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PART II
ISSUE 18
January 2023

FRANCISCA ROCKEY

BLACK GEOGRAPHERS
Francisca Rockey tells us how and why she set up Black Geographers

TSHEPISO MALEMA SPEAKS
Tshepiso Malema introduces the motivational platform that helps young people achieve their dreams

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ISSUE 18
Part II

WELCOME

We are delighted to be marking the start of 2023 with a new look for Futurum magazine. This celebratory double issue showcases the impressive range of research taking place in the world today and introduces students to the wonderful researchers behind this ground-breaking work. Redesigned and looking more striking and engaging than ever, all the resources in Futurum magazine continue to be freely available online for students and teachers to use – and always will be.

As the new year dictates, we have reflected on the past year – on the fascinating educational brochures, animations and PowerPoints we have had the pleasure of creating – and are looking ahead to exciting new resources that will connect researchers with students even more. Futurum podcasts will enable researchers to 'talk to' students, sharing their personal insights, experiences and career pathways. We want students to know that everyone has a different path to take, and there is guidance and inspiration available to help them find theirs.

For this special issue, we knew we needed someone as passionate and driven as we are for our cover star. Francisca Rockey (p. 46) found the experience of being the only Black person on her undergraduate geography course isolating, but she did not let that diminish her passion for her subject or her aspiration. She was determined to make a difference, and Black Geographers, a support and mentoring network, was born.

Ambitious and forward-thinking, Tshepiso Malema (p. 04), a student from South Africa who has turned his love of computer games into unique and life-changing enterprises, providing students with guidance and mentorship on their careers, and instilling a spirit of entrepreneurship.

Futurum magazine is more accessible and visually appealing than it has ever been, and we could not be prouder of Issue 18 – parts 1 and 2 – and of the inspiring articles it contains. We are excited to see what the future holds – both for us and the next generation!

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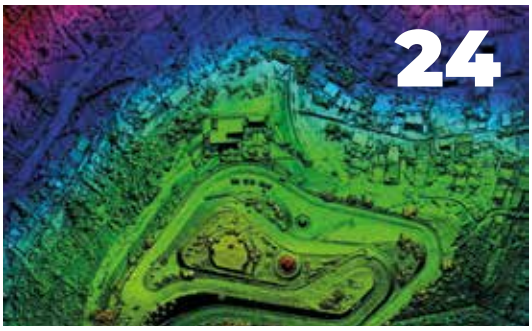

Research articles

INTERVIEWS

COVER STORY

Francisca Rockey

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WE WANT YOUNG PEOPLE'S DREAMS TO BE UNLOCKED THROUGH GAMING AND VIRTUAL REALITY.

TSHEPISO MALEMA

Tshepiso Malema was 15 when he set up **Gamer's Territory**, a place for young people to meet and play computer games, in Ivory Park, a Johannesburg township in South Africa. He then went on to set up **Tshepiso Malema Speaks**, a motivational platform to help young people achieve their dreams. He explains how his drive to support others set him on his entrepreneurial journey.

Why did you study information systems at the University of Pretoria?

At first, I wanted to study computer science, but, in South Africa, your grades determine which course you can take, and my grades weren't good enough. So, I did some research and came across information systems at the University of Pretoria. When I read the course description and saw that it was a combination of entrepreneurship and IT, I thought, "Wow, this is what I should be doing!" At that point, the idea of studying computer science left me, and here I am, studying information systems and really enjoying it. Not having the grades I thought I needed was a blessing in disguise.

How do you stay motivated to learn?

The fear of failure keeps me motivated. My mom always tells me that I'm the one who will change our family situation. If I'm lazy and unmotivated, that means I'm ruining others' futures.

In 2021, during the COVID-19 lockdown, I only had three months of face-to-face contact with my teachers. The rest of the time, I was studying on my own, which was terrifying. It's so easy to get distracted and, during that time, I read books about entrepreneurship and emailed people to ask them to mentor me. But when I went back to class, I had to start catching up. My exam results were so bad, but the thought that I may not be able to stay at university hit me and I didn't want to lurk behind. I had always imagined myself at a university, and so I started putting in more hours.

Why did you set up Gamer's Territory?

I come from a township, and during the holidays,

© Katlego Mphuloane

I used to visit my cousins who live in the city. Obviously, the environment in the city is very different to the environment in the township.

I remember seeing my cousins play X-Box. I didn't know what an X-Box was. For me, it was so magical to see them control the players, and it was at that point that I knew I wanted to get into gaming. When I was in grade 10, I won a laptop in a school competition, sponsored by Nka'Thuto Edu Propeller (a non-profit STEM organisation) and became one of 30 top technopreneurs in South Africa. The first thing I did was install a game on that laptop. This set me apart from my peers in the township because no one had seen a laptop, let alone a computer game. Everyone came to my home to watch me play. That was when I thought I could make some money from this. I charged people one rand (approximately 50p or 60 cents) to watch me play, and that's how Gamer's Territory was formed.

What happened next?

I realised that interacting with digital devices like PlayStation is not just an entertainment, it stimulates the brain. So, I started doing some research on gaming, the technology divide and how to bridge that divide. That's when I wanted to do more. I became passionate about bringing tech to the townships, and I reinvested the money I made into Gamer's Territory – buying more devices, entering competitions, exploring virtual reality – and, just like that, the business grew into what it is today.

How does playing computer games bridge the divide between people living in townships and people in more affluent circumstances?

When I was in school, I took coding classes and was able to start coding my own games. This was a revelation for me. Not enough people in the townships have access to such skills. My younger brother, who's 12 now, watched me build a computer from scratch, and the next thing I knew, he was building his own. That gave me so much hope, and I thought even if we just start teaching coding to five kids (because we have limited equipment), we would still be making a huge difference.

Introducing young people to virtual reality is also great because you can be from the most disadvantaged area and yet still visit places like Dubai, places you've never been or may never have to chance to see. You can see Messi or Ronaldo in the FIFA football games.

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Gamer's Territory uses the phrase 'unlocking dreams'. We want young people's dreams to be unlocked through gaming and virtual reality.

How old were you when you set up Tshepiso Malema Speaks?

I was 17. At the time, I was very shy, but I was in a space where I was surrounded by mentors and people who inspire me. Some of my peers in the township are just living for the sake of it, and I wanted to do something that would help them feel just as motivated as me.

I started a blog and wrote down my thoughts, motivational insights, how I managed to change my mindset and my life goals. A few months later, I'd had over 500 visitors from all over the country – all over the world, actually — and the feedback I was getting was so positive. I thought if I could reach people's hearts just through the blog, I could convert the blog into an organisation.

When I say organisation, I was still doing this by myself, talking to students, talking to my classmates, but there I was, acting as a motivational speaker for young people. At my school principal's request, I spoke in an assembly and, before I knew it, I was visiting other schools and talking to other students there.

Now, we're a team of 14 young people, all of whom have diverse skills. Tshepiso Malema Speaks aims to give students guidance and mentorship on their careers and instil a spirit of entrepreneurship in South Africa, which has such high levels of unemployment.

How did you find your voice when you were so shy?

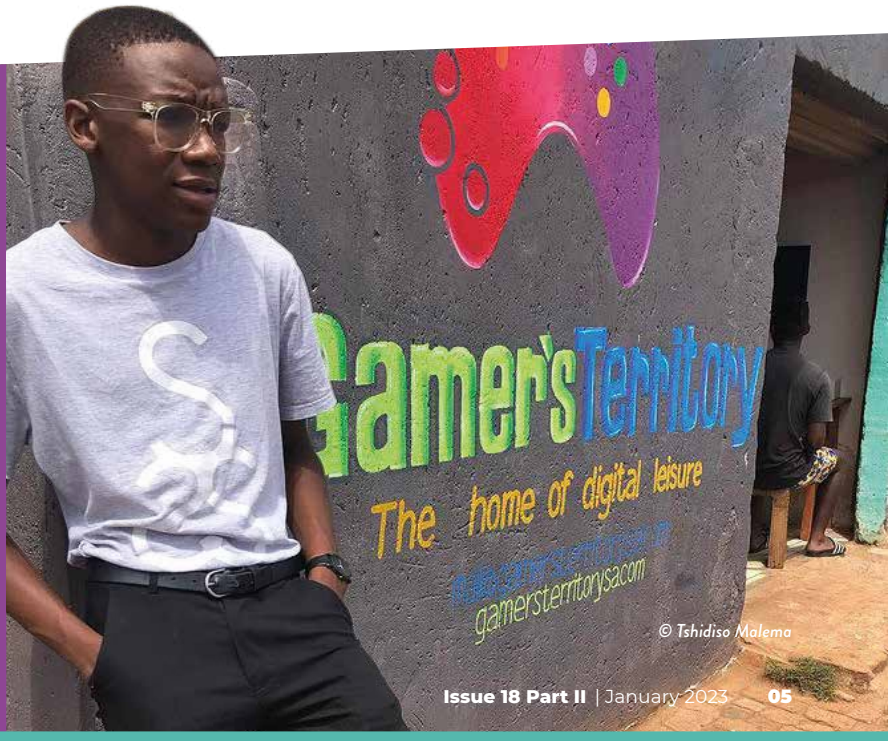
I was forced to have a voice because of the work I do and the competitions I was entering. People started inviting me to become a speaker. When you start to see positive results, it gives you power to keep going. I could see the impact I was having, and so I was forced to get out of my comfort zone.

You once said, "The entrepreneur space taught me to take risks and I cannot take risks if I still want validation." What did you mean?

I said that a long time ago, inspired by my mentor, Emmanuel Bonoko. When my entrepreneurial journey started, I was fortunate enough to have this mentor who took me by the hand and guided me on a weekly basis. Once, Emmanuel was hosting an event attended by esteemed entrepreneurs in South Africa, and he asked me to pitch my ideas to them. I'd never pitched my ideas to anyone, but his aim was to teach me the spirit of taking risks because opportunities come when you least expect them, when you're scared. If I didn't take this opportunity, it would be because I was seeking validation from other people.

I'm glad I didn't listen to people who told me to focus on school and forget about being an entrepreneur because I was too young. I didn't need validation, I had to take risks.

> **"GAMER'S TERRITORY USES THE PHRASE 'UNLOCKING DREAMS'. WE WANT YOUNG PEOPLE'S DREAMS TO BE UNLOCKED THROUGH GAMES AND VIRTUAL REALITY."**



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> ***THE MAIL & GUARDIAN'S TOP 200 YOUNG SOUTH AFRICANS AWARD HAS OPENED SO MANY OPPORTUNITIES FOR ME. IT'S LIKE A TAP ON THE SHOULDER TO SAY, 'KEEP GOING WITH WHAT YOU'RE DOING'.***

What are you most proud of, and why?

Being nominated for the Mail & Guardian's top 200 Young South Africans. It's an iconic list that every young person wants to be a part of, and I feel humble to be nominated alongside other young people who inspire me.

I was taught how to do 5- and 10-year plans, and the Mail & Guardian was in my 10-year plan. I thought I was going to be nominated when I was 25 or 26, but it happened much sooner. Even now, I don't know who nominated me, but I really hope they come clean one day so that I can thank them.

This award has opened so many opportunities for me and allows me to make an impact for even more people. It's like a tap on the shoulder to say, 'Keep going with what you're doing'.'

On your LinkedIn profile you say: "In a nutshell, Tshepiso Malema is what the world is waiting for'. Where does your self-belief come from?

That's a really, really a hard question! It's not really about me right now, it's about other people. Entrepreneurship is one of the hardest journeys someone can take. Most of the time, I doubt myself. I'm not always self-confident, and I'm always asking myself whether I should continue. But I wouldn't be able to get any work done if I didn't have the confidence to do it. I wouldn't be able to go to publishers, ask people to be my mentors, nor would others be able to learn and benefit from my journey. So, I always have a 'why'.

I'm writing a book called *What is Your Why?* I believe it's my 'why' that keeps me going. My initial 'why' was to change my family situation, but now it's more about helping people improve their lives so that they can improve their families'

lives and then maybe even more people will be inspired by them.

It's not about self-confidence or how I feel. One of the biggest responsibilities we have as leaders, or as people who are destined to do more, is to do certain things no matter how we're feeling. We just have to fight.

Can everyone learn this ethos?

Yes, because I've witnessed it. To give an example, one of my team members at Tshepiso Malema Speaks used to be very shy. But when she saw the change I was making just by telling my story – because everyone has a unique story that might change someone's life – she started telling us, the team, her story, and it was so inspiring.

One day, I put her in the spotlight. I said, "Just talk to these kids, I'm sure they really want to hear your story." Today she's getting gigs just for telling her story.

I think if you can get away from the idea that you're doing this for yourself and stop thinking about the masses of people you're going to impact, this makes things a lot easier. When you start to think about the potential outcomes of what you're doing, it can be daunting, and you can lose confidence. You just need to do it without over-thinking!

> **"ENTREPRENEURSHIP IS ONE OF THE HARDEST JOURNEYS SOMEONE CAN TAKE. MOST OF THE TIME, I DOUBT MYSELF."**

> **"IT'S NOT REALLY ABOUT ME RIGHT NOW, IT'S ABOUT OTHER PEOPLE."**

About Tshepiso Malema

Tshepiso is in his second year studying information systems at the University of Pretoria in South Africa. He is also the founder of Gamer's Territory, which provides young people in townships access to computer games, and Tshepiso Malema Speaks, which aims to help people overcome challenges and fulfil their dreams. Tshepiso has been named one of the Mail & Guardian 200 Young South Africans and has been awarded a FOYA Award for Most Promising Founder of the Year 2022.

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tshepisomalema.home.blog

ABOUT

Left: Tshepiso at the Gordon's Institute of Business Science. © Wingman Communications
Top right: Tshepiso mentoring boys © Mpumelelo Buthelezi
Bottom right: Tshepiso with his team at Tshepiso Malema Speaks. © Fernando Nando

HOW IS MATHEMATICS APPLIED TO REAL WORLD PROBLEMS?

Mathematics is essential to our way of life. It is used all around us, from weather forecasting, engineering and finance to modelling how diseases spread. **Professor Anotida Madzvamuse**, an applied mathematician at the **University of Sussex,** in the UK, and the **University of British Columbia,** in Canada, led the UK-Africa Postgraduate Advanced Study Institute in Mathematical Sciences.

Professor Anotida Madzvamuse

Department of Mathematics, University of British Colombia, Vancouver, Canada

Previously: School of Mathematical and Physical Sciences, University of Sussex, UK

PROFILE

Fields of research
Mathematical and Computational Biology, Numerical Analysis and HPC Scientific Computing

Research project
Co-ordinating the UK-Africa Postgraduate Advanced Study Institute in Mathematical Sciences (UK-APASI) which supports the training of early career African researchers in applied mathematics

Funders
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TALK LIKE AN ...

APPLIED MATHEMATICIAN

Dynamical system — a collection of objects and their interconnections which evolve in time and space

Mathematical modelling — the ability to translate observations (experimental or otherwise) using mathematical theories and laws of physics to represent important features from a real world problem. Modelling approximates the reality as reality is far too complex to be described. Modelling is used to build understanding of the application area, test a theory or hypothesis, and visualise or predict an outcome

Parameter — a variable that is configurable and defines the specific behaviour of a model. This variable is independent of space and time, and, in many cases, denotes the physical units associated with the dynamical system

Applied mathematics is the application of mathematics to real world problems. It is an incredibly useful field with a wide range of applications from biological and social sciences to computer animation and finance. Professor Anotida Madzvamuse is a professor of mathematical and computational biology whose work includes data-driven mathematical modelling, mathematical analysis of models, parameter estimation and model selection by fitting models to data. This cyclic modelling approach allows for models to be validated – or invalidated – and enables Anotida to select the models or processes that best describe the applications under study. Passionate about training a new generation of early career scientists, he is the principal investigator for the UK-Africa Postgraduate Advanced Study Institute in Mathematical Sciences (UK-APASI).

Mathematics in the real world

Whilst pure mathematics is about solving problems and developing theories within mathematics, applied mathematics uses those mathematical theories to solve real world problems. Mathematicians can utilise modelling to do this, usually in the form of equations. They then use the models to both help understand the original problem, and to discover new features about it. Modelling is fundamental to much of our understanding of the world. For example, weather forecasts are a well-known example of mathematical modelling.

Mathematics and government decision-making

Using powerful predictive models, mathematicians can provide quantitative solutions which can influence government policies. "Decision making based on the models are rigorously tested and validated as part of our modelling-data approach," says Anotida. This way, predictions and forecasting are driven by the dynamical systems, which, in turn, are driven by observations. For example, mathematics has been essential to the modelling of COVID-19 for directing government decisions on non-pharmaceutical interventions such as lockdowns. Anotida has worked on predictive models which have been applied innovatively to provide early warning surveillance systems to support the operational management of hospitals and mortuaries. This work was done in collaboration with Dr James Van

Professor Anotida Madzvamuse (far right, front) and Dr Gift Muchatibaya (far left, front, Head of Department of Mathematics at UZ), with master's students at the University of Zimbabwe

Yperen (University of Sussex, UK) and Dr Eduard Campillo-Funollet (University of Lancaster, UK), and public health analysts and NHS commissioners from the southeast of the UK.

Data-driven mathematical modelling

Anotida works with non-mathematicians to formulate new mathematics from scratch based on physical observations and principles, which he calls 'data-driven mathematical modelling'. "Once we have the models, I am interested in the rigorous mathematical analysis of them," he explains. "Since most of these models are highly complex, nonlinear and in many cases involving many equations (systems), analytical solutions are not readily available." From here, Anotida and his collaborators develop and implement novel numerical methods to efficiently and accurately solve the models. These approximate solutions are extremely useful to understand the physics of the problem. "A key part of the numerical method is that it must capture the inherent properties of the mathematical formalism, and these could be mass conservation, positivity of solutions, bounded of solutions and many other properties," says Anotida.

"Many of these models are characterised by parameters that describe, for example in the case of cell migration, biochemical molecular rates and mechanical properties of the physical model," he explains. Some of these parameters can be measured during observations but many are not obtained through measurements. It is here that mathematics, through statistical modelling, comes to the rescue. Anotida infers these parameters by fitting models to physical data in a statistical sense. This leads to the concept of identifying the best model that describes the physical phenomena. Anotida's philosophy is to propose various models depending on the biological or physical and mathematical assumptions, rather than a single model.

Applied mathematics in Africa

Applied mathematics is essential to solving real world problems in many areas, and Anotida's work goes far beyond his own research in theoretical and computational biology. He wants to ensure the next generation of African applied mathematicians has the skills it needs to impact society in a positive way. There have been recent advances in data acquisition across the African continent in infectious diseases, crime, wildlife management, conservation and other areas. This demands new approaches to understanding the dynamics of such datasets and to make predictions that can help practitioners make policies that are based on rigorous scientific studies. However, many junior staff members in university mathematics departments across Sub-Saharan Africa do not possess a PhD, with almost 80% of faculty staff having, at most, a master's degree. "It is critically important that the next generation of scientists should be able to communicate seamlessly across disciplines to facilitate cross-fertilisation of ideas, techniques and approaches," says Anotida.

