETRIST

KATIE'S TOP TIPS

01 Developing a career that you are happy and satisfied with can take time, so be patient.

02 Many job opportunities are available, and it is important to research these carefully and seek advice from the right people.

03 We will all encounter rejections at some point in our careers and it is crucial to learn and develop from these.

Part of my role in the Queen's University Belfast team is to ensure transfer of learning. I am delighted to help strengthen the REACH-DR programme with my expertise.

During my PhD, I worked in Vietnam and Bangladesh where most of my work focused on strengthening diabetic retinopathy services. I recently embarked in a role as a Wellcome Trust research fellow at QUB and continue to work on retinal diseases.

I always had a keen interest in science subjects in school and always wanted to work as a healthcare professional. My uncle lost his sight at a young age and I completed my work experience in an optician's when I was 16. Following my work experience, I was keen to pursue a career in optometry.

After four years working as an optometrist, I decided to take a career break to explore South-East Asia. Although I enjoyed working as an optometrist, I wanted a career that would offer some flexibility and allow me to be involved in eye care research. I completed a master's in public health and a PhD at QUB which gave the opportunity to pursue a career in academia, whilst maintaining my role as an optometrist on a part-time basis. This enables me to interact with patients and conduct research in my area of interest.

I have been extremely lucky to work with successful and motivational people throughout my career. Tunde provides guidance and support to me to become a successful academic whilst building on my experience as an optometrist. Her expertise as a professor and ophthalmologist is invaluable for me.

One of my main attributes that has helped me is my dedication to work. If I set out to achieve a goal, I work hard to ensure I reach that goal.

My proudest career achievement so far is completing my PhD and having the opportunity to work with international collaborators, particularly in low-middle income countries.

DR RECIVALL SALONGCAY
RESEARCH OPHTHALMOLOGIST

RECIVALL'S TOP TIPS

01 It is never too late or too early to become involved in science.

02 It will take time to gain expertise in your chosen scientific field, so keep that in mind when you start out and remain patient!

03 Ask questions and start searching for the answers.

I am responsible for the planning and delivery of REACH-DR related research activities so the objectives of the project are met including liaising between the UK and the Philippine teams. I also assist Tunde with preparing reports for scientific journals, conferences and funders.

In Manila, I was a consultant ophthalmologist, specialising in retinal diseases, and a research scientist, where most of my work revolved around retinal imaging for diabetic retinopathy. I knew a research fellowship at QUB would be a good opportunity for me to learn from and collaborate with renowned experts in my field.

I always wanted to become a medical doctor; growing up I was always interested in the biological sciences. My other interests included music, books and anime.

As a trainee in ophthalmology, I realised I also wanted to pursue a career in research; I would often have questions about how we can better diagnose and treat patients with eye conditions, and how these potentially blinding diseases can be prevented.

I worked with some amazing mentors and collaborators who inspired me to pursue this career path. I learned more about teleophthalmology and diabetic retinopathy screening while working at the Philippine Eye Research Institute, and I realised that something needed to be done on a national level.

I am motivated by helping people who suffer from blinding retinal diseases and by being around individuals who share the same passion for ophthalmology and vision science as I have.

Resilience has really helped me in my career. In a clinician-scientist's career, we encounter many setbacks and rejections – from unsuccessful study grant applications to a research experiment not producing the desired outcome – but we cannot let these derail us or make us lose focus on our goals. We need to accept these setbacks and move on, using them to inform our future decisions.

Being offered my current post at QUB is one of my proudest achievements, not only because of the wealth of opportunities that this has brought me but because I know that the work we are doing is meaningful and will make an impact on the millions of people with diabetes in my home country.

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