> ***"IT IS CRITICALLY IMPORTANT THAT THE NEXT GENERATION OF SCIENTISTS SHOULD BE ABLE TO COMMUNICATE SEAMLESSLY ACROSS DISCIPLINES..."***

Introducing UK-APASI

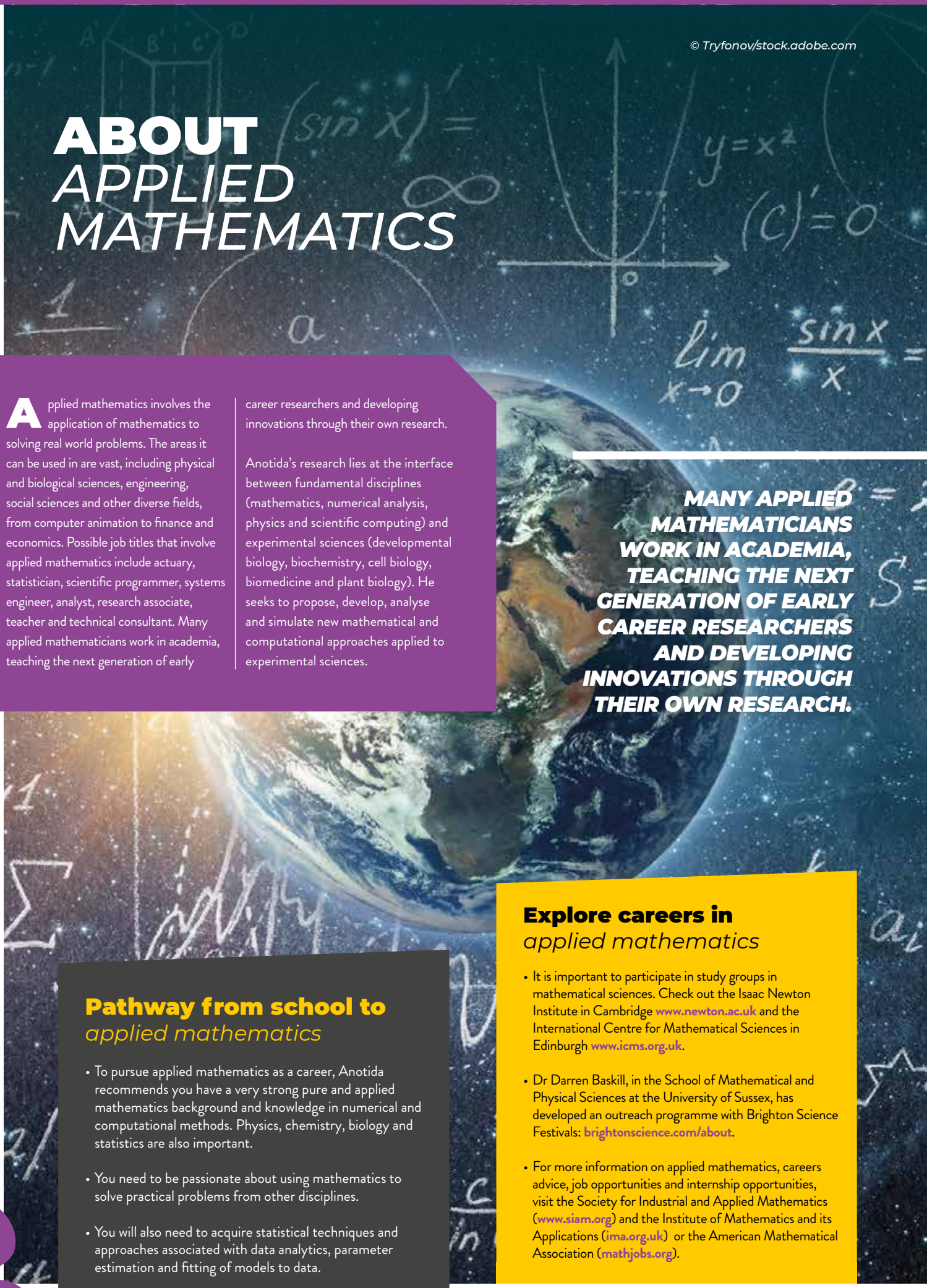
To train and develop such highly skilled mathematicians, Anotida is the principal investigator of the UK-Africa Postgraduate Advanced Study Institute in Mathematical Sciences. This is a research consortium between the UK, Africa and other interested partners which is forging relationships between applied mathematicians in the UK and the Sub-Saharan African region, Europe and North America. The expertise of world-leading international researchers and academics is vital for supporting other continents where such expertise is either non-existent or difficult to access. In particular, knowledge transfer from international applied mathematicians to early career researchers in Africa, while they are resident in their host countries, is key. This benefits both, as established academics develop research projects involving international collaborations, while early career researchers in (or from if they are moving away to host countries) Africa are exposed to world-leading knowledge, techniques and approaches which they can use to address global challenges.

UK-APASI's Achievements

Around 40 early career African researchers were enrolled in the programme, from Malawi, Nigeria, Kenya, Ghana, South Africa, Botswana, Eswatini, Mozambique and Zimbabwe. The UK-APASI trained them on current state-of-the-art theoretical, statistical, computational and applied techniques in mathematical sciences. The researchers worked on crime modelling, infectious diseases (COVID-19), plant biology (infectious diseases in plants), cell biology (the mechano-biochemical models for cells) and financial mathematics.

The future of UK-APASI

The long-term impact of the programme includes early career African researchers assuming senior academic positions (through promotions and appointments), increased employment in Africa, influencing public policy through science and the creation of new mathematical models and, therefore, new knowledge. The programme was funded for one year and, due to the COVID-19 pandemic, a one-year extension was awarded. Anotida believes it is critically important that long-term funding for such programmes is made available as many early career researchers in Africa were not able to take part due to limited numbers. In particular, Anotida calls for African governments to create funding schemes for training early career researchers. Without such funding, a lot of early career African mathematics researchers are not able to pursue further postgraduate training in applied mathematics while they are resident in their home countries. It is imperative to continue to seek funding from any funding bodies that can support capacity building and human infrastructure training in Africa.



ABOUT *APPLIED MATHEMATICS*

Applied mathematics involves the application of mathematics to solving real world problems. The areas it can be used in are vast, including physical and biological sciences, engineering, social sciences and other diverse fields, from computer animation to finance and economics. Possible job titles that involve applied mathematics include actuary, statistician, scientific programmer, systems engineer, analyst, research associate, teacher and technical consultant. Many applied mathematicians work in academia, teaching the next generation of early career researchers and developing innovations through their own research.

Anotida's research lies at the interface between fundamental disciplines (mathematics, numerical analysis, physics and scientific computing) and experimental sciences (developmental biology, biochemistry, cell biology, biomedicine and plant biology). He seeks to propose, develop, analyse and simulate new mathematical and computational approaches applied to experimental sciences.

MANY APPLIED MATHEMATICIANS WORK IN ACADEMIA, TEACHING THE NEXT GENERATION OF EARLY CAREER RESEARCHERS AND DEVELOPING INNOVATIONS THROUGH THEIR OWN RESEARCH.

Pathway from school to *applied mathematics*

- To pursue applied mathematics as a career, Anotida recommends you have a very strong pure and applied mathematics background and knowledge in numerical and computational methods. Physics, chemistry, biology and statistics are also important.
- You need to be passionate about using mathematics to solve practical problems from other disciplines.
- You will also need to acquire statistical techniques and approaches associated with data analytics, parameter estimation and fitting of models to data.

Explore careers in *applied mathematics*

- It is important to participate in study groups in mathematical sciences. Check out the Isaac Newton Institute in Cambridge www.newton.ac.uk and the International Centre for Mathematical Sciences in Edinburgh www.icms.org.uk.
- Dr Darren Baskill, in the School of Mathematical and Physical Sciences at the University of Sussex, has developed an outreach programme with Brighton Science Festivals: brightonscience.com/about.
- For more information on applied mathematics, careers advice, job opportunities and internship opportunities, visit the Society for Industrial and Applied Mathematics (www.siam.org) and the Institute of Mathematics and its Applications (ima.org.uk) or the American Mathematical Association (mathjobs.org).

Q&A

Meet Anotida

What was your childhood like?

I enjoyed cattle grazing, hiking, playing football, volleyball and basketball, as well as reading and playing chess. Growing up, I learnt that hard work pays! Whilst harvesting was a great joy, it was planting seeds that was the essential work. You must plant the seeds of knowledge by developing new areas of study; you only reap what you sow.

I was motivated to study hard when I was young. I lived in poverty and had to work in building construction on weekends and term holidays to afford my boarding school fees at Pakame High School in Shurugwi, Zimbabwe. I realised early on that mathematics was akin to my second name. I was the only student to obtain an A in ordinary level mathematics out of a cohort of approximately 150 students. It was then that I realised that I had the potential to do well in mathematics.

What has your research looked at?

Alongside my PhD, I have a bachelor's degree in applied mathematics and a master's degree in mathematics and education. I joined a group in mathematical biology at the University of Oxford, where my numerical analysis and modelling techniques fitted naturally with the research questions being addressed at the time.

Amongst several other projects, I have looked at how patterns form in nature, based on Turing's idea of pattern formation driven by diffusion. I have used mathematical models to look at how cells migrate through complex environments. I have also worked in high performance scientific computing, an area which is key to delivering useful models that can be used by experimentalists and other users in modelling and numerical analysis.

What are you passionate about?

Working with non-mathematicians, such as experimentalists or public health analysts, to formulate new mathematics based on physical observations and principles. I am also extremely passionate about training a new generation of early career scientists with expertise at the boundary between disciplines: theoretical and experimental.

What other opportunities has your career provided?

I have been lucky enough to have travelled around the world, to all continents. The highlights include my five-year stay in Cuba during the Zimbabwe-Cuba International Higher education collaboration and a three-year stay in Alabama, in the US, that was critical in showing me the need to belong to an appropriate department with expertise complimentary to mine.

Attending international conferences has seen me travel to Penang Island in Malaysia, where I was stung by a jelly fish (we do not have such creatures in Zimbabwe!). I also visited the Amazon as part of my research trip to Brazil to study stingrays. My other favourite places are the Tennessee mountain belt, skiing resorts off Grenoble in France, beautiful churches in Lecce, Italy, and villages outside Shanghai, in China. I should not forget my trip to Hyderabad in India where seeing the mixture of city and wildlife is spectacular; animals can be roaming wildly in the city, tricycles are raving from all angles and buses, cars and humans intermingle continuously with no accidents at all! It is such a complex dynamical system to model!

What are you most proud of?

Being awarded the Royal Society Research Merit Award, the book prize for being the top student in mathematics at the University of Zimbabwe, and the golden medal for being the top student across all subjects from the Zimbabwe-Cuba programme. I would be thrilled if I can be nominated to be a Fellow of the African Academy of Sciences, as well as being a Fellow of the Royal Society. My ambition for the future is to develop new areas of research that will occupy mathematicians for centuries to come.

Anotida thanks his collaborators in the UK, Africa, Europe and North America for supporting the UK-APASI programme and the UK-APASI students for their participation. Thanks also go to the International Centre for Mathematical Sciences (ICMS) for hosting the virtual UK-APASI workshops (2020-2022).

This work is dedicated to Anotida's wife, Suna, his daughters, Mona and Leila Madzwamuse, and and the Madzvamuse and Eryigit families.

Anotida's *top tips*

1. You are capable of being the best in your area if you work very hard and are humble in your quest for knowledge.

2. Be resilient, resourceful and adaptive.

3. Don't follow the common hypothesis; you must follow your instincts and strengths, take risks when appropriate. What I have learnt is that every door is there to be opened!

4. When choosing a mentor, choose wisely! I have been lucky to be supervised by two extremely top-drawer advisors: Professors Andrew J. Wathen and Philip K. Maini. I also have been lucky to have been taught by two other brilliant professors at the University of Zimbabwe: Dr David Henwood and Professor Mark Roberts. To my Cuban professors (too many to mention), it was a great pleasure to be under their stewardship.

5. To those from minority backgrounds, the reality is: researchers from minority and under-represented groups always work twice as much as other researchers. This is a simple fact of reality.

IMAGING THE INVISIBLE: HOW CAN RESEARCH SOFTWARE AND IMAGING TECHNIQUES HELP SCIENTISTS STUDY THE THINGS WE CAN'T SEE?

From microscopic plankton to individual atoms, the subjects of many scientific studies need special devices to be seen. Scientific imaging devices, like electron microscopes, have become increasingly powerful in recent years, allowing scientists to study their subjects in even more detail. These devices need to be partnered with software to allow the images they produce to be analysed. **Dr Joanna Leng,** from the **University of Leeds** in the UK, is a research software engineer who designs and develops the software that allows scientific imaging devices to be used to their full potential.

Dr Joanna Leng

School of Computing, University of Leeds, UK

PROFILE

Field of research
Research Software Engineering

Research project
Developing new software for new imaging techniques

Funder
Engineering and Physical Sciences Research Council (EPSRC)
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TALK LIKE A ...

RESEARCH SOFTWARE ENGINEER

Scientific imaging — the process of capturing or creating images of scientific phenomena. This often involves the use specialist devices such as microscopes

Scientific model — a conceptual or mathematical representation of a real-world phenomenon that allows scientists to study the phenomenon in more detail

Scientific simulations — an advanced type of computational model that not only represents a real-world phenomenon, but aims to predict how the phenomenon might change under different conditions or parameters

Software — a set of instructions, scripts or programmes that are used to operate computers and perform specific tasks

Synchrotron — a type of particle accelerator

From miniscule sub-atomic particles to gargantuan black holes, the world of science deals with a dramatic range of sizes. Atoms are millions of times smaller than a grain of sand, and the visible universe stretches out for 13.5 billion lightyears. This poses the question: How do you study things that you cannot see?

This quandary has led to the creation of many imaging devices that allow scientists to work with such extreme scales. For example, using electron microscopes, we can now capture images at an atomic resolution in which each pixel is less than the size of an atom. At the other end of the scale, NASA's recently-launched James Webb Space Telescope will be able to see to the very edge of the visible Universe, showing us the stars and galaxies that formed shortly after the Big Bang.

As scientists gaze deeper and further into the extreme reaches of our Universe, the need for more powerful and sophisticated imaging devices grows. But these devices do not work by themselves. They need to be operated by experts who know how to use them and paired with software that allows scientists to analyse the images they produce. Dr Joanna Leng, from the University of Leeds in the UK, is a research software engineer who specialises in developing software for new imaging techniques.

Why is scientific imaging so important?

"Scientific images and videos allow us to see things that we cannot see with our unaided-eyes," explains Joanna. Objects such as cells and crystals, and the processes through which they are created, exist at microscopic scales, and scientific imaging allows scientists to study them. With the help of scientific imaging, researchers can conduct experiments to test their hypotheses and build new theories about how the Universe works. "These are the first two pillars of scientific discovery," says Joanna. "Theory and experimentation."

Joanna believes the third pillar of scientific discovery is computer simulation, a technique which is becoming increasingly popular. Scientists can now turn their theories into mathematical models, which can then be expressed in software as simulations. After running the simulations, scientists can study


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their outputs and compare them to experimental results. For example, the outputs can be visualised using computer graphics and compared directly to the images captured in experiments. This can lead to new discoveries or the development of new theories that can advance our understanding of the Universe.

Over the last couple of decades, a new technique has been developed that merges computer simulation with scientific imaging techniques. Called image-based modelling, the technique turns images into 2D or 3D models, which can be a complex process. Simulations and images handle data in individual units, whereas in reality, space is continuous. "The process of turning continuous space or real objects into a set of discrete units is called mesh generation," explains Joanna. Since computer simulations were first introduced, computers have become much more powerful, allowing them to create meshes which are larger, more detailed and more realistic. "This is an exciting change as it has significantly increased the speed and accuracy of scientific discovery," says Joanna.

What is research computing?

As imaging systems and modelling techniques have become more powerful and complex, they have become harder to operate and the results they produce harder to interpret. As a result, a new discipline, known as research computing, has emerged to apply computers, not just software, to research including to help scientists capture images, construct models, which are turned into simulations, and analyse results.

Research computing is a sub-discipline of computer science. However, it is needed across a wide range of academic fields. As scientific imaging and simulation has become more widespread, the need for research computing has created synergies between disciplines that, traditionally, had little in common. The techniques used to analyse images and the software used to create them are often very similar, no matter which discipline a scientist is working in.

Many national research facilities have sophisticated imaging systems that often require specific expertise to operate. For example, Diamond Light Source is home to the UK's national synchotron. When researchers visit the facility to capture images, they are supported by scientists, including research software engineers who help them process their data and access software.

Although research computing support is present at most national research facilities, other organisations in the UK may not offer similar support. For example, when researchers return from a national research facility to their home university or business, they may lack the equipment or expertise needed to progress with their work. The lack of research computing at these organisations means that it can take years for researchers to analyse their data in full.

How can the UK improve its research computing?

"There is a need for expertise in the UK that allows techniques and knowledge to be shared and transferred across all academic disciplines," explains Joanna. There is an opportunity for budding computer scientists to make themselves invaluable to the UK's scientific community.

Research computing is slowly becoming recognised as a distinct profession, with its own set of practices, but Joanna believes a lack of funding is limiting its progress. "Funding needs to be sustained over a long period so that people can develop the skills, jobs and then careers in research computing," she says.

Without the development of research computing expertise, the UK's scientific community risks falling behind. One area of research computing that is in high demand is research software engineering.

Why do we need research software engineers?

"There is little we can do in the modern world without computers," says Joanna. "This is true for research, too." Research software engineers design and adapt the software that scientists need when working with complex scientific imaging and simulation tools. This software is needed to collect and analyse the data from images, as well as to create simulations and compare their results.

> ***"THERE IS A NEED FOR EXPERTISE IN THE UK THAT ALLOWS TECHNIQUES AND KNOWLEDGE TO BE SHARED AND TRANSFERRED ACROSS ALL ACADEMIC DISCIPLINES."***

Because computational methods originated in the natural sciences, some disciplines, such as chemistry and physics, have lots of research software at their disposal. Other disciplines, like the social sciences, have much less, although they are starting to catch up in areas which are important to social media and its regulation, like computational linguistics and social network analysis.

Nowadays, all areas of research have a need for software, and this need will only increase in the future. As such, research software engineering has the potential to become one of the most important scientific disciplines in the coming years. As new computational technologies are developed, imaging systems and simulation techniques are likely to become even more complex than they are now. These advancements in technology will need to be matched by advancements in software, resulting in an even more pressing need for research software engineers.

Joanna's *research*

Joanna is a senior research software engineer (RSE) at the University of Leeds, holding a prestigious RSE Fellowship from the Engineering and Physical Sciences Research Council (EPSRC). It is her responsibility to support other researchers at the university when their projects require complex imaging devices and modelling software. As an RSE, her work spans many different disciplines, so she gets to work on lots of exciting projects.

Chemistry with Dr Nicole Hondow and Stuart Micklethwaite

Joanna is working with Nicole and Stuart on a project that involves an analytic technique called Energy-Dispersive X-ray spectroscopy (EDX). This technique is used to analyse the elements that make up a sample. To do this, they use an electron microscope to take a very detailed image of the sample.

The electron microscope fires an electron beam which is scanned across the surface of the sample. When the atoms within the sample are excited by the electron beam, they emit electrons, which is recorded as an image, and X-rays. As each atom emits unique X-rays, Joanna is able to determine the elemental composition of the sample. Once the surface layer of the sample has been mapped, it is removed, allowing the layer underneath to be mapped in the same way. Slowly, a 3D map of the sample is built up. "As you can imagine, the size of these images is huge, and they require large computational resources to process and analyse," says Joanna.

This technique enables Joanna to study samples from the millimetre to the atomic scale, meaning that she can consider the chemical states of materials in much finer detail. By using the EDX technique, Joanna, Nicole and Stuart can study the properties of well-known materials and apply their findings to creating new ones.

Chemical engineering with Professor Sven Schroeder

Joanna is working with Sven, an expert in chemical and process engineering, on a technique known as continuous tubular crystallisation (CTC). This is a new technique that has enormous potential to improve efficiency and consistency in industrial processes and reduce costs.

Sven and one of his PhD students have been working at Diamond Light Source to develop new ways of producing video footage of CTC using X-Rays. When first experimenting with video footage, the features were so faint that they could hardly make out any crystals, at all. Fortunately, Joanna was able to help them use a new video processing technique called Eulerian Video Magnification (EVM). This enabled Sven and his team to study the crystals in much more detail and track their growth. In the new footage, they were able to identify a process a called 'oiling out' which is bad for chemical processes and indicates impurities in the crystals. Using more sophisticated imaging systems to identify problems like this can help to improve industrial processes like CTC.

Joanna and Jonathan Pickering, an RSE employed by the EPSRC fellowship, developed software that allows EVM video footage to be analysed and annotated manually. She is also helping Sven to supervise a new PhD student who is using this software to improve the CTC imaging technique so that the EVM post-processing technique is no longer necessary. Once this is done, the CTC video footage will be accessible to artificial intelligence image analysis techniques.

Biology with Professor Michelle Peckham and Dr Alistair Curd

Michelle and Alistair develop and use new imaging techniques. Joanna has worked closely with them to help develop and improve the software that these imaging techniques use. This requires a lot of work, including updating the code, running tests and producing reports. As a result, Michelle and Alistair's software is now easier to install and use.

ABOUT *RESEARCH SOFTWARE ENGINEERING*

Research software engineering (RSE) is a relatively new discipline that involves developing and using the software that is needed for scientific research. Software is needed in almost all scientific fields, so research software engineers (RSEs) are in high demand.

What opportunities will be open to the next generation of RSEs?

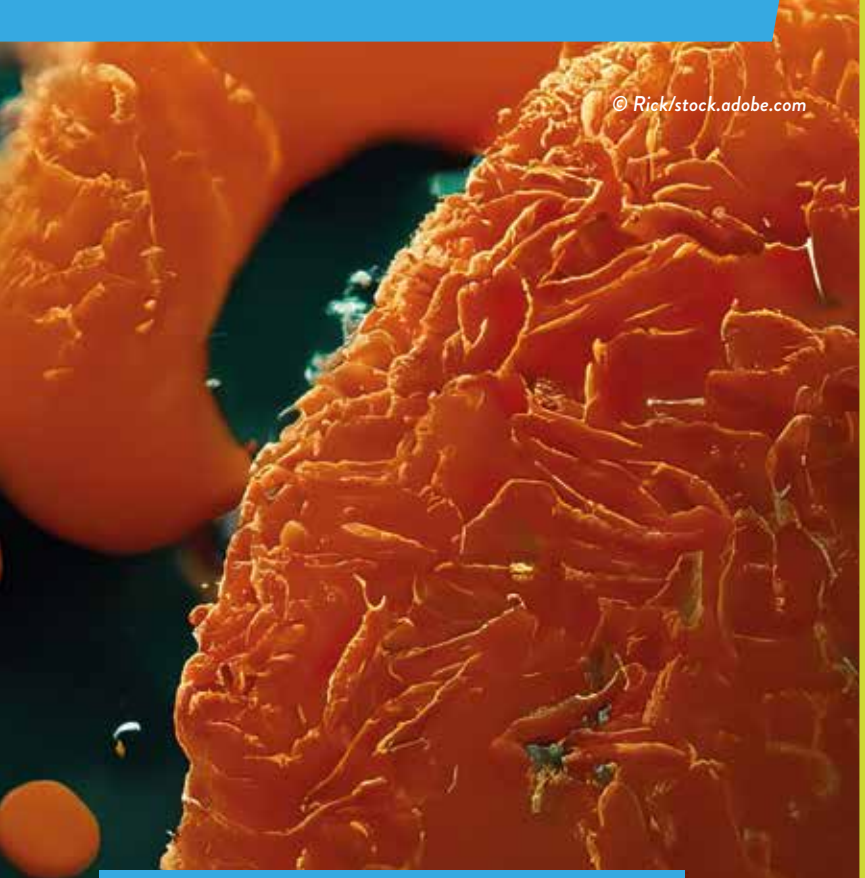
As more disciplines embrace computational and imaging techniques, funders and senior university administrators will recognise the growing need for RSEs. As a result, funding will increase, and organisational structures will change to reflect the needs of academic research. This will increase the opportunities for RSEs and allow them to develop new and innovative software for more research areas. They will also have access to better infrastructure and laboratory equipment, such as supercomputers and quantum computers.

While software will be designed by RSEs for research, it may have unexpected applications for wider society. "Don't forget, the World Wide Web started as a way for scientists at CERN to share information, and Google was devised by two PhD students while they were at Stanford University," says Joanna. As RSE accrues better recognition as a profession, with a clear career path, the opportunities will continue to expand.

Joanna's *top tips*

1. The best way to find out about the opportunities in your area is to talk to a research software engineer! Attend national research facility open days and events, and talk to as many scientists as you can.

2. If you can't attend open days, sign-up for universities' and colleges' social media updates and newsletters.



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Pathway from school to *RSE*

- RSEs use computers and software to solve problems, so you will need to be curious and enjoy tackling challenges.
- You will also need to develop your people skills so that you can communicate well. It is important that you fully understand the problems that researchers are trying to solve.
- Most RSEs have a degree and/or PhD in their chosen area, such as maths, physics or chemistry. Whilst taking part in research projects, they will have had to develop software and learn about different software engineering techniques. These skills help them to transition into RSEs.
- Modelling and simulations are often required for complex problems, such as climate change, and are employed by government agencies. RSEs who develop this software will likely have qualifications in maths, statistics, physics and/or computer science.
- It is important to study maths to at least A-level/post 16-years-old. Learning computing and computer programming will also be beneficial.

Antibody binding to human cell receptors
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"I WANT TO UNDERSTAND HOW PROTEINS AND DNA USE THE LAWS OF PHYSICS TO PERFORM THEIR FUNCTIONS."

DR SARAH HARRIS

Scientific imaging *in physics*

Sarah's *research*

Dr Sarah Harris

Theoretical physicist, School of Physics and Astronomy, University of Leeds

Sarah's interests are in understanding biology. "I want to understand how proteins and DNA use the laws of physics to perform their functions," says Sarah. "To do that, I use computer simulations of these proteins and DNA."

Sarah models individual proteins or small pieces of DNA. These structures are so tiny that they often change shape due to fluctuations in thermal energy. The models and simulations that Sarah and her team create allow them to study these changes in atomic detail.

One of the biggest applications of Sarah's models is in drug design. Drugs bind to proteins using a lock and key mechanism, in which the drug is the key, and the protein molecule is the lock. "You need to have the key that's the right shape to go into the lock for the interaction to proceed," explains Sarah. "The difficulty with proteins is that they're always changing shape, and you need to try lots of different keys against lots of different shapes of this lock to see which ones fit most of the time." The models that Sarah creates help to solve this problem.

Computational tools are used throughout the pharmaceutical industry. Despite this, they still suffer from limitations. "Even with the fastest and biggest supercomputers and the best software, we still can't run simulations that are long enough to predict how strongly a drug will bind to a protein," explains Sarah. Currently, lots of research is focused on developing faster and more powerful software.

Sarah's *top tips*

1. Be curious and open-minded.
2. Don't give up when things go wrong.
3. Don't expect everything to work the first time you try it.

"PRODUCING IMAGES OF PROTEINS THAT CAUSE DISEASES MAY POINT THE WAY TO NOVEL TREATMENTS AND CURES."

PROFESSOR MICHELLE PECKHAM

Scientific imaging *in cell biology*

Michelle's *research*

Professor Michelle Peckham

Faculty of Biological Sciences, University of Leeds

Michelle's research is focused on the cytoskeleton, a network of interlinking protein filaments found in cells. The cytoskeleton helps cells maintain their shape and move around. It also facilitates the internal transport of organelles and other structures present within the cell. For example, a motor protein called myosin uses the cytoskeleton as a track to navigate around the cell. Without the cytoskeleton, it would not be able to perform its role as a key component of muscle contraction. Michelle's research ranges from basic research into how myosins perform their functions to more complex studies of how mutations in cytoskeletal proteins cause disease.

How does Michelle use scientific imaging in her research?

Michelle uses a variety of complex imaging techniques when conducting her research. For example, cryo-electron microscopy, which she uses to study the structure of myosins, involves freezing samples to below -150 °C and imaging them using beams of electrons. Another imaging technique, called super-resolution light microscopy, has allowed Michelle to produce detailed images of the cytoskeleton within different kinds of cell. These images have enabled her to investigate a range of biological questions including how viruses move around in cells and how the cytoskeleton is organised within specialised cells such as muscle cells.

Michelle has collaborated with various other scientists to develop a type of microscopy known as dSTORM. This system allows her to see how proteins are organised within tiny structures that would not be visible with standard fluorescent microscopes. For example, some proteins found within specialised structures in muscle cells are just 20nm apart. Objects of this size are well below the capabilities of standard fluorescent microscopes.

Why is dSTORM microscopy better than fluorescent microscopy?

Fluorescent microscopy uses a high-intensity source of light to excite fluorescent molecules within a sample. When these molecules are excited, they emit a lower energy light with a longer wavelength, which generates the final image. The problem with this technique is that all the molecules emit their fluorescence at the same time. This makes it impossible to identify molecules that are too close together, as their fluorescence overlaps and creates a blurry image.

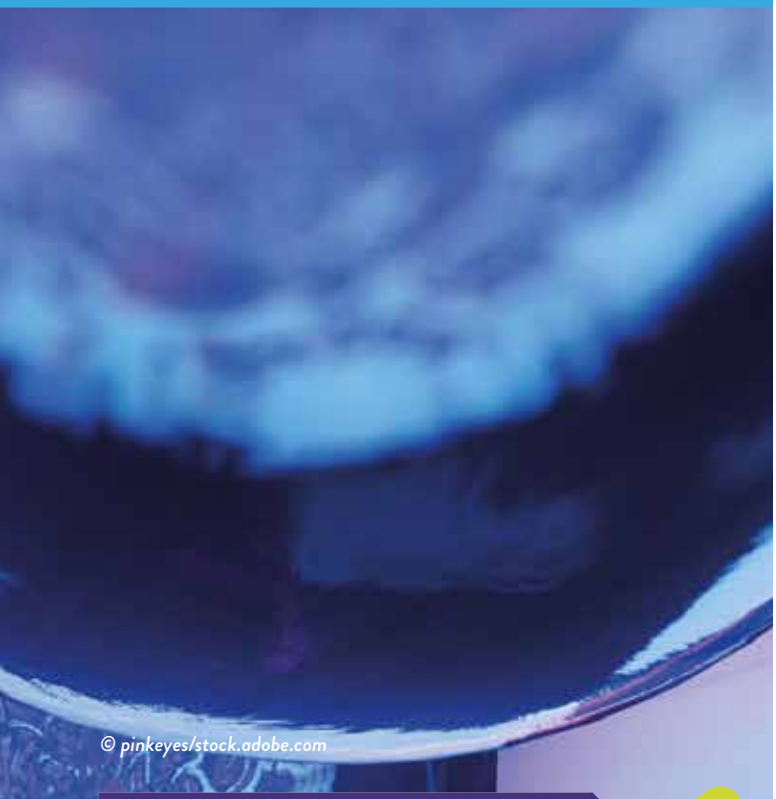
In the dSTORM system, a special buffer is used that encourages most of the fluorescent molecules to enter a non-fluorescent state. This means that at any one time, only a small subset of the molecules are fluorescent and these are far enough apart to be imaged as single molecules, and their locations identified precisely. After a short period of time, this subset of fluorescent molecules bleach and a new subset of molecules becomes fluorescent, imaged and identified. This 'blinking behaviour' continues over a long period of time and generates a large number of localisations, which are combined to generate a much more accurate and detailed image.

What is the dSTORM system used for?

dSTORM is used in laboratories all over the world to determine how proteins are organised in many different cellular structures. For example, the dSTORM system has been used to analyse the organisation of proteins within the nuclear pore, a channel which regulates the movement of molecules between the nucleus and the rest of the cell. Michelle has also used dSTORM to produce images of a protein that causes diseases relating to cilia, which are small antennae found on the cell surface. Using this technique, she was able to demonstrate, for the first time, how this protein is organised.

Does the dSTORM system have real-world applications?

Producing images of proteins that cause diseases may point the way to novel treatments and cures. For example, understanding how proteins are organised in muscle cells is important for understanding heart and skeletal muscle disease. Many of these proteins can undergo mutations that are caused by disease. Investigating how they are organised could be key to understanding the molecular basis of such diseases.



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Alistair's *research*

Dr Alistair Curd

Faculty of Biological Sciences,
University of Leeds

Alistair conducts research that seeks to improve optical microscopy techniques and use them to investigate biological systems and diseases. Alistair develops super-resolution microscopes and new data analysis techniques which he uses to collaborate on experiments with other biologists and medics.

Recent advances in microscopy have enabled microscopes to see down to extraordinarily tiny scales. Unfortunately, this has resulted in the systems becoming much slower and more complicated. Because of their complexity, some of these highly-powerful microscopes can still miss molecules when producing an image. Alistair is developing software for super-resolution microscopes that can identify the patterns that dictate how molecules are arranged in cells. This software would then be able to use these patterns to work out the positions of the molecules missing from an image.

Alistair's software examines pairs of molecules that have been captured in images by a super-resolution microscope. It then calculates the relative position of each pair by observing the distance and direction between them. The software finds the relative positions for many molecule pairs and is then able to identify patterns within a sample. The software can then compare the pattern of relative positions with the positions that would be expected in specific circumstances. From this comparison, the software can identify the hypothesis which best matches the data.

He is currently working with a cancer surgeon to investigate bowel cancer. They are trying to discover how bowel cancer develops and why some treatments are more effective than others. Alistair's software will enable them to study the important molecules in greater detail than would otherwise have been possible.

ABOUT *CELL BIOLOGY*

Cell biology is a branch of biology that studies the structure, function and behaviour of cells. Due to the microscopic nature of the subjects, cell biologists constantly make use of imaging systems.

What is rewarding about cell biology?

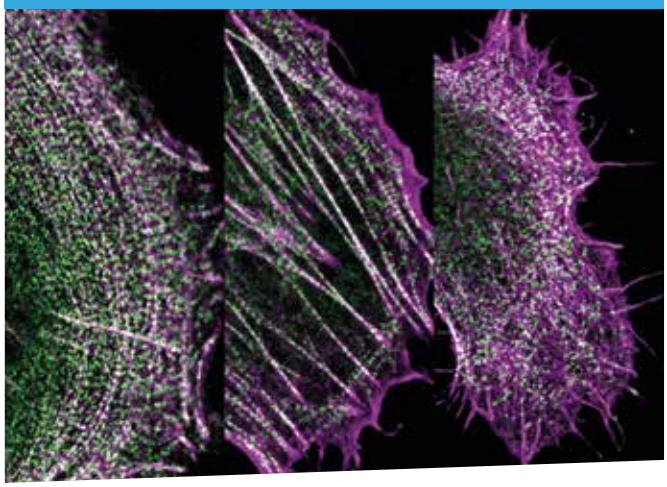
"Cell biology is an area of research full of unsolved problems," says Michelle. "As a problem solver, for me, gaining an understanding of how things work for the first time is extremely rewarding." Michelle also enjoys developing the research methods which enable her to conduct new types of experiments and discover new things.

How will scientific imaging in cell biology develop?

An as yet undeveloped technique called correlative light and electron microscopy is the next big challenge. It combines light microscopy with electron microscopy to overcome some of the limitations of cryo-electron microscopy. CryoEM allows researchers to study the structure of proteins when they are isolated. However, it is much harder to study proteins in their natural environment within a cell as specific proteins cannot be labelled. On the other hand, fluorescent microscopy is able to label and image proteins within cells.

"Combining the two approaches should help us to see protein structure and organisation within cells to extraordinarily high resolutions," says Michelle. She hopes that this new technique will pave the way for new discoveries into how proteins interact with each other, and how these interactions are disrupted due to diseases.

Cancer cells under the microscope (© Michelle Peckham)



Pathway from school to *cell biology*

- Study as many science subjects as you can at school. Michelle recommends studying physics, chemistry, maths and biology.
- Science is becoming much more interdisciplinary, so the more disciplines you learn about, the better!
- Michelle says, "Find something that you enjoy and be persistent with it. Not everything is going to go right first-time round."

"IT IS ALWAYS EXCITING TO SOLVE A PROBLEM OR FIGURE OUT ANY SMALL PART OF SOME LARGER QUESTION."

DR NICOLE HONDOW

Scientific imaging *in chemistry*

Nicole's *research*

Dr Nicole Hondow

School of Chemical and Process Engineering, University of Leeds

Nicole's research focuses on material characterisation, which is the process of probing and measuring the properties of different materials. These properties might include the chemical make-up of a material or its physical and mechanical structures. Nicole's research focuses primarily on using electron microscopes to study nanomaterials.

Nicole uses electron microscopes to study what her samples are made of and what shapes and sizes they are, as these properties influence their potential uses. Engineered nanomaterials are being utilised in a number of different areas including medicine, energy and the environment. For example, nanomaterials can be used to remove toxins and harmful substances, such as those found in car exhaust fumes, from the air.

What imaging techniques does Nicole use?

Nicole uses a Focused Ion Beam Scanning Electron Microscope (FIB-SEM) to image her samples. These microscopes use electrons (to image the sample) and ions (to alter the sample). The ion beam is used to remove layers of the sample so that the interior structure can be viewed and imaged. Nicole uses this technique to take successive images of a sample, probing deeper into its structure each time. She uses these images to build videos and 3D models of the samples, which she can then analyse.

What are the applications of Nicole's research?

The FIB-SEM technique allows Nicole to study her samples in much more detail than more conventional microscopes would. "Being able to undertake nanoscale analysis inside materials helps us understand their structure," says Nicole. "From this we can then look at what might make them better – how we can make the materials perform better or how to improve their design."

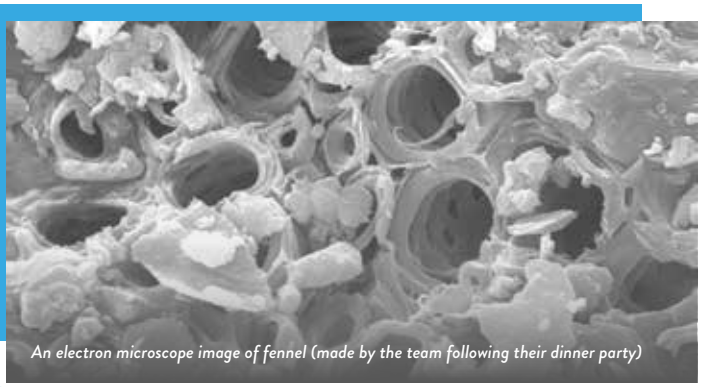
Nicole's aim is to discover new ways in which the design of her nanomaterial samples can be improved to maximise their performance in a range of different applications. Nicole hopes to expand her range of samples to include nanomaterials being used in the development of new medicines, foods and technologies that tackle environmental problems.

What opportunities are there for research software engineers in chemistry?

There are lots of opportunities to get involved in the development of new materials and chemical products, particularly those that benefit the environment and human health. As global issues such as climate change and the COVID-19 pandemic become increasingly prevalent, the need for innovative solutions will only increase.

Research software engineers will be a vital part of this process. Chemists like Nicole can use microscopes to generate lots of data and images; but they then need to be able to process and analyse them. Nicole relies on research software to help her truly understand the materials that she studies. As imaging techniques become more complex and powerful, the research software that accompanies them will need to improve at the same pace.

"It is always exciting to solve a problem or figure out any small part of some larger question," says Nicole. Research software engineers are often at the heart of this problem-solving process.



An electron microscope image of fennel (made by the team following their dinner party)

Proof of concept test for turning microscopy information into an acrylic sculpture
© Lawrence Molloy

Fourth iteration of a unit cell at DESY, a synchrotron in Hamburg © Lawrence Molloy

Third Iteration of Unit Cell set up to coincide with the Bragg Centenary Lecture by Nobel laureate Professor Dan. © Lawrence Molloy

Pathway from school to *chemistry*

- In addition to chemistry, maths is very important, but also consider physics, biology and computing as these can provide great opportunities.
- Salters' Institute provides lots of resources and organises events to help students explore chemistry and related careers. Its student page is a good starting point: www.saltersinstitute.org/i-am/i-am-a-secondary-school-student
- Nicole says, "Finding an area that you are passionate about is crucial. Find an area that you are truly interested in, and pursue it."

"I STARTED TO SEE HOW EXPLORING SCALES THIS SMALL COULD FEEL LIKE A JOURNEY THROUGH, AND INTO, SOMETHING ALIEN."

LAWRENCE MOLLOY

Scientific imaging *in art*

Lawrence's *work*

Lawrence Molloy

Artist in Residence, The Museum of the History of Science, Technology and Medicine at the University of Leeds

Lawrence is a sculptor, performer and curator who explores scientific concepts through creativity and play. He has worked with both Joanna and Nicole to create art based on their research projects. Working collaboratively and across disciplines allows Lawrence to explore the mechanisms of creativity and play in unexpected areas.

Lawrence has worked with museums, educators, scientists and historians to create a variety of artworks. "In each case, I have responded to the subject matter or technology," says Lawrence. "But the hook has always been the excitement that my collaborators have for their field." Some subjects may appear to be mundane or confusing at first glance, but when seen through the eyes of a specialist, they can become something magical. Often, these specialists have dedicated their lives to understanding and exploring something very specific, so their passion really shines through.

As a collaborative artist, Lawrence's first job is to learn about his collaborator's field. He needs to understand their subject area so that he can ask them meaningful questions that could spark creative and artistic ideas. Lawrence's aim is to create art that allows audiences to experience scientific phenomena in a playful and engaging way. For example, he created a sculpture called Unit Cell to explore the mapping of crystal lattices. Unit Cell was made up of 125 beach balls arranged in a cubic grid, with each ball representing an atom. Lawrence and his collaborators, Professor Ben Whitaker, Dr Mike Nix and Dominic Hopkinson, fired sound waves at the balls to demonstrate how diffraction through a crystal lattice affects mapping techniques.

Lawrence met Nicole and her team at the Leeds Electron Microscopy and Spectroscopy Centre (LEMAS). It was important for Lawrence to experience the scanning process first-hand for three reasons. He explains, "Firstly, I started to see how exploring scales this small could feel like a journey through, and into, something alien. Secondly, I saw the skill it took to use, navigate and interpret results from these complex microscopes, and thirdly, I began to understand the limits and advantages of different microscopy techniques."

Lawrence and Nicole had many discussions about how to visualise her data and the different strategies that they could use to communicate her complex scientific ideas. "Even though I knew the scales and had it repeatedly explained to me, I could not get my head around navigating or conceptualising at such small sizes," says Lawrence. Another problem that Lawrence encountered was that the images produced by electron microscopes are already beautiful and captivating. He explains, "The question for me was, what do I bring to the party?""

To explore this question, Lawrence invited Nicole and her team over to his house for a curry. They discussed how Lawrence could facilitate the team's ideas and Lawrence encouraged them to be wildly creative. He then returned to LEMAS and scanned images of the spices that they had used while cooking the curry. "The images that came out of this were interesting," says Lawrence. "Some were even beautiful, but the subject matter, while fun, was not important."

Lawrence is still exploring the question of how to turn data sets from microscopy into interactive sculptures. The process of creating these artworks can be long and challenging, but taking the time to truly understand his subject is a key part of Lawrence's work. It is this involved approach that makes Lawrence's sculptures so captivating as he is able to combine his collaborator's knowledge and passion with his unique creativity.

UNDERSTANDING THE ATMOSPHERE: WHAT CAN ATMOSPHERIC CHEMISTRY TEACH US ABOUT AIR POLLUTION?

Chemical reactions taking place in the atmosphere have a huge impact on our lives. Chemicals released from the burning of fossil fuels create air pollution and are one of the main drivers of global climate change. **Dr Tran Nguyen**, from the **University of California Davis** in the US, is studying newly-discovered atmospheric reactions to understand the effects they have on air pollution and the climate.

Dr Tran Nguyen

University of California Davis, USA

PROFILE

Field of research
Atmospheric Chemistry

Research project
Studying chemical reactions in the atmosphere to understand their impact on air quality and climate change

Funders
US National Science Foundation (NSF) Environmental Chemical Sciences Program (grant #2046933), National Oceanographic and Atmospheric Administration, Tobacco Related Disease Research Program

TALK LIKE AN ...

ATMOSPHERIC CHEMIST

Aerosol — a suspension of fine solid particles or liquid droplets in a gas

Chlorofluorocarbon (CFC) — a particularly potent greenhouse gas that is largely responsible for the depletion of the ozone layer

Greenhouse gas — a gas that contributes to the 'greenhouse effect', also known as 'global warming', by trapping heat in the Earth's atmosphere

Radical — an unstable atom or molecule that has at least one un-paired electron, making it highly reactive

Smog — a type of intense air pollution, most commonly experienced in cities, caused in part by the excess output of noxious gases and smoke

Every year, you will take more than 8 million breaths. That's roughly 22,000 breaths every single day. If you happen to live in the countryside, many of those breaths will be full of fresh air and the earthy aromas of rain-soaked forests and freshly ploughed fields. If you're lucky enough to live on the coast, your lungs may be filled with salty sea air and the fishy fragrances of old stone harbours. If, however, you are one of the 4.4 billion people living in a city or urban environment, many of your breaths may not be quite so refreshing.

Air pollution is a major problem in cities across the globe. Emissions from the swarms of vehicles that clog up the streets and industrial complexes that belch out smoke increase the number of toxic particles and pollutants in the air. In some instances, these pollutants build up to extreme levels and create smog that lingers over cities in a thick, odorous cloud. Smog poses a serious hazard to human health and can cause long-term health problems.

Airborne emissions can also have dangerous effects on a much larger scale. Greenhouse gases released from human activities are one of the main drivers of climate change. Carbon dioxide is the major greenhouse gas emitted from human activities, and its atmospheric concentration has exponentially increased since the industrial revolution. Chlorofluorocarbons (CFCs) are particularly potent greenhouse gases that are largely responsible for the holes in the ozone layer above Antarctica and the North Pole. The ozone holes allow harmful levels of ultraviolet (UV) radiation to pass through our atmosphere. Thankfully, research in the field of atmospheric chemistry identified CFCs as the culprit, and subsequent efforts to reduce the use of these gases has led to a partial recovery of the ozone holes.

Atmospheric chemistry is hugely important to society. On top of discoveries relating to smog and CFCs, atmospheric chemistry has also shed light on the source of acid rain, and the harmful nature of fertilisers and pesticides that seep into the water cycle. Understanding how chemicals interact with particles and water droplets in the air is a key focus of the field. At the University of California Davis, Dr Tran Nguyen is one such atmospheric chemist who is investigating these interactions.

Why are these interactions important?

Water exists at many different scales in the atmosphere. Wet aerosols are nanoscopic water-

containing particles suspended in the air and are at the smallest end of the spectrum. Raindrops, on the other hand, are much larger. The size of the water particles can have a large impact on how concentrated certain chemicals are in the atmosphere. Smaller particles have higher concentrations because they contain less water to dilute the chemicals. For example, wet aerosols contain high concentrations of salts and other organic molecules.

The size of water particles can also impact how quickly chemical reactions take place in the atmosphere. For Tran and her team, this is very important because the quickest reactions can have more pronounced effects than slower ones.

What questions is Tran trying to answer?

Tran and her team are trying to assess how these chemical reactions are altered by human activity. Many human activities release chemicals into the surrounding environment, in the form of gases or aerosol particles, which then go on to react with oxygen, water and other compounds in the air. For example, acid rain forms when the sulphur dioxide released from burning coal reacts with water droplets. This is one chemical reaction that atmospheric chemists have studied in detail. However, because the atmosphere is so complex, and because we release so many different chemicals into the environment, many reactions are still being discovered.

> ***"OUR LONG-TERM PLAN IS TO PRODUCE INSIGHTS ABOUT WHICH REACTIONS ARE MOST IMPORTANT FOR ATMOSPHERIC MODELLING."***

In her lab, Tran studies the mechanisms and kinetics of newly-discovered atmospheric reactions. In other words, she studies how these reactions happen and how quickly they occur. She uses this information to see how these reactions affect air quality and the climate.

How is Tran studying these reactions?

Tran and her team study aerosols in an atmospheric chamber. This is a specialised enclosure in which they can study how aerosols react with different chemicals and respond to different atmospheric conditions. For example, they can control the humidity, temperature and light conditions to mimic different climates.

There are countless reactions taking place in the atmosphere at any one time; however, in order to study a particular reaction, researchers have to isolate it. The atmospheric chamber allows them to do just that. "In the atmosphere a molecule can be free to react in any number of ways," says Tran. "In our chamber, we use different chemical conditions to push the reaction toward one 'fate' to really study a single pathway in depth." This technique allows Tran and her team to study individual reactions in great detail.

Surrounding the atmospheric chamber are several powerful instruments that monitor each reaction. These instruments measure how fast the reactions take place and what chemical products are produced. This gives the team an idea of the impact that each reaction might have on the atmosphere outside of the lab.

What has Tran discovered so far?

Tran and her team have made several interesting discoveries. In one recent project, they observed a reaction that has never been seen before. They found that shining artificial sunlight on a concentrated solution of sulphate ions can generate sulphur-containing radicals. These are highly reactive molecules that react with many other particles in the atmosphere.

When radicals are created in the atmosphere, they can degrade other compounds. For example, when CFCs reach the upper levels of the atmosphere, they are destroyed by UV radiation from the sun, releasing radicals. These radicals then react with ozone molecules and cause rapid depletion of the ozone layer. In other situations, radicals can have complex effects on pollution. For example, hydroxyl radicals are great at breaking down hydrocarbons and carbon monoxide molecules. While the hydroxyl radical is called the 'cleanser of the air,' this chemistry can also result in ozone and particle pollution depending on the environmental conditions.

It is not always clear what effect a particular chemical reaction will have on the atmosphere. The sulphur-containing radicals generated in Tran's newly-discovered reaction can produce organosulphates. These chemicals are found in both polluted and clean air, and research into their impact on air pollution and the atmosphere is ongoing.

What are the next steps for Tran's research?

"Our long-term plan is to produce insights about which reactions are most important for atmospheric modelling," says Tran. Atmospheric modelling is used to predict what the atmosphere and climate will look like in the future. To make these predictions, scientists need to have a good understanding of the various chemical reactions that take place in the atmosphere.

Atmospheric models can look at both short-term and long-term changes in the atmosphere. Short-term models can help inform weather forecasts and recognise the conditions that might lead to dangerous air pollution events such as the formation of smog. Long-term models make predictions about what the Earth's climate might be like in the future. These models can help us prepare for the ever-worsening effects of climate change and will likely be an important tool for decades to come.

ABOUT *ATMOSPHERIC CHEMISTRY*

Atmospheric chemistry is the study of the chemical reactions that take place in the Earth's atmosphere and the impacts that they have on our planet. The composition of the atmosphere can be affected by natural phenomena, such as volcanic eruptions and lightning storms, as well as human activity. Burning coal, driving cars and spraying pesticides are just some of the ways in which humans influence changes in the Earth's atmosphere.

The impact that these activities have on the atmosphere can be problematic. The problems caused by these activities range from the production of acid rain and smog to the depletion of the ozone layer and the acceleration of the greenhouse effect, which is a major driver of global climate change.

Atmospheric chemists study these changes and the chemical reactions that cause them in an attempt to find solutions. Our atmosphere is very complex, so understanding the chemical reactions that take place within it and their effects is a huge challenge. However, it is important work and the concerted efforts of atmospheric chemists like Tran are likely to play a huge role in the fight against climate change.

What research opportunities will be open to the next generation of atmospheric chemists?

Scientists are constantly creating new chemicals for society to use. Some of these, such as microplastics and a new generation of industrial products, personal care products and pesticides, are bound to end up in the atmosphere. As such, the next generation of atmospheric chemists will have lots of opportunities to study how these new chemicals interact in the atmosphere.

As climate change continues to worsen, atmospheric chemists will have opportunities to study the chemical processes in the atmosphere that contribute to the problem. For example, understanding how wildfires affect the chemistry in the atmosphere will become increasingly important as wildfires become increasingly common. The next generation of atmospheric chemists will be tasked with understanding these problems and discovering any potential solutions for their mitigation.

Other areas of study include the interactions between aerosols and clouds, the long-range movements of pollution in the air and the ever-advancing field of computer modelling.

What is rewarding about working as an atmospheric chemist?

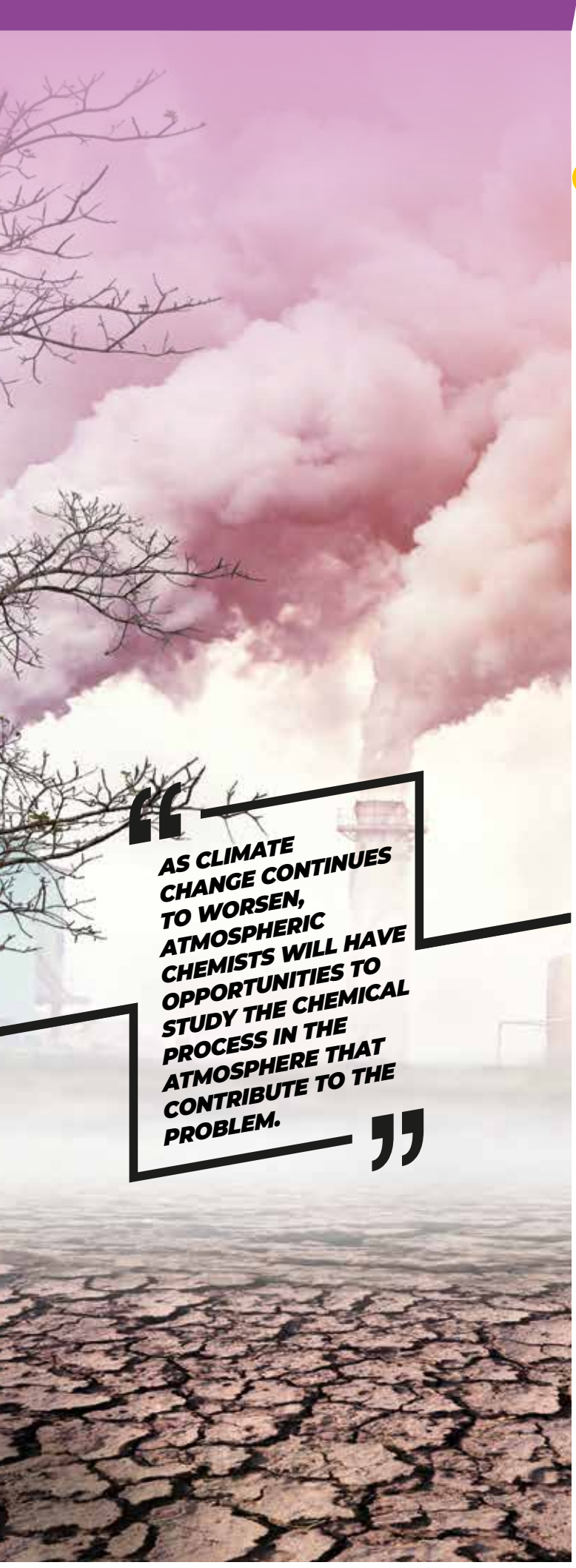
Being an atmospheric chemist involves collaborating with many different scientific disciplines including physics, maths, engineering and ecology. Atmospheric chemistry is also quite a young field of science and so there are lots of important things to discover. These discoveries often prove to be very useful to society as a whole, providing insights into air quality and climate change.

Pathway from school to *atmospheric chemistry*

- At school, chemistry, physics and geography will cover the basics of pollution, climate change and chemical reactions.
- Learning how to code and understand programming languages will be very useful.
- At university, degrees in atmospheric chemistry, chemistry, atmospheric science or meteorology could all lead to a career in atmospheric sciences.

Explore careers in *atmospheric chemistry*

- The National Centre for Atmospheric Research (NCAR) has a free class on atmospheric chemistry taught by leading scientists in the field (www2.acom.ucar.edu/atmos-chem-class).
- The NCAR also has a YouTube channel with lots of informative videos (www.youtube.com/c/ncaratmosphericchemistryobservationsmodeling).
- The National Oceanographic and Atmospheric Administration has lots of useful resources, including a great education series on climate science (www.noaa.gov/climate-education).



> **AS CLIMATE CHANGE CONTINUES TO WORSEN, ATMOSPHERIC CHEMISTS WILL HAVE OPPORTUNITIES TO STUDY THE CHEMICAL PROCESS IN THE ATMOSPHERE THAT CONTRIBUTE TO THE PROBLEM.**

Meet Tran

Growing up in Southern California inspired me to study air quality as smog is a common problem that we face. When I was young, I was mainly interested in arts, sports and reading.

Throughout my time at school, my teachers fostered my love for learning. By the time I went to college, I still hadn't decided which subject to major in and I was leaning towards getting a degree in fine arts. However, I took a general chemistry course which I really enjoyed as I could see the potential for chemistry to help society.

I graduated from the University of Southern California with a degree in chemistry. Although there were no environmental chemistry courses there, I had excellent chemistry professors who inspired me to pursue my interest in environmental chemistry and continue to graduate studies. My graduate experience at the University of California Irvine and postdoctoral experiences at Caltech University shaped the atmospheric chemistry specialty that I ended up doing research in.

I am proud of how much I have learnt as a scientist. I was once on a field sampling mission in Alabama and learnt lots of new things in a very short space of time. I learnt how to do a physics-based Eddy Covariance analysis and how to fix some of our instruments, all within the span of a few days and with no prior experience. It was the most intense and on-the-spot learning experience I've had, and it taught me how fast we as humans can learn things when we need to use them right away.

When I need a break from work I like to retreat to my garden or walk and cycle around in nature. I like to hang out with my family and friends, especially my daughter.

In the future, I would like to inspire as many people as possible to learn about environmental science.

Tran's *top tips*

1. Don't be scared to try new things! I didn't have any experience of atmospheric chemistry before I started my research but being passionate about it helped me to be successful.

2. Be confident and vocal about your research and your passions. We need scientists who aren't afraid of speaking to the public and to policymakers.

3. Make sure to have a good work-life balance. Spending quality time in nature or with your friends and family is just as important as your research, if not more so.

THE POWER OF GEOGRAPHIC INFORMATION SYSTEMS: BRINGING DATA TO LIFE WITH MAPS

What is the connection between the number of trees in a neighbourhood and the ground surface temperature? Are incidences of cancer linked to polluted areas? Is there a correlation between the socioeconomic characteristics of a community and the number of wildlife species present? These are just some of the questions that can be answered thanks to the power of geographic information systems, or GIS.

GIS is a tool to analyse and display spatial data, meaning any problem containing a spatial component can be addressed with the help of GIS. GIS software allows any information associated with a location to be plotted on a map. "However, GIS isn't just about mapping," says Matthew Santagata, Regional Planning Manager at Openlands, a non-profit conservation organisation in the US. "We use GIS to see and understand patterns and relationships between things."

Maps are a useful visual aid for seeing how data are laid out, and GIS enhances these maps by linking all the data associated with each location. "For example, you can plot both temperature and tree density on a map to investigate the connection between these two factors," explains Lindsay Darling, GIS administrator at Morton Arboretum. "But on this same map, you can also plot marginalised populations or areas of poor health outcomes, and you will see that these also correlate with neighbourhoods with few trees. GIS allows us to disentangle the complicated interactions between social and environmental inequality, providing a starting point for initiating change."

In this article, we speak to GIS experts about how they use GIS to address social and environmental issues in Chicago, Illinois, and the surrounding area.

TALK LIKE A ...

GEOGRAPHIC INFORMATION SYSTEMS EXPERT

Cartography — map making

Environmental justice — ensuring equitable access to the environment for all people. For example, marginalised populations are less likely to have access to nature but are more likely to be exposed to hazardous waste

Fracking — a process to extract gas from subsurface rocks

Geographic information system (GIS) — software that enables data to be displayed visually in map form. To learn more about GIS, visit ESRI: www.esri.com/en-us/what-is-gis/overview

Georeferenced — with a specific location attached

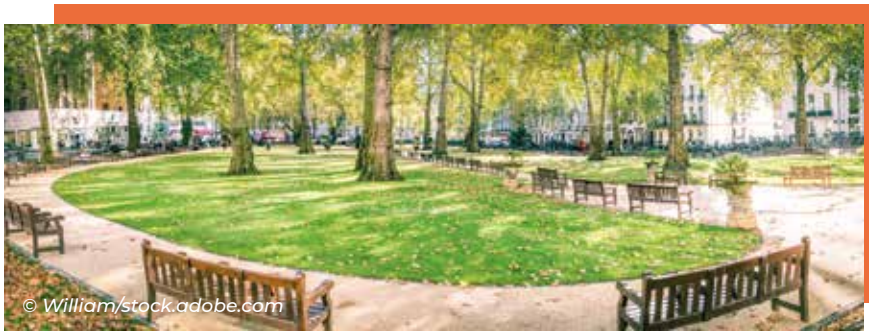
iNaturalist — an app in which the public can record nature observations, including species and location

Marginalised populations — communities that experience discrimination and exclusion

Socioeconomic — the combination of social and economic factors. Social characteristics include population demographics, such as age, race, languages spoken and level of education. Economic factors include occupation and income

Spatial — relating to a location

Tree canopy — the coverage of tree leaves and branches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Meet *some GIS experts*

Carmen Maso

Role: Supervisor, Information Service Section

Organisation: US Environmental Protection Agency (Chicago, Illinois)

I supervise the GIS team at the US Environmental Protection Agency (EPA), which works on projects with GIS components. For example, some team members have been working with our environmental justice group to develop maps that build a picture of what is happening in different communities.

I am very proud to have worked on the NEPAssist project several years ago, for which we created an interactive mapping application to support NEPA reviewers. Whenever anyone wants to build anything, they must submit an environmental impact statement to show how the environmental impacts of the construction will be minimized. The NEPA reviews these statements before deciding whether to allow the building work to go ahead. NEPAssist provides the reviewers with an interactive map where they can draw the boundaries of the construction site, which is integrated with all the environmental data for the region. This enables the reviewers to determine quickly and easily what impacts the construction work will have, and whether these are being suitably addressed by the environmental impact statement. The application has since been taken up by lots of agencies, including the Council for Environmental Equality at the White House.

When I was younger, I always loved math and science. I was especially interested in meteorology and astronomy – I love everything to do with the sky and weather. I went to university to study geography, then started a master's in meteorology. I was also taking classes in remote sensing and GIS which I found very exciting, so I transitioned back to geography and focused on climatology for my master's thesis.

I've been working for the EPA for 30 years, and it's been a great career. I was initially hired to work with the US-Mexico Border Program, where they needed someone with GIS skills who spoke Spanish. This gave me great experiences, and I used GIS in many ways, working in towns along the border and collaborating with colleagues in other US federal agencies and in Mexico.

When I transferred to the Chicago EPA office, I started leading GIS training. This gave me more incredible experiences as I travelled around the US delivering workshops on how to use GIS tools. Leading training in a small community in Alaska, up in the Arctic Circle, was a definite highlight.

People say that a picture speaks a thousand words. I say that a map speaks a million words. I love how maps connect people with data. GIS is a powerful tool as it provides people with information that hopefully encourages them to investigate further. Everyone will see something different when they look at a map and will be inspired to ask different questions.

Every environmental question is a spatial question. GIS can, therefore, help answer environmental questions as it provides spatial data. I believe GIS can make a real difference in the world, and it gives me great satisfaction when maps I create lead to improvements in the environment.

Carmen's *top tips*

1. It is always OK to change your mind about the direction of your life. I thought I would be a meteorologist but switching to GIS ended up being one of the best things I ever did.

2. All aspects of school are important, not just the academic content of your classes. Make the most of your time at high school to develop skills such as public speaking, teamwork and leadership.

"THE DATA ALLOW US TO DEFINE THE CHARACTERISTICS OF LANDSCAPES AND COMMUNITIES, HELPING IDENTIFY WHERE WE SHOULD BE CREATING GREENING PROTECTION PLANS, WITH THE LENS OF JUSTICE AND EQUITY, TO PROMOTE BIODIVERSITY CONSERVATION ACROSS OUR CITY"
DR ELSA ANDERSON

Dr Elsa Anderson

Role: Assistant Professor, Program in Environmental Science

Institution: Northwestern University (Evanston, Illinois)

I teach an urban ecology class that aims to engage students in learning about nature where they live and understanding the interactions between people and their surroundings. I also teach GIS and data science classes, all with a geophysical component, and conduct research in these topics.

I'm interested in what drives the patterns of nature where people live, and what that means for people who are experiencing nature in different ways in our cities. As well as being data driven, my work involves talking to community members to explore questions of restoration and environmental justice.

I use census data, satellite imagery, remote sensing information and community science records, and GIS allows me to make connections between these disparate data.

In one project, my collaborators and I are taking records from iNaturalist. These observations are georeferenced, so we can see where in Chicago people are using this app and where they have seen different plants and animals. From this, we have created two landscape models, from biophysical and social perspectives. The data allow us to define the characteristics of landscapes and communities, helping identify where we should be creating greening protection plans, with the lens of justice and equity, to promote biodiversity conservation across our city.

For example, although the neighbourhood of Pilsen is very urban with little green space or canopy cover, it still supports biodiversity. Very few iNaturalist observations have been made in the area, with most concentrated around a single school. Historically, Pilsen is a lower income, working class, immigrant community, but it's gentrifying quickly. This means the neighbourhood is at the forefront of conversations about equity and justice and there are discussions about how we can guarantee affordable housing for residents.

If people don't see nature, they don't respect, understand or want to conserve it. Knowledge is power, and knowledge of nature is no different. We want to empower the people of Pilsen by showing them maps of where different species are found, so they can see they have nature in the community. The GIS work we do can support grassroots, community-led conservation efforts, to evoke positive change for the people who live there and love these communities.

Although I had some good teachers, I felt stifled by high school. I graduated a semester early and travelled to Colombia, Ecuador and the Galapagos Islands. My travels opened my eyes to the amazingness of the world. Seeing people thrive in poor communities, despite their struggles, made me want to do some good in the world, instead of just making money. I knew I was going to go to college as I was a third-generation college student from an academic family, and I knew my experience was a huge privilege.

I started studying architecture, but after two weeks, I realised I didn't want to study buildings. I wanted to study something living, so I switched to an animal science program. I studied abroad in Spain and visited an elephant nature park in Thailand, which was my first foray into conservation. The relationship between people and the environment, and how people fit into conservation from a variety of perspectives, has been a major theme in my work.

One of the things I love most about science, and GIS and ecology in particular, is that it's a creative process. It requires the ability to ask questions and determine how to answer them, or how to depict or communicate them. I find this meaningful and intellectually stimulating. I love sharing ideas and working with a variety of people, and that's how I travel now – vicariously through conversations with people!

Elsa's *top tips*

1. The world is a big, interesting, exciting place. Embrace that by trying new things, exploring and seeking opportunities

2. Surround yourself with good people. Help and support others, and let them help and support you.

Erika Halse

Role: Lead Conservation Ecologist

Organisation: Museum of Natural History, Keller Science Action Center, Field Museum (Chicago, Illinois)

I am trying to understand the role that urban lands can play in providing habitats for pollinators such as monarch butterflies. Monarchs are endangered, so it's important to support them. As monarch caterpillars feed solely on a plant called milkweed, growing sufficient milkweed is vital for this mission. We conducted field sampling in Chicago to determine how much milkweed grows in the city. Plotting our results with GIS helped identify parts of the city where more milkweed can be grown.

I also work with social scientists and anthropologists to study the human aspect of urban wildlife habitats. I became interested in how not only parks, but also people's yards, can provide habitats for native species. Turf grass is the largest irrigated crop in the US. We spend our water resources on this monocrop that we do not eat or use in any productive way. Yards have the potential to provide important habitats for wildlife.

I didn't enjoy my time at high school. I was an autistic, queer kid in Texas and I didn't fit in. Although I was competent in my subjects, I gave the minimum amount of effort, and I left as soon as I could to go to college as far away as possible.

I started studying chemistry because it seemed like something I would be able to get a job in. I soon realized I was more interested in biology because you can see the systems you are working with, so I switched degrees. I went to graduate school thinking I wanted to get a degree in conservation and then live out West and not have to deal with people anymore. But conservation is always about people!

I worked on a project investigating migrating pronghorn antelope in western Wyoming. Fracking had just started in the region, and conservationists wanted to assess its impact on the antelope, so I used GIS to map their migration routes. I was surprised the landowners, who were cattle ranchers, wanted to talk to me because I had grown up with cattle in Texas. It was powerful to learn that what I had been running away from was actually an asset to me. Remember, there is always value in your personal background. There are always things in your community that can be assets.

I began my career in the technical side of GIS, but I have been wooed to the social sciences. The reality is that conservation is done every day by ordinary people. If we want to succeed in conservation projects, we need to get the people on board. Conservation is about so much more than just the facts. It is about people's cultures and values, and if we don't take these into consideration, conservation projects will fail.

I think of myself as a translator – I have the technical skills to understand maps, and I translate this knowledge back to communities. This is especially important in areas where there is conflict around conservation. For example, if white conservation organisations without local partners tell a marginalised community that they will stop mowing the grass in the local park, it will look like the conservationists are going to stop taking care of the community. In fact, allowing grass to grow is an investment for creating wildlife habitats, but this needs to come as part of a larger project that has community buy-in and meets community needs.

Maps are incredibly powerful – they can take complicated data and turn them into a picture. When I make a map, I hope that, as well as giving the reader answers about what the data show, it also leaves the reader asking more questions. However, a lot of people struggle to read and interact with maps. If I show high school students a map of Chicago, many of them can't identify their neighbourhood. Although they use Google Maps to navigate around town, they don't engage with the city in this way, so they can't visualize how Chicago is laid out.

I enjoy my job because I love hearing stories from people about why they value a place and what it means to them. I also like talking to people about plants, especially native plants. And I love people who love weird weeds!

Erika's *top tips*

1. Remember that urban places have wildlife too. You don't need to go to the jungle to get conservation experience. Protecting species in urban environments is just as important, and your experiences of interacting with urban conservation are just as valid.

2. High school can be a hard place. But know that even if you feel 'othered' now, you will find your path in life where you feel valued.

Meet *some GIS experts*

Karen Klinger

Role: GIS Analyst

Organisation: Keller Science Action Center, Field Museum (Chicago, Illinois)

As a GIS analyst, a lot of the work I do in my department is about conservation. For example, I co-lead the Monarch Community Science Project where Chicago residents act as community scientists by collecting data about monarch butterflies. They send us information about monarch eggs and caterpillars they find on milkweed in their yards. Their observations show how urban habitats can successfully support monarchs.

GIS helps you see the bigger picture in data, as visualizing data makes them easier to analyse and explain. GIS is amazing as it can be used in many ways to help us understand the world around us and make better decisions. For example, GIS can help with environmental justice by mapping where there are disparities in access to public parks, showing where we need to focus efforts to improve equitable access.

In high school, I focused on math and science as my main interests were in geometry and biology. I also had a passion for animals, so I spent a lot of time volunteering at a wildlife rehabilitation center. At college, I studied wildlife biology as it allowed me to follow my passion and learn about different aspects of ecology, and every summer, I completed an internship at a zoo or animal sanctuary.

During college, I spent three months studying in Kenya where I used GIS skills to create maps showing the location of wildlife in relation to people, buildings and roads. This highlighted potential areas of conflict between communities and wildlife. Using these maps to start conversations with communities about how to avoid these conflicts showed me the potential for GIS in conservation. Completing an internship with the US Fish and Wildlife Service showed me again how GIS can be used to ensure land is being managed for wildlife.

I like the variety in my job. I do a lot of map-making, creating different types of maps using a range of tools and techniques, but I also design surveys, gather data and share the results through storytelling. I enjoy working with communities to make positive changes for conservation. There is so much you can do with GIS that has real-world impact.

I recently started volunteering at the Lincoln Park Zoo in Chicago, where they currently have a new and very cute lion cub called Pilipili! I jumped at the opportunity to get involved with their animal monitoring, and it is cool to get back into what inspired me to become a wildlife conservationist.

Karen's *top tips*

1. Never stop learning and exploring.
2. Find what interests you, and follow your passions.

Lindsay Darling

Role: GIS and data administrator

Organisations: Morton Arboretum, Chicago Region Trees Initiative (Lisle, Illinois)

I swim in GIS all day, every day! Most of my work involves displaying data in pretty maps. At the arboretum, we want to understand where there are trees in Chicago, why they are there, and what effects they have on other plants, animals and people. I create maps of tree canopy cover and, by comparing these with publicly available census data, I investigate how this interacts with the socio-demographic aspects in different neighbourhoods.

Maps are very powerful. It is really cool to create a map that allows people to visualize and understand data. For example, I made a very simple interactive map that shows tree canopy cover and surface temperature in Chicago. Looking at this map, it's so obvious that these factors are related to each other. The map allows the public to clearly see this, as areas of low tree density correspond to higher surface temperatures. Once they understand this, people can then appreciate how simple acts, such as planting trees, can make tangible improvements in their environment.

> ***"IT IS REALLY COOL TO CREATE A MAP THAT ALLOWS PEOPLE TO VISUALIZE AND UNDERSTAND DATA."***

I always liked being outdoors when I was younger. My friends and I would ride our bikes through the forest and play in the rivers, canoeing and catching crayfish. I went to university to study biochemistry but, by the time I finished, I knew I didn't want to be a chemist. After graduating, I joined the Peace Corps where I worked in natural resource management and agriculture. I loved this work and decided I wanted a career working in natural systems, so I returned to university to get a degree in ecology, then landed a job at Morton Arboretum.

I've taught myself GIS over the years, as and when I have needed to learn new skills, which has involved a lot of googling and watching YouTube videos. It has been very fulfilling to teach myself, and I love doing it.

I love being outside. When I'm not working, I enjoy canoeing with my family and gardening. I have a huge vegetable and flower garden. I think tomatoes are my favorite plant to grow. You can't say no to good tomatoes, though our garlic crop has also been amazing the last few years.

Lindsay's *top tips*

1. Follow your interests. Find the spark that makes you want to learn more.
2. Don't feel like you need to rush into your career or your future. Take your time to make decisions.

Matthew Santagata

Role: Regional Planning Manager

Organisation: Openlands (Chicago, Illinois)

As the regional planning manager for Openlands, I work in the fields of policy, conservation and urban planning to increase the City of Chicago's climate change resiliency and expand equitable access to nature. This involves taking a holistic approach when thinking about the city's relationship with the environment across social boundaries. For example, a watershed will cover an area that includes different administrative districts.

I use GIS to understand the relationship between people, the physical environment and the social environment. For example, I have been using satellite data of ground surface temperatures to understand the effects of tree canopy cover, and to investigate the health consequences that are commonly suffered in lower income neighbourhoods due to a lack of trees. GIS is a very powerful tool and fun to use – I also create story maps that take complex data and narratives and express them in a way that's easy for the public to understand.

I had a huge interest in nature when I was younger. I enjoyed being outside doing sports and activities, such as running and rock climbing – anything that allowed me to interact with the natural world.

I was interested in a lot of different subjects at school, especially English and math. I studied political science at university but didn't know what I wanted to do after I graduated. It's OK to not know what you want to do, as you will continually learn and figure things out along the way.

When I met an urban planner, I realised this field checked so many boxes for what I wanted from a career, so I returned to university to do a master's in urban planning. I did an internship with the City of Chicago's Office of the Mayor, a department that, like me, was concerned with environmental issues. During my internship, I worked on urban planning topics involving the city's riverfront, parks and waterways.

I love the fact that every day at my job involves something new. GIS is reliant on the data that's fed into it, which comes from lots of different sources. This means I get to work with many different people, such as biologists, epidemiologists, farmers and engineers. I enjoy learning about the world around me and being exposed to new people with new ideas.

My interest in nature has stayed with me and influences my current work using GIS to address environmental issues. When not working, I like being outside – gardening, skateboarding or scuba diving. I'm also a big Dungeons and Dragons nerd, and I use GIS to create fantasy maps for the campaigns we do!

Matthew's *top tips*

1. GIS can be applied in so many fields in so many ways, so any of your interests could be combined with GIS.
2. Don't be discouraged when things don't seem to go your way. You won't always know everything, but let this fuel your interests rather than demotivate you.

Dr Sophie Taddeo

Role: Conservation Scientist

Organisation: Chicago Botanic Garden (Glencoe, Illinois)

My role as a conservation scientist involves a variety of tasks. I conduct research to inform conservation efforts to protect the biodiversity of plant and animal species, and I help protect nature, both at the Chicago Botanic Garden and in other places around the world. I am involved with science outreach and engagement activities, communicating the results of my research to the public and organising activities to encourage people to talk about the importance of biodiversity and conserving natural areas. I also work with students who are investigating environmental issues. I help them formulate their research questions, develop hypotheses and determine appropriate methods to use, then I support them as they conduct their own research.

I love my job as I really enjoy collaborating with other people. I like helping students and contributing to their discoveries, and I enjoy working with other researchers, both here at the Botanic Garden and in other organisations. It's fun to explore how we can tackle questions from new angles and resolve environmental issues in creative ways. I also love the fact that the Botanic Gardens are a wonderful environment to work in, and I enjoy walking in the gardens during my lunch break.

I'm currently working on an exciting project using community science observations to investigate biodiversity across Chicago. We're taking observations of plant and animal species from iNaturalist and using GIS to create maps of species diversity. We want to understand questions such as: What is shaping this diversity? How does species diversity vary within and between nerighbourhoods? How does it vary with human population density or distance to the lake? GIS is useful in this project as it allows us to visualize the data and explore what factors explain the differences we observe.

I studied environmental geography at university, where I learned about soil science, water science, plant identification and GIS. Some years later, I returned to university to do a PhD, during which I investigated wetlands. I was trying to understand why different wetlands respond to conservation interventions in different ways. I used GIS a lot for my PhD research to map wetlands and how they were changing through time.

Having GIS skills helped me find a job as most environmental science and conservation roles require knowledge of GIS. After my undergraduate degree, I spent several years working for the Nature Conservancy and other non-profit organisations that are protecting natural areas and tackling conservation issues.

When I was younger, I loved reading, drawing and painting. As I got older, I became interested in nature and enjoyed going on hikes and travelling. These days, I do a lot of hiking and biking in my spare time. I'm relatively new to Chicago so have been having fun exploring the city and visiting different neighbourhoods and parks. Chicago is a great place to live as there is always lots going on.

Sophie's *top tips*

1. Networking is a great way to connect with people working in the fields you are interested in. Ask them what their role involves, how they got there, and what the highs and lows of the job are.
2. Look for opportunities to learn and apply your skills to different questions.

Todd Schuble

Role: Director of GIS

Organisation: Bureau of Technology for Cook County Government (Chicago, Illinois)

As Director of GIS in the Bureau of Technology, I provide GIS services for the departments of the Cook County Government. My department is responsible for data curation and distribution. We distribute GIS software to the agencies that require it, create maps for different government departments and train members of other departments in how to process data using GIS.

Everyone needs a map for something, at some point. I don't think there's a department in Cook County that's not touched by GIS. For example, we have created maps for the County Clerk, who handles local elections along with parcel divisions, and the County Assessor, who assesses new and existing properties. In both cases, we displayed data visually using maps and distributed them to the public and interested parties. When the most recent census data was released, we created a website analysing how demographics in Cook County had changed over time. We filtered the data from the census and made them easily understandable to the public by displaying them in visual ways, as maps.

GIS is exciting because spatial analysis can serve so many facets of society. One day I may be mapping new precinct boundaries, the next I might find myself helping probation officers find the most efficient route through Chicago to visit their parolees, and the day after, I could be collating aerial photography of the county.

When I was younger, I enjoyed playing video games and softball with my friends, and I was always curious about how the world worked. At school, I gravitated towards the social sciences. I was interested in geography, sociology, history, psychology and political science. I wanted to make maps, so I studied geography in college, majoring in urban-economic geography and GIS.

Studying GIS in the early 90s was an interesting time, as cartography was beginning to shift from mapping with protractors and colored pencils to mapping with computers. I was lucky to be learning during this transition, just as data was beginning to become widely available in digital form, which is crucial for GIS and digital mapping.

After completing a master's degree, I got a job as a researcher at the University of Chicago. During my 17 years there, I had numerous roles, including lecturer, computational scientist and GIS manager. Although I was working in academia, these positions allowed me to keep one foot in the real world and apply my skills to real-world issues. I often worked as a consultant for projects outside the university – I helped Chicago public schools analyse population demographics in school districts and did political consulting by analysing election data.

Local governments are very good at collecting data, but often don't have the resources to analyze them. Starting my job at Cook County Government was a researcher's dream – there were hordes of unanalysed data for me to work with. It was like finding a cavern filled with treasure! I love my job because I'm never bored. There is always a challenge to solve or something interesting to investigate.

Geographers have a unique perspective on the world. At school, we are taught to communicate quantitatively or in written form, but maps allow us to communicate aesthetically. With a map, we can display data in a way that can be easily understood by the public. It's satisfying to communicate with people in a way that leads to positive changes. For example, maps can provide evidence to show government officials where policy changes will have the greatest impacts.

Todd's *top tips*

1. Employers want to hire people who are excited and passionate about what they do. In a job interview, they want to see you light up when you talk about your interests.

2. You will undoubtedly hit bumps or brick walls as you travel along the road of your life. But it is important to keep going.

Are you interested in *a career in GIS?*

As the GIS experts featured in this article demonstrate, there is a wealth of career opportunities available in the field of GIS that can be reached by a variety of different pathways. For more information about the range of jobs that use GIS, visit ESRI: **www.esri.com/en-us/what-is-gis/careers**

Pathway from school to *GIS*

- Ask you teacher if you can learn about GIS in class!
- As GIS involves using computers to analyse and display spatial data, take subjects at school that will give you a foundation in these areas. "Geography will teach you how to think spatially," says Carmen. "It teaches you to understand the world around you." Take computing classes to learn programming skills, and study statistics to help you understand data.
- At university, GIS is usually taught within geography programs. You could, therefore, study a geography degree to pursue a career in GIS. "Geography is really cool!" says Erika. "In school, geography is often just memorizing countries and mountain ranges. But in college, geography is a radical discipline all about understanding why things happen."
- However, as GIS is applied in so many different fields, most of the GIS experts featured here did not study geography. So, take GIS courses while studying whatever interests you. "It's a good idea to take an introductory GIS class alongside whatever you are majoring in," says Lindsay. "Even basic GIS skills will open doors for you."
- "Combine your studies in GIS with another subject," says Todd. "This will make your skills more applicable and will make you more valuable as a job candidate. For example, if you combine GIS with business marketing, you will have a very powerful toolkit to enter the world of work. Or, if you are interested in addressing health issues, you could combine GIS with medical science, epidemiology or public policy."
- Some universities offer postgraduate degrees specifically in GIS.

Why are GIS skills important?

- "Employers recognize GIS skills as being very valuable," says Elsa. "GIS is multi-functional so you can apply these skills in a huge range of jobs. I use GIS to answer environmental questions, but archaeologists use it to map excavation sites, engineers use it to reconstruct water systems under cities, the military use it to map defense strategies..."
- "GIS can offer a new perspective on view the world," says Todd. "It allows you to link different information together and make connections." For example, he cites the remarkable spatial similarity observed when overlaying a map of pollution with a map of cancer incidences. "Is the pollution causing cancer?" Further health research would need to be done to determine if this is the case, but GIS can spark these inquiries.
- "No matter what you use GIS for, it's a transformational tool," says Matthew. "You can use it to improve your understanding of the world around you, then you can use it to make changes to the world. Whether you use GIS for urban planning or architecture, social work or policymaking, you can shape your career with GIS to your own interests."
- "GIS is a powerful communication tool," says Sophie. For example, using GIS to compare maps of past and present forest cover is an effective method of highlighting global deforestation to the public.

How to get started *with GIS*

- QGIS (www.qgis.org) is a free open-source GIS software, ESRI (www.esri.com) is a leading GIS provider that offers free access for students, and GIS analysis can be performed with R programming (www.r-project.org). Download a GIS platform and start exploring how to analyse and display data. "Once you know how to work in one GIS platform, you can work in any," says Lindsay.
- Explore the wealth of resources available online to help you learn GIS skills. YouTube is a great place to find tutorials that will walk you through the process of using GIS.
- "Think about how GIS could be applied to your own interests," Karen advises. For example, Matthew uses GIS to create fantasy maps for his Dungeons and Dragons campaigns, while his friends use GIS to locate clay in riverbeds for making pottery. How could your hobbies benefit from GIS?
- Find publicly available data on topics that interest you, and analyse them with GIS software. "It can be hard to have the discipline to learn something new unless you have a tangible outcome that you want to achieve," says Lindsay. "Find opportunities to apply GIS skills to answer real-world questions," suggests Sophie.
- "You can do GIS with just pencil and paper," says Carmen. She suggests walking around your community and mapping your neighbourhood. What features are present, and how do these relate to each other and to the landscape?
- Think about where and when you interact with GIS in your daily life. "If you use Google maps on your phone, then you are using GIS, even if you don't realise it," says Todd. "Using digital maps to search for your nearest shop or pizzeria is GIS. Take an interest in this, and develop your understanding of space."
- Embrace all aspects of GIS. "There is a very creative side to GIS," says Matthew. "Some of the best GIS products border on art." If you are artistic, focus on how you can bring this talent to GIS.

A ROCKY REVOLUTION: CAN VIRTUAL 3D MODELS TRANSFORM THE TEACHING OF GEOLOGY?

Fieldwork has long been a mainstay of geology education, but it is not everyone's cup of tea. Not all students want to participate in fieldwork when it means being outdoors in all weathers, while others cannot participate due to disabilities, financial hardship or lack of opportunities. Professors **Terry Pavlis** and **Laura Serpa**, from the **University of Texas at El Paso**, USA, are creating virtual 3D models to make the benefits of geology fieldwork accessible to everyone.

Professor Terry Pavlis

Field of research
Structural Geology

Professor Laura Serpa

University of Texas at El Paso, USA

Field of research
Geophysics

Research project
Creating virtual 3D models of geological features to revolutionise the teaching of geology

Funder
US National Science Foundation (NSF)

PROFILES

TALK LIKE A ... GEOLOGIST

Geological features — physical features of the Earth (e.g., cliffs, valleys, faults) formed by the movements of rock and other geological processes

Contour — a line on a map joining points of equal elevation

Photogrammetry — creating digital 3D models from 2D photos

Fieldwork — the process of observing and collecting data from the 'field' (i.e., not in a classroom)

Virtual 3D model — a three-dimensional representation of a feature that can be explored on a computer

Stood in the pouring rain, wearing a not-so-waterproof raincoat, your numb fingers try their best to sketch the rocky cliff your teacher is pointing at. It is hard to concentrate because your friend will not stop going on about the dead squirrel they saw when they got off the bus. You are about to label a layer of sandstone when a gust of wind blows your notebook out of your hand and into a puddle. This trip is not going as you had hoped.

Not all geology trips are this challenging. Fieldwork can be an exciting and enjoyable experience. Spending time outdoors, exploring beautiful landscapes and investigating complex rock formations is often what draws people to the subject of geology.

But fieldwork is not for everyone. And taking students to unfamiliar outdoor settings is not always a productive way of teaching. The physical exercise and numerous distractions commonly cause students to tune out from the lesson. They may be more interested in chatting with friends or worrying about other issues, such as 'Where are the bathrooms?', 'How can I charge my phone?' or 'When's lunch?'

At the University of Texas at El Paso, Professor Terry Pavlis and Professor Laura Serpa have devised a new geology teaching technique that may prove more effective. They are creating virtual 3D models of geological locations that students can explore from the comfort of their classrooms.

Creating 3D models

You can create a virtual 3D model of anything, from a rocky cliff face to your own hand, if you take enough overlapping 2D photos of the object and input them into a photogrammetry software package. "The software moves the photographs around, much like you might move a mirror to see different sides of your face, then stores them in their 3D position," explains Laura. The software then stiches these orientated 2D images together to generate a 3D model of the object.

A virtual 3D model of Nobel Hills in south-eastern California, created by Terry and Laura

Laura and Terry photograph the geological features they want to model, usually by flying a drone over the landscape. The photos must overlap so the software can combine them and must be of high resolution. "If it is not clear on the photographs, it will not show up on the model," says Terry. Once stitched together, the 3D model can be viewed and manipulated, allowing anyone with a computer to explore the geology of the landscape.

What advantages do 3D models have over 2D teaching resources?

Geology concepts are commonly taught in the classroom using 2D maps and diagrams, which many students struggle to visualise in 3D. For example, students unfamiliar with reading contours may find it difficult to view 2D maps as 3D landscapes. Virtual 3D models can improve the classroom learning experience by removing this hurdle and providing students with 3D representations of geological features.

In addition, 2D representations, such as photos in textbooks, only provide limited information about the 3D geological characteristics of the feature, and they cannot be used to take certain measurements that are critical for geological learning. Normally, geology teachers must take students on field trips to teach these skills, but Terry and Laura's 3D models provide a classroom-based alternative.

What advantages do 3D models have over field trips?

Virtual 3D models provide a weather-proof, distraction-free alternative to field trips. "We have spent many years teaching at a university where visiting field sites is difficult," says Terry. As a result, 3D models play a significant role in their classes, in which students explore virtual field sites on computers. Similar to a 'real' field trip, students on a virtual field trip can make measurements of geological features and interpret their observations to suggest what geological processes may have formed them.

> **"IT IS IMPORTANT TO STRESS THAT ANYONE CAN BECOME A GEOLOGIST, REGARDLESS OF THEIR ABILITY OR DESIRE TO HIKE OUTDOORS IN ALL WEATHERS."**

Virtual models make geology accessible to students who cannot participate in fieldwork (for geographical or financial reasons, or due to mobility issues) and who do not want to participate in fieldwork. "It is important to stress that anyone can become a geologist, regardless of their ability or desire to hike outdoors in all weathers," emphasises Laura. "People with disabilities should feel they are just as qualified to become a geologist as anyone else."

"3D models bring the field to the individual," says Terry. "Any geoscientist can therefore study field geology, a potentially transformative change." Terry and Laura hope 3D models and virtual field trips will open the geosciences to a wider range of students.

3D models in action

Laura and Terry are developing classes where students explore a variety of 3D models, describe and measure the features they see, and make interpretations about how these features formed. If possible, students can then be taken to the field site. Having already developed an understanding of the geology by examining 3D models in the classroom, students will gain more from the experience of fieldwork than if they were taken to an unfamiliar location.

Feedback on these classes has been extremely positive so far, with students reporting that they loved the experience. This technique is especially effective compared to traditional teaching methods, as it creates a far richer classroom learning environment. "We believe the development of 3D models will ultimately transform fieldwork into a hybrid of real and virtual field experiences," says Laura.

These 3D models will revolutionise the field for seasoned geologists as well as for students. For example, cliffs are both a geologist's dream and nightmare. While vegetated landscapes hide the underlying geology, cliff faces expose rocks. However, cliffs are usually inaccessible and, as vertical features, are virtually invisible on 2D maps (a cliff is represented by a line). So, although cliffs contain a wealth of geological data, it can be hard to access and record this information. "3D models change all that," says Terry. Drones can capture images of inaccessible cliff faces, then geologists can measure and map features directly on the 3D model.

Geology is for everyone

"There are too few students studying geology today," Laura laments, "and too many non-geologists who do not even think of geology as a science." In fact, geology is critical to global well-being. Underpinned by scientific skills such as making observations and testing hypotheses, geology is the science of understanding the world around us.

Knowledge of climate changes in the geological past is critical for addressing the current climate crisis. Geology is the fundamental science behind mining, necessary for extracting the resources required to transition to clean energy. Before any building is constructed, a geologist must assess the underlying rock to ensure the foundations will be stable.

By making geology accessible for everyone, Laura and Terry hope to show that it is not just a subject for those who love hiking. They hope to inspire more students to see geology as an opportunity to make a positive difference in the world.

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ABOUT *GEOLOGY*

Geology is the science of the Earth. As such, it is fundamental to understanding our planet's past, present and future. Geologists are also essential for enabling society to function. There are many branches of geology, so you can specialise in whichever field most interests you.

By monitoring volcanoes, volcanologists try to predict when the next eruption will occur, thereby giving communities warning so they can evacuate before the danger occurs. Seismologists collaborate with engineers to design earthquake-proof buildings, and they study earthquakes to investigate the internal structure of the Earth. Palaeontologists examine fossils to uncover the mysteries of life and the species that roamed the Earth before humans evolved.

Some sedimentary geologists use their skills to locate reservoirs of fossil fuels to meet global energy needs, while others apply the same skills to find rocks that can store carbon dioxide and therefore mitigate the impacts of greenhouse gas emissions. Engineering geologists assess ground characteristics before any construction work occurs, to ensure buildings and roads will not collapse. All the metals used in technological devices must be mined from the Earth, and geologists are responsible for locating these resources. Hydrogeologists investigate the flow and quality of underground water, ensuring communities have access to safe drinking water.

"We are facing an uncertain future due to climate change, and geoscientists are uniquely qualified to take a leading role in long-term sustainability planning and mitigation of climate disasters," says Terry. Studying geology will equip you with the skills and knowledge needed to address the many challenges faced by humanity. "Now is a good time to think about learning more about the Earth we live on, and the planets we may visit in the near future," says Laura.

"WE ARE FACING AN UNCERTAIN FUTURE DUE TO CLIMATE CHANGE, AND GEOSCIENTISTS ARE UNIQUELY QUALIFIED TO TAKE A LEADING ROLE IN LONG-TERM SUSTAINABILITY PLANNING AND MITIGATION OF CLIMATE DISASTERS."

Pathway from school to *geology*

- Geology is not commonly taught as a subject at school, though some geology topics may be covered in geography and science classes.
- Study geography to learn both about the physical processes that occur on and within the Earth and about how these processes influence, and are influenced by, humans.
- Skills and knowledge from maths, physics, chemistry and computing will be useful when studying geology at university.
- At university, study geology or Earth science, or a related degree such as geophysics or physical geography.

Explore careers in *geology*

- The US Geological Survey has a wealth of resources for students and teachers, including lesson plans on a huge range of geological topics and citizen science projects you can get involved with: **www.usgs.gov/youth-and-education-in-science**
- The American Geosciences Institute provides information about careers in geoscience and resources for teachers: **www.americangeosciences.org/education**
- Get involved in Earth Science Week in October, or use their educational resources any time of year: **www.earthsciweek.org/educational-resources**
- Explore career pathways in geology with this interactive platform from The Geological Society: **www.geolsoc.org.uk/geologycareerpathways**

How did **Terry** *become a structural geologist?*

As an undergraduate, I enjoyed my structural geology class as I had a natural talent for 3D visualisation. I was inspired to become a structural geologist when I took a field geology class and realised I could combine my love of the outdoors with an academic pursuit in structure and tectonics. I was lucky to be a student at the time when the concept of plate tectonics was new.

Most of my career has focused on field-based studies in structural geology and tectonics. I love unravelling the complex structure of metamorphic rocks (think of beautiful granite-like kitchen countertops). These rocks carry one of the most complete archives of Earth history.

My other passion is the modernisation of field geology, which has spawned the present research Laura and I are working on. Twenty years ago, I was at a museum when I had an epiphany. There was a display showing 'a geologist's compass from the 19th century' – it was exactly like the compass I used! This launched my passion for making digital geological mapping routine.

> ***IT IS THIS HISTORICAL ASPECT OF GEOLOGY THAT MAKES IT UNIQUE AMONG THE SCIENCES***

I love the joy of fieldwork, with its physical and mental challenges. I also love the challenge of unravelling the geological history of an area by studying rocks. It is this historical aspect of geology that makes it unique among the sciences, and it takes effort for novice geologists to grasp the immensity of geological time.

I could tell stories for hours about my memorable fieldwork experiences! I've spent a lot of time in the remote wilderness of Alaska where I've had more wild animal encounters than I could count. Although I have seen many bears, I have always been lucky and never had a serious encounter, unlike some of my colleagues (one had to kill a bear, and another spent a night watching a bear destroy her camp).

When not working, I love hiking, travelling and growing plants in our yard. I'm also an amateur woodworker and an occasional fisherman.

How did Laura *become a geophysicist?*

As a small child, I was always trying to dig holes to reach China from my home in the United States. I have always been interested in science and I was curious about what was down there.

I went to college when I was 18 years old but was kicked out. When I returned, ten years later, I took a geology class because a friend recommended it. After that, I was having so much fun that I forgot to quit going to classes until I finished my PhD and the university made me leave.

I enjoyed going outdoors and climbing around on mountains when I was a student, but I chose geophysics because I could drive a car to most of the places where I needed to collect data! I particularly loved searching through my data for new discoveries and I really enjoyed computers, which were relatively new when I was a student.

In general, my research involves mapping the inside of the Earth without digging holes. I use a variety of devices to measure changes in the Earth's gravitational, magnetic, electromagnetic, thermal and seismic velocity fields. The variations in these fields indicate variations in the composition or activity occurring within the Earth. I build computer models of the Earth's subsurface to determine what could cause these variations. I really enjoy working with computers and programming new methods to analyse data or get new information out of existing data.

As a geophysicist, I have had some great fieldwork experiences. I was really scared, but in a good way, when I worked with Terry in Alaska. Looking back having survived the experience, it now seems exciting. And I loved hiking across Death Valley with all my equipment, taking measurements in such a beautiful place.

Terry and Laura fly a drone to collect aerial photographs of the landscape which will be used to create 3D models

Terry and Laura's *top tips*

1. Cultivate your critical thinking skills and curiosity. You need to be open to new ideas as geological understanding progresses.

2. Be ready to adapt to changes in the way you learn and acquire information, as new technologies will permeate all aspects of geoscience education and research.

CAN MODERN TECHNOLOGY UNCOVER THE SECRETS OF EVOLUTION?

A mysterious group of fossils called the Elgin Reptiles has been puzzling scientists for centuries. Existing only as cavities hidden within rocks, these fossils could help scientists unravel the mysteries of evolution. Thanks to modern technologies, **Dr Davide Foffa**, a research associate at **National Museums Scotland**, and his colleagues have examined these fossils using digital technologies for the first time, resulting in some exciting new discoveries.

Dr Davide Foffa

Research Associate
National Museums Scotland, UK
University of Birmingham, UK
Virginia Tech, USA

PROFILE

Fields of research
Vertebrate Palaeontology, Palaeobiology, Palaeoecology

Research project
Using micro-computed tomography to uncover the secrets of the Elgin Reptiles

Funder
Royal Commission for the Exhibition of 1851

TALK LIKE A ...

PALAEONTOLOGIST

Anatomy — the science that studies the structures of living (extinct or still living) organisms

Evolution — the process of gradual change over many generations through which species slowly develop into new species

Fauna — the animal life of a particular region or time period

Fossil — the remains (e.g., bones) or impressions (e.g., footprints) of prehistoric life-forms that have been preserved in rocks

Mass extinction — a widespread (global) and rapid decline in biodiversity in which many species die out

Micro-computed tomography (µCT) — a 3D imaging technique that uses X-rays to see inside objects

Permian — a period of geological time, from 299 to 252 million years ago

Triassic — a period of geological time, from 252 to 201 million years ago

Over the past few billion years, life on Earth has evolved into the incredible diversity of organisms we see today. All species that exist today have evolved from earlier ancestors, while many others have long since died out. In fact, more than 99% of all species that have ever lived on Earth are no longer around. The family tree that links these species together is therefore incredibly complex.

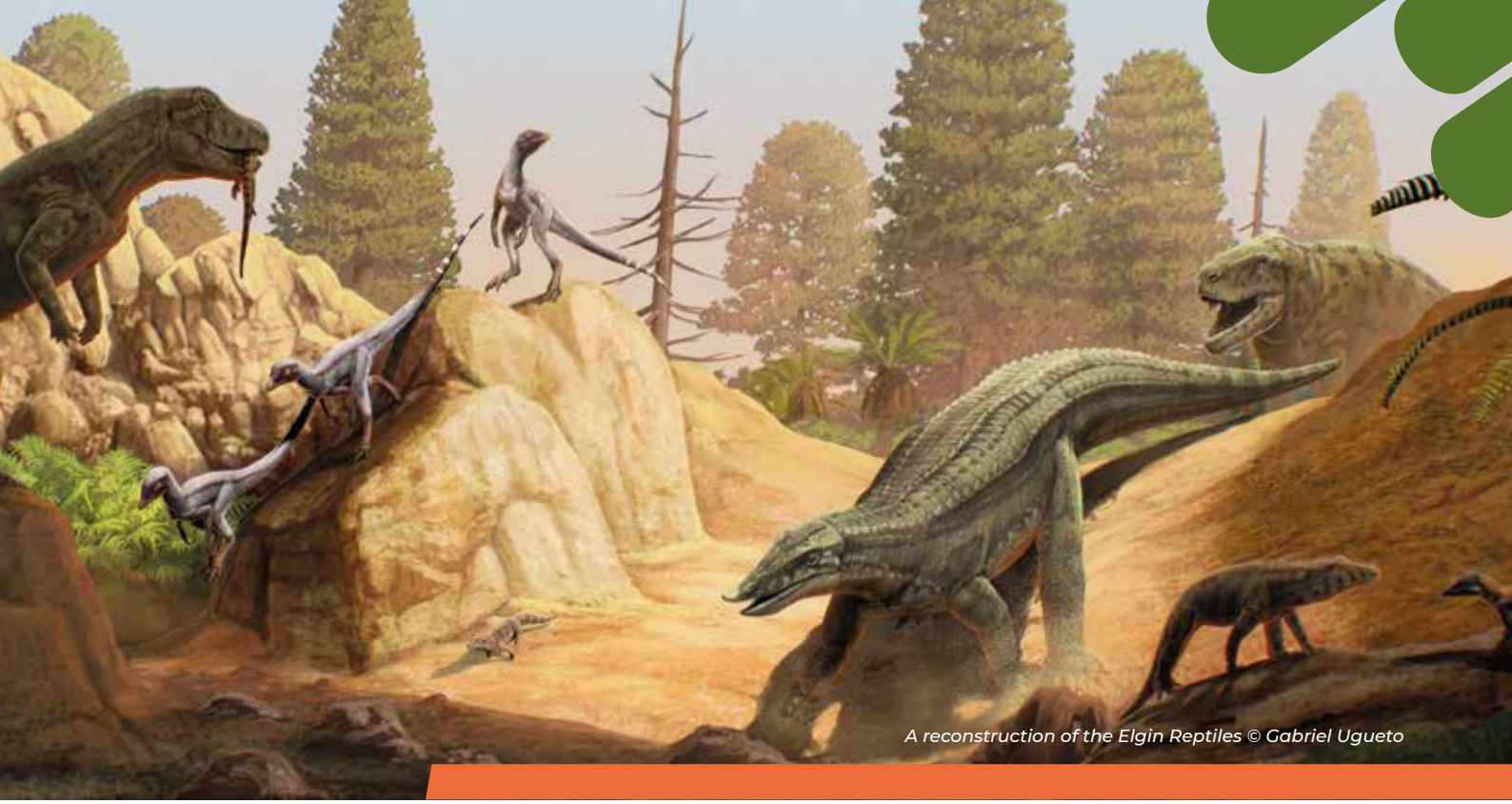
This 'tree of life' describes the pathways of evolution and shows us how organisms are related to each other. Since Charles Darwin first proposed the theory of evolution in 1859, scientists have been trying to solve this giant jigsaw puzzle. Dr Davide Foffa, a researcher at National Museums Scotland, is one such scientist who has been studying a key piece of this puzzle – the Elgin Reptiles.

What are the Elgin Reptiles?

In the late 1800s, workers were extracting rock from a sandstone quarry near the town of Elgin on the north coast of Scotland when they made an interesting discovery: these rocks contained fossils of ancient animals. Named the 'Elgin Reptiles', the fossils from this region can be split into two groups, one from the later part of the Permian period (more than 252 million years old) and one from the Late Triassic period (around 235 million years old). "At these times, Scotland was much closer to the equator than it is today, and the climate was considerably warmer," says Davide. The sandstone rocks in which the Elgin Reptiles are preserved were once desert sand dunes, indicating these animals lived in a significantly hotter and drier environment than is found in Scotland today.

Why are the Elgin Reptiles important?

The Elgin Reptiles give us a glimpse of life on Earth both before and after the most severe mass extinction event that has ever occurred. Known as the Permian-Triassic Mass Extinction, this took place 252 million years ago. During the extinction, over 70% of all species that lived on land and over 90% of all species in the oceans were wiped out. With fossils of creatures that lived at the end of the Permian and the beginning of the Triassic, the Elgin Reptiles can tell us how life on Earth is affected by catastrophic events such as mass extinctions, and how it recovers from them. These fossils can also teach us about the anatomy and behaviour of extinct animals, as well as the origins of evolutionary lineages and ecosystems. In his research, Davide has been focusing on the Triassic fossils of the Elgin Reptiles, which include groups of animals that survived or evolved just after



A reconstruction of the Elgin Reptiles © Gabriel Ugueto

the extinction, many of which still have descendants living today. The Triassic Elgin fauna include some of the oldest ancestors and cousins of crocodiles, lizards, dinosaurs (and therefore birds) and pterosaurs. "The Elgin Reptiles are important windows into the past, which tell us about the very origin of modern faunas," says Davide.

Why are the Elgin Reptiles so hard to study?

"Most of the Elgin Reptiles are not preserved as traditional fossils, where the bones turned into rock over millions of years," explains Davide. "Instead, there are no bones left in many specimens, particularly in the smaller animals." After fossilisation, the bones of these animals dissolved, leaving cavities in the rock that perfectly preserve the shape of their skeletons. Since their discovery in the late 1800s, the best way to study the Elgin Reptiles has been to crack the rocks open and pour rubber into the holes to create casts of the bones.

Unfortunately, this technique has several disadvantages. Firstly, it is destructive. The rock must be broken to examine the fossil so the specimen is damaged in the process. Secondly, the casting process often misses important details as it is hard for the rubber to reach all cavities. Large parts of many specimens remained unknown and small details such as hand and foot bones were often missing.

How is Davide studying the Elgin Reptiles?

Davide has been making use of modern technology to uncover the secrets of these ancient fossils. After re-assembling the broken rocks containing Elgin Reptile specimens, he scans them using micro-computed tomography (μCT). "A μCT scanner is essentially a fancy 3D X-ray machine," he explains. "When you get an X-ray at the hospital, the machine produces a 2D image showing the inside of your body. A μCT scanner takes thousands of 2D X-ray pictures showing the inside of an object, all from different angles. Using special computer software, we can stitch these 2D images together and use them to create a 3D model of the inside of the object." These 3D models show the shape of the fossil skeletons, preserved as cavities within the rock, in incredible detail, revealing parts of the specimen that were not known from the original rubber casts.

> **"MOST OF THE ELGIN REPTILES ARE NOT PRESERVED AS TRADITIONAL FOSSILS, WHERE THE BONES TURNED INTO ROCK OVER MILLIONS OF YEARS. INSTEAD, THERE ARE NO BONES LEFT IN MANY SPECIMENS, PARTICULARLY IN THE SMALLER ANIMALS."**

What has Davide discovered?

"The amount of information we can get from the rocks with μCT data is outstanding," says Davide. His scans of fossils have helped him determine the anatomy of some of the Elgin Reptiles, including *Erpetosuchus*, a cat-sized animal from the crocodile-line of reptiles, and *Scleromochlus*, a tiny creature that has been puzzling researchers for over a century. Understanding an animal's anatomy is essential for palaeontologists to place it in the evolutionary family tree and develop hypotheses about aspects of its behaviour, such as what it ate and how it moved.

From his 3D models, Davide discovered new details across all parts of *Scleromochlus's* skeleton, from its skull and spine down to its feet and tail. "The new information has transformed our idea of what *Scleromochlus* looked like," he says. Some palaeontologists, for example, had previously assumed that *Scleromochlus* moved by hopping like a frog, due to its apparently short tail and shallow body. However, Davide has revealed that it had a deep ribcage and a long tail, as well as small, weak hips that would not have been suited to hopping.

With this new information, Davide deduced that *Scleromochlus* belongs to an evolutionary group known as the lagerpetids. These are the closest relatives to pterosaurs, the first boned animals to start flying. "*Scleromochlus* is not a direct ancestor of pterosaurs," emphasises Davide. "However, *Scleromochlus* tells us that pterosaur's ancestors would have been small, agile and light-built land-dwelling animals."

What next?

"This research demonstrates that there is a lot to be gained from μCT scanning these fossils," says Davide, "and there is a lot we still do not know about other animals preserved from this exceptional assemblage." Therefore, he hopes to perform the same process with other specimens of the Elgin Reptiles.

Davide will use the new information he uncovers to reconstruct past ecosystems and investigate what happened to them before, during and after the Permian-Triassic Mass Extinction. "The fossil record is the only source of information we have to understand what happens to life on Earth during biodiversity crises, such as the one that we are currently facing due to climate change," explains Davide. His research is therefore vital to help us prepare for our current ecological challenges.

ABOUT *PALAEONTOLOGY*

There is far more to palaeontology than dinosaurs! Dinosaur discoveries may make the headlines and dinosaur films may fuel our imagination, but palaeontologists investigate all types of prehistoric life. While Davide currently studies the creatures that came before the dinosaurs, and has previously studied those that lived in the sea while dinosaurs roamed the land, other vertebrate palaeontologists investigate the ancestors of mammals, the evolution of amphibians and how fish first came ashore to start animal life on land. Invertebrate palaeontologists study prehistoric animals without a backbone, addressing topics such as how the earliest life began and how the first shelled sea creatures became fossilised. Palaeobotanists study fossilised plants.

Fossils give us a window into the past and show us what ancient plants and animals looked like. By studying them, palaeontologists can learn what life on Earth looked like many millions of years ago. Palaeontologists may be involved in finding and excavating fossils from the ground as well as re-examining fossils that have spent years in museum archives.

What does fieldwork involve?

"Fieldwork is usually very hard work!" says Davide. "Days in the field are long, we sometimes walk a long way, and we are out in all weathers. But fieldwork is also a lot of fun." Before they start fossil hunting, palaeontologists must ensure the area has the right type and age of rocks for the fossils they hope to find. For example, sedimentary rocks deposited in low energy environments (e.g., in calm lakes not fast-flowing rivers) are more likely to contain fossils than lavas erupted from volcanoes.

"Patience is key for palaeontologists," says Davide, as excavation is delicate work and there are then many more steps to complete before a fossil is ready to be studied. "Overall, it is very exciting and the thrill of finding a fossil for the first time is one of my favourite parts of the job!"

What does museum work involve?

Museums play a fundamental role in curating fossil specimens and making sure they can be studied by researchers. Most specimens held in museum archives are not displayed in exhibits that are open to the public. "Browsing among collection drawers is very exciting and even old collections are constant sources of new discoveries," says Davide. When he visits museum collections, Davide will examine, photograph and describe fossils to add to his knowledge of past species.

What are the joys of palaeontology?

"Being the first person to see an animal that has been buried for millions of years is breath-taking," says Davide. "I enjoy learning new techniques from other fields of research and adapting them to answer questions about the fossil record. Overall, I see palaeontology as a team effort. We keep building on new discoveries to push the field forward."

Pathway from school to *palaeontology*

- As palaeontology draws on skills and knowledge from geology and biology, you can enter the field from either of these directions. University degrees in geosciences, evolutionary biology, zoology and natural sciences can all lead to a career in palaeontology.
- "Palaeontologists often need to know anatomy very well, as we use the features of individual bones to identify fossil species," says Davide. Therefore, whatever route to palaeontology you follow, ensure you take anatomy classes.
- "Palaeontology is evolving fast and now requires more skills not traditionally associated with the field," says Davide. Computer coding is essential for complex data analyses, and knowledge of maths and statistics is also important. Some palaeontologists are using techniques from engineering to study how extinct animals moved.
- As most scientific literature is in English, Davide advises that a good grasp of the English language is important, and that reading and writing are fundamental skills.

Explore careers in *palaeontology*

- Many palaeontologists work in research institutions, such as universities or museums, where they study specimens found in the field or contained in collections.
- One of the best ways to gain palaeontology experience is by getting involved with a museum. Many museums have volunteer programmes or even paid internships.
- The Palaeontological Association creates a Careering off Course newsletter that features tips from palaeontologists that have been successful in their chosen career paths: **www.palass.org/careers/series-careering-course**.
- In this interview, Dr Susie Maidment, a palaeontologist at the Natural History Museum in London, shares how she got into this career: **www.nhm.ac.uk/discover/how-to-become-a-palaeontologist.html**

A reconstruction of Scleromochlus © Gabriel Ugueto

Q&A

Meet Davide

What were your interests when you were younger?

When I was very young, I loved collecting dinosaur figurines and cards. I then 'forgot' about that early interest, and I didn't pick up palaeontology again until I was in university. In my teenage years, I spent a lot of time hiking outside and playing computer games.

What pathway has led you to become a palaeontologist?

I went to the University of Pisa in Italy to study maths, but quickly realised that although I had loved maths at school, it was not a suitable career for me. I switched to studying geoscience, thinking I could apply my maths skills in the field of geophysics. But when I took a geology course in vertebrate palaeontology, I became convinced that this was the branch of geoscience that was most interesting for me.

After I graduated, I moved to the UK to complete a master's in palaeobiology at the University of Bristol. This taught me that palaeontology is much more than studying dinosaurs – there are so many interesting groups and time periods to be studied! For my master's research I used 3D models to understand the feeding behaviour of a large Jurassic marine reptile, called *Pliosaurus*.

My time in Bristol opened the doors for the many opportunities that have followed. I completed a PhD at the University of Edinburgh, where I described some odd ancient relatives of crocodiles that lived in the sea, and I looked at the ecology of Jurassic marine reptile faunas and their evolution through time. I studied the Elgin Reptiles during my postdoctoral research with the National Museums Scotland and I have now moved to the US to expand on this research by investigating the evolution of ecosystems across the Permian-Triassic Mass Extinction, working with colleagues at Virginia Tech (USA) and the University of Birmingham (UK).

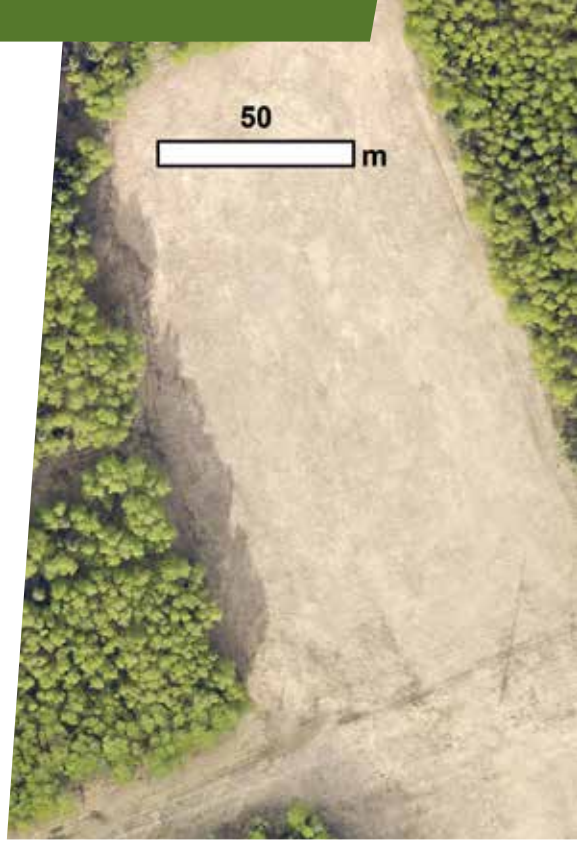
What have been your favourite fieldwork experiences?

I will always remember the first plaster jacket I made. To extract a fossil from the ground, you must first cover it with plaster to protect it. My first plaster jacket was for the bone of a turtle from the Cretaceous period. Although it was nothing special from a scientific point of view, it was a great moment for me.

I did quite a bit of fieldwork on Scottish islands. A highlight was finding a new site of Jurassic dinosaur footprints and a large tooth from a carnivorous dinosaur on the same day. Since moving to the US, I have been involved with fieldwork in the deserts of Texas, Arizona and New Mexico where we have discovered lots of fossils.

What do you enjoy doing in your free time?

I love many activities that go well together with my interest in geology and palaeontology, such as visiting museums, hiking, outdoor activities and travelling.



FARMING ON PERMAFROST

Climate change is creating new opportunities for agriculture, by providing longer and warmer growing seasons, and thawing frozen ground. But farmers in permafrost regions face many challenges, including subsidence in their fields. **Dr Melissa Ward Jones**, a permafrost geomorphologist at the **University of Alaska Fairbanks**, USA, has established **Permafrost Grown**, a research project investigating the interactions between permafrost and agriculture.

Permafrost Grown

University of Alaska Fairbanks, USA

Fields of research
Permafrost Science, Agricultural Science, Remote Sensing, Sustainable Food Systems, Natural Resource Economics

Research project
Investigating how permafrost affects agriculture and how agriculture affects permafrost in Alaska

Funder
US National Science Foundation (NSF)

PROFILE

TALK LIKE A ...

NORTHERN HIGH LATITUDE RESEARCHER

Boreal — the climatic region just south of the Arctic, characterised by cold temperatures and conifer forests

Food security — reliable access to healthy, affordable foods that meet dietary needs

Geomorphology — the study of how landforms and landscapes form and evolve

Ground ice — ice below the ground surface

Mulch — any material humans use to cover soil to insulate and/or enrich it

Northern high latitude — regions above ~60°N

Permafrost — ground material (e.g., rock, soil, ice) that remains at or below 0° C for at least two consecutive years

Thaw subsidence — the sinking of land due to the melting of ground ice

Topsoil — the upper layer of soil where most biological activity happens

As the world warms, the way we farm will have to change. In some parts of the world, higher temperatures and extreme weather conditions will reduce the amount of food that can be grown, so how will we feed everybody? Some people are looking to the north, where areas previously unsuitable for growing food are becoming available due to warming trends, creating increased agricultural opportunities.

When you think of Alaska, you might picture snow-covered rocky peaks, glaciers and bears roaming across great wildernesses. Here, for more than half the year, it is too cold and dark to grow crops, so it does not seem like the most inviting place to start a farm. However, temperatures in the USA's most northern state are on the rise, and this is being accompanied by an increase in agricultural activity. As permafrost thaws, people are moving north to plant vegetables, cereals and flowers in the newly defrosted soil.

At the University of Alaska Fairbanks, Dr Melissa Ward Jones is digging into the details to uncover what impacts permafrost has on agriculture, and what impacts agriculture has on permafrost. She is leading an NSF-funded project called Permafrost Grown, which aims to determine what it will take to successfully farm in this northern high latitude region.

Why do farmers in Alaska need to watch out for collapsing ground?

Permafrost is defined as ground material (e.g., rock, soil, ice) that remains at or below 0° C for two or more consecutive years. There are many types of permafrost, depending on the proportion and location of the ground ice it contains, and this influences the ground's response when the permafrost thaws. If permafrost contains no ground ice, then when the ground thaws, the surface is likely to be unaffected. However, when ice-rich permafrost thaws, the ground ice will melt, changing from a solid to a liquid. The unfrozen ground will lose the volume and structure originally provided by the ice, causing the ground surface to collapse or subside. If ice is evenly distributed through the permafrost as a continuous layer, when it melts, subsidence is likely to be relatively even as the whole ground surface will sink. But permafrost commonly contains ice wedges – wedges of ice that extend deep into the ground but are not laterally continuous. When these melt, subsidence will be much greater over the ice wedges than over the surrounding ground, meaning a flat field can become riddled with mounds, depressions and ponds, damaging tractors and causing them to get stuck in the mud.

An aerial image of a field experiencing permafrost degradation and ice wedge melt, leading to uneven topography with depressions that become waterlogged. The 2017 Pictometry mosaic image was provided by the Fairbanks North Star Borough GIS web Services

Subsidence is a serious problem for farmers in permafrost regions as fertile topsoil is lost and areas may become waterlogged. "Subsidence also damages farm infrastructure, such as fences and buildings, while making it difficult or impossible to use farm equipment in fields that are no longer level," says Melissa.

Despite the risks of subsidence, the promise of warmer summers is drawing people to northern high latitude farming. Currently, Alaska only produces about 5% of its own food, meaning it has poor food security. "There are limited options for importing food as some villages are only accessible by boat or plane," says Melissa. "This means shelves are often empty of certain foods, particularly in winter." For the 700,000 people who live in Alaska, increased agriculture comes with the hope of fresher food and more reliable supplies.

Do Alaskan vegetables taste different?

While the average growing season in Fairbanks is only 110 days long, at the height of summer there are over 22 hours of daylight every day. This is ideal for many fruits and vegetables, as they can keep growing, photosynthesising and producing sugars for longer. "This means carrots grown in Alaska taste sweeter!" says Melissa.

But care must be taken to choose the right plant varieties for northern farming, as long daylight hours can make some crops, like spinach, more likely to 'bolt'. Instead of putting energy into the edible portions, the plant puts energy into seed production which can reduce edibility and flavour.

Could agriculture increase permafrost thaw?

Another challenge of farming in permafrost regions is to ensure agriculture does not accelerate thawing. Much of Alaska is covered by boreal forests. These provide shade in summer and catch and hold snow in winter, allowing cold air to penetrate the ground.

> **"PERMAFROST GROWN AIMS TO BETTER UNDERSTAND THE INTERACTIONS BETWEEN PERMAFROST AND AGRICULTURE AND TO DEVELOP BEST-PRACTICE GUIDES FOR FARMERS."**

When trees are cleared for fields, there is no longer any summer shade and, in winter, snow on the ground will act as a blanket, insulating it and causing warmer ground temperatures. These cause the rate of thaw to increase. Farmers also warm the soil to make it more favourable for crop growth, by tilling the soil and applying mulches, which may contribute to permafrost thaw.

What is Permafrost Grown investigating?

Melissa, a permafrost geomorphologist, is teaming up with local farmers and academics from different fields to tackle the challenges of agriculture in permafrost regions. These include Dr Mikhail (Misha) Kanevskiy, a permafrost scientist, Dr Benjamin Jones, a remote sensing specialist, Glenna Gannon, a sustainable food systems researcher, and Dr Tobias (Toby) Schwoerer, a natural resource economist, for a truly transdisciplinary approach. The most important members of the research team are the farmers themselves. "We are collaborating with farmers because they know the problems, the management strategies they have tried and the unique characteristics of their fields," says Melissa. To assess permafrost conditions, the team conducts ground penetrating radar (GPR) surveys and collects ground cores. "GPR uses radar pulses to image the subsurface, so we can identify areas with ground ice," explains Melissa. "The cores validate the results of the GPR surveys and allow us to determine ground ice content and soil properties." The team also uses drones to take images of fields, enabling researchers to measure and monitor subsidence, snow depth and plant health.

The team is conducting agricultural experiments on farms to test the thermal impacts of different mulches and the suitability of different crop species and management practices. "Preliminary results show that certain mulches can elevate temperatures below 1 m depth in the soil," says Melissa, highlighting that farming practices are contributing to ground warming. She hypothesises that larger, leafier plants, such as squash and cabbage, may help keep the ground cool in a similar way to the original boreal forests, so the team is growing different crops to test their thermal impact.

To determine the socioeconomic impacts of permafrost-agriculture interactions, the team is interviewing farmers to understand their attitudes towards different permafrost mitigation strategies.

The future of Alaskan farming

The unique environment in Alaska means agricultural practices must be adapted for the region, as low latitude farming methods will not succeed at high latitudes. Permafrost Grown aims to better understand the interactions between permafrost and agriculture and to develop best-practice guides for farmers. "These guides will provide a resource for farmers to help identify what type of permafrost they may have in their fields," says Melissa. "They will then offer suggestions of management strategies to deal with the challenges associated with this permafrost." With these tools, the dream of fresh, local produce could become a sustainable reality in Alaska.

ABOUT *NORTHERN HIGH LATITUDE RESEARCH*

Northern high latitude regions are warming faster than anywhere else on Earth. As climate change continues, it is more important than ever to understand how these regions are impacted. This research involves a range of specialities, many of which are represented in the Permafrost Grown project:

PERMAFROST SCIENCE

There are many aspects of permafrost to study. Misha specialises in ground ice, which involves conducting fieldwork to investigate ground ice distribution in permafrost. He also works in the lab to determine soil properties, such as how much frozen ground compresses during thawing. "Ground ice studies are very important for permafrost studies, as the distribution and amount of ground ice determines the permafrost behaviour during thawing," he explains.

GEOMORPHOLOGY

Geomorphology is the study of landforms and landscapes, including how they are created and change over time. As such, geomorphology is all around you – in hills, rivers and coasts. Melissa is a permafrost geomorphologist, specialising in Arctic landscapes, but geomorphologists are not restricted to studying Earth. "Because Mars is cold, permafrost environments on Earth are the closest analogies we have for Mars," she explains. "By understanding how landforms form on Earth, we can learn how they form on Mars, and this is a sub-field of permafrost geomorphology."

REMOTE SENSING

Remote sensing involves making measurements of Earth (or other planets) from a distance. Cameras and sensors mounted on drones, planes or satellites capture images of the Earth's surface, and by taking repeat measurements and comparing the results, scientists can detect how landscapes are changing. Remote sensing is, therefore, a powerful tool for mapping and monitoring environmental changes.

Benjamin is using remote sensing to study the effects of cultivation on permafrost stability and the response of crops to changes in permafrost. "Pursuing a career in remote sensing offers a diverse portfolio for you to explore anything on Earth or in space," he says. "There is a wide range of applications for remote sensing specialists, so there will always be jobs in the field." Remote sensing technology is rapidly advancing, providing new techniques for observing the Earth's land, atmosphere, oceans and icecaps.

SUSTAINABLE FOOD SYSTEMS

A food system is everything that needs to happen to put food on the table. This includes farming, harvesting, processing, marketing, distributing, consuming and disposing of food. "A food system is influenced by political, social, economic and environmental contexts," says Glenna, whose role in Permafrost Grown is to investigate how permafrost environments can feed people in the future.

With an ever-growing population, global food security is becoming a pressing issue and sustainable food systems are key to addressing this. We need to find ways to feed everyone while also protecting biodiversity. With so many components to our complex food systems, there are endless career opportunities in the field. "A career in food systems could focus on the economics of food production, large-scale composting, plant breeding for climate resilient crops or policymaking on hunger relief," says Glenna.

NATURAL RESOURCE ECONOMICS

Natural resource economics involves the interactions between natural and human (social and economic) systems. Researchers collect data from people and companies, compare them to measurements of natural systems to understand they are connected, then communicate with policymakers about what impact their decisions will have on the economy and the environment. "We want to understand human behaviour so that we can make more sustainable decisions for a better future," says Toby. "If you are curious about how human behaviour and policy affect the outcomes for nature, then natural resource economics can give you skills to help make the world a better place."

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Pathway from school to *northern high latitude research*

- **Permafrost science** is a branch of Earth science that requires knowledge of geology, glaciology, geomorphology and climatology.
- If you are interested in **geomorphology**, consider studying physical geography, geology or Earth science at university.
- There are many paths to becoming a **remote sensing specialist,** including degrees in geography, physical sciences, mathematics or computer science. Whatever you study, ensure you take as many courses in geographical information systems (GIS) as you can.
- While some universities offer degrees specifically in **sustainable food systems,** the skills and knowledge you learn in almost any degree can be applied to the field.
- A range of subjects could lead to a career in **natural resource economics,** including mathematics, economics, data science, ecology, policy and conservation science.

Meet *the team*

Dr Melissa Ward Jones

Research Assistant Professor,
Institute of Northern Engineering,
University of Alaska Fairbanks, USA

Field of research:
Permafrost Geomorphology

I spent a lot of time outside as a child, and my family often went camping. Doing research projects was my absolute favourite task in school.

I became a geomorphologist by accident! I was inspired to become a scientist by a children's TV show, *Kratts' Creatures*, so I initially pursued biology. But at university, I discovered biology wasn't for me as I didn't enjoy the molecular and cellular biology classes. Instead, I liked the look of physical geography classes and so switched subject. While studying geography, I met my future master's and doctoral supervisor, who told us he conducted his research outside. As I enjoyed being outside, I pursued graduate studies with him. He happened to be a permafrost geomorphologist, and so I discovered that I, too, loved the subject!

The best thing about being a permafrost geomorphologist is being outside and the flexibility of the subject area. Because everything interacts with landscapes, the possibilities for research projects are endless.

All the travel and adventures have been a real highlight of my career. I have been all over the Arctic, travelling by small aircraft, helicopters and snow machines, staying in incredibly beautiful places and seeing all sorts of wildlife. These places are very remote, so there is often no running water, electricity, phone signal or internet.

Melissa's *top tip*

Get involved in extra-curricular activities and say yes to opportunities, even if they don't quite fit with what you are studying. At university, I helped organise a student-led sustainability conference. This taught me many skills, such as fundraising, budget management, recruiting and managing volunteers, and working with an interdisciplinary team. I didn't realise it at the time, but this experience is benefitting me now as I lead the Permafrost Grown project.

Dr Benjamin Jones

Research Assistant Professor,
Institute of Northern Engineering,
University of Alaska Fairbanks, USA

Fields of research:
Remote Sensing, Permafrost Studies

When I was younger, I was interested in outdoor activities and playing sports. Over the years, my interest in sports changed from playing to spectating, but my love of the outdoors has always remained.

When I moved to Alaska in 2005, I found my home. I could combine my love of the outdoors with my career, focusing on integrating field-based research with remote sensing to better understand how the Arctic is changing in response to climate change.

As a remote sensing specialist, I enjoy the diversity of topics that I work on. I am currently working on projects studying the drainage of Arctic lakes, the movement of beavers in Arctic tundra and erosion of Arctic coastlines. To be a good remote sensing specialist, you have to get out into the field to see what the place you are trying to image and classify looks like, which I really enjoy.

Establishing a remote Arctic research station at Teshekpuk Lake, at the northern tip of Alaska, has been a highlight of my career. It has been a labour of love that has opened many opportunities for me and led to many wonderful collaborations and friendships. It's a great place to return to year after year, to study the effects of climate change on permafrost terrain and the Arctic tundra.

Benjamin's *top tip*

Be flexible and don't pin yourself down to a career without exploring the world. I started college wanting to be an engineer, but quickly realised my passions lie in exploring remote Arctic landscapes.

Melissa drills in soil to install ground temperature sensors at the Boreal Peonies farm, while her 3-year-old daughter waits to install the site marker

Glenna Gannon

Assistant Professor, Institute for Agriculture, Natural Resources and Extension, University of Alaska Fairbanks, USA

Field of research: Sustainable Food Systems

As a child, I loved being outdoors. I enjoyed walks, canoeing, playing soccer, cross country skiing and observing the natural environment, and I still enjoy these activities today. I've also always been creative. I love making art, and I have a dual bachelor's degree in anthropology and art.

From a young age, my father taught me about harvesting wild plants, both for food and medicine, and this was influential in my choosing to pursue a career in sustainable food systems. I was also inspired by a class in ecological anthropology during my undergraduate studies, which tied together my interests in the environment, ecosystem services and how we as humans fit into and shape the natural systems in which we live.

I'm happy that my career in sustainable food systems allows me to combine my love of being outdoors with my profession. I love that I get to work with people and try lots of interesting and amazingly fresh foods. I grow food as part of my research, and I work with policymakers who influence how food gets to consumers. This combination is highly rewarding and never boring.

I'm proud to have followed my passions. Pursing opportunities and my interests has led me to my current position. I'm also extremely honoured to have been elected to the Alaska Food Policy Council due to the merits of my work.

I'm excited to see how the research I conduct will help shape Alaska's food systems for the better. My efforts have already led to incremental changes, with producers adopting alternative growing practices, and Alaska Native Tribes now having greater access to funding for food-based programming.

Glenna's *top tips*

1. Follow your passions. If there is a class you are interested in, take it, whether it fits your degree requirements or not. A diverse educational background will make you more resilient.
2. It is important to have a creative outlet. Arts can be a fun way to express what you learn in the sciences.

Dr Mikhail (Misha) Kanevskiy

Research Assistant Professor, Institute of Northern Engineering, University of Alaska Fairbanks, USA

Field of research: Permafrost Science

I lived in a very big city when I was younger, but took every opportunity to spend time in nature as I enjoyed outdoor activities such as mountain trekking, spelunking (exploring caves) and rafting. By the age of 17, I had participated in exciting field trips with archaeologists, geomorphologists and glaciologists.

I saw the Arctic for the first time when I was 16. I was trekking in the Polar Urals mountains, and I realised then that I wanted to spend my life doing Arctic fieldwork. I was also inspired by my parents who had studied glaciers in remote Arctic islands, so I went to Moscow State University to study geology.

My work gives me unique opportunities to visit Artic and high-latitude study sites. Of course, the life of a field researcher is not just endless fieldwork! We also process samples and write up our results, which is less exciting but gives me real satisfaction. Our goals are to solve the mysteries of the Arctic, obtain new knowledge and share our findings.

I came to Alaska in 2005, and I think it was one of the best decisions in my life. I have an interesting job where I work on interesting projects with interesting people. After so many years of fieldwork in Siberia, Alaska and Canada, my scientific ambition is to summarise all my findings and write a book about ground ice in Alaska.

Misha's *top tip*

When you are young, take opportunities to explore various fields, study various subjects and learn from various teachers. I don't regret choosing a career path in permafrost when I was very young and sticking with this, but I feel it would have been beneficial if I had explored more opportunities.

Dr Tobias (Toby) Schwoerer

Research Assistant Professor, International Arctic Research Center, University of Alaska Fairbanks, USA

Field of research: Natural Resource Economics

I have always been curious about the economy and the natural world, especially wild places where nature hasn't seen human impacts yet. When I was younger, I liked math and wanted to study engineering or geology.

I'm interested in how to bring humanity onto a more sustainable path, so chose to become a natural resource economist. The interactions between humans, natural systems and policymakers are very powerful.

I enjoy working with teams of scientists to analyse complex problems in social and natural systems, such as the issue of invasive species. These projects require team members with a range of knowledge and expertise to work together to provide critical insights for policymakers.

Becoming a research assistant professor and creating my own research programme has been a highlight of my career. It's not always easy to work in academia as you must constantly compete for funding, but if you thrive in a creative environment, it's great.

One of my goals in life is to become more self-reliant, by growing and hunting my own food. I am learning a lot from Permafrost Grown about sustainable farming in Alaska, and I am now growing lots of vegetables.

Toby's *top tips*

1. Follow your passions.
2. Work hard, and always do your best.
3. Always be kind.

Iris Sutton

Ice Wedge Farm
Goldstream Valley,
Alaska, USA

I have a small farm that feeds ~10 families, including my own. I grow everything that can easily be grown in our short summer growing season, including potatoes, carrots, leeks, squashes, beans, lettuce, broccoli, cabbage and herbs. I also raise chickens for eggs and meat, and goats for milk.

I enjoy the community created by farming. I started farming after working on another farm in Fairbanks and realising how valuable it is to have my children with me outside all day and how amazing it is to have lots of fresh veggies. It feels good to do my small part to contribute to local food.

My farm faces many challenges due to permafrost thaw. New holes appear every year, and old holes get deeper. Having a humpy landscape means it's hard to use a tractor and other equipment. Lower areas on the farm take longer to dry out, so are colder for crops and become infested with weeds.

I'm really excited to help make local food more sustainable. I'm excited by Permafrost Grown because I want to learn about making my farming practices more efficient, and I want to support scientists in their work.

> ***"MY FARM FACES MANY CHALLENGES DUE TO PERMAFROST THAW. NEW HOLES APPEAR EVERY YEAR, AND OLD HOLES GET DEEPER."***

Dr Jill and Dr David Russel

Boreal Peonies
Two Rivers, Alaska, USA

Boreal Peonies is a 40-acre family-owned peony farm that produces exceptionally large cut peonies. We sell these to wholesalers and florists worldwide. Our farm is also a scientific research station that serves as a resource for the Alaskan peony industry, as we conduct experimental trials on peony varieties.

We started the farm in 2012 because it seemed like a fun challenge. We wanted to create a family farm and leave a legacy for our children. At the same time, we are research scientists, so we were really interested in conducting research to develop best practices for the Alaskan peony industry.

We both love making the farm a success and working with our staff, students, other researchers and our adult children. Jill enjoys getting her hands in the dirt and watching the plants grow and develop. She also loves monitoring plant development and collecting and analysing data. Dave most enjoys designing our nutrition and farming practices and new research projects. He loves trying something new and seeing that it actually works!

Due to permafrost thaw, our farm has faced subsidence, pooling water and acidic soils. We also encounter challenges not related to permafrost, mainly the precision required during post-harvesting handling of the flowers to ensure a high-quality product arrives to the customer.

We are excited about Permafrost Grown as it gives us the opportunity to generate information that will help us make better growing decisions on our farm.

Christine and Brad St. Pierre

Goosefoot Farm
Fairbanks, Alaska, USA

Our family farm grows over 30 varieties of fruit and vegetables which we sell at the farmer's market and to local restaurants. We started the farm because we were fascinated by the ways farmers can observe, work with and harness the cycles of nature to produce food in a way that supports the health of all creatures.

It's very important to produce healthy food here in Alaska, to increase food security, reduce our food's carbon footprint and support a thriving local economy. We love working outdoors to produce food for our community in a way that supports our ecosystems, and it's rewarding to see the smiling faces of people buying delicious food.

> ***"CONTRIBUTING TO PERMAFROST GROWN AND HELPING DEVELOP METHODS TO DETECT AND MITIGATE PERMAFROST DEGRADATION IS INVALUABLE TO US AND THE FUTURE OF FARMING IN ALASKA."***

Since starting Goosefoot Farm, we have seen frost lenses open in our hay fields. If they are too deep to fill in, we can no longer grow and harvest hay from that field. Permafrost degradation is moving closer to our vegetable field and some of our farm buildings. The ongoing threat from permafrost thaw makes it hard to find land that will be suitable for agriculture many years into the future.

It's exciting to be part of a project studying the true effects of climate change on agriculture. While many people say climate change brings benefits for farming here, such as longer growing seasons, we are seeing worrying indicators of what it actually means for agricultural stability. Contributing to Permafrost Grown and helping develop methods to detect and mitigate permafrost degradation is invaluable to us and the future of farming in Alaska.

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“I WAS THE ONLY BLACK PERSON ON MY UNDERGRADUATE GEOGRAPHY COURSE.”

FRANCISCA ROCKEY

Black Geographers is an expanding support network for Black geography students and graduates. The network wants to encourage more Black students on geography courses and is campaigning for a more engaging and inclusive curriculum. Award-winning geographer, writer and founder, **Francisca Rockey**, tells us how and why she set up Black Geographers

Black Geographers have identified four main barriers preventing Black students from studying geography:

Isolation: Feeling isolated in geography courses at all levels of higher education, from undergraduate to postgraduate and PhD. Being the only visible minority on fieldwork in remote greenspaces, towns or villages fuels this sense of isolation, as does feeling unsafe, unwelcome or fearful of hostile encounters in the workplace.

Limited access to postgraduate study: Some careers relating to geography, geology or the environmental sciences require a master’s degree, including academic careers and graduate schemes in environmental consultancy. The government master’s loan barely covers postgraduate course costs, and increased living costs mean low-income students cannot access higher education beyond undergraduate studies.

Limited financial means: For Black students from low-income backgrounds, accessing postgraduate study or doing unpaid internships is not viable. Other sectors, such as finance, for example, tend to offer higher graduate salaries and paid internships.

Lack of guidance, support and career knowledge: Geography students are less likely to pursue a career in the field if they do not know people in academia or the environment sector. Given the lack of Black geographers, it is more likely that Black students will not be aware of the opportunities geography can offer, nor have access to a network and role models for guidance and career inspiration.

Francisca reaches the summit of Place Fell, Cumbria, UK, in 2021.

How did you come up with the idea of creating a community of Black geographers and geoscientists?

I came up with the idea of creating a community for Black geographers and geoscientists after finding that I was the only Black person on my undergraduate geography course, and I found the experience very isolating. I decided to set up an Instagram page to try to connect Black people in geography and the rest is history!

How easy was it to set up?

I launched my campaign during a time when we couldn’t go outside, due to COVID-19 restrictions, and people were spending a lot of time on social media. So, I took advantage of the increased activity on Twitter, Facebook, LinkedIn and other social platforms to get my message across and ensure that there would be people listening. Within a matter of weeks, our campaign had reached mainland Europe, Asia, South America and North America.

Lockdown gave us the time to discuss issues that prevent inclusivity, accessibility and diversity in geography, and we were able to facilitate transnational discussions. I am no expert, but social media is a very powerful tool and a great way to share your message far and wide. As I discovered with the Black Geographers campaign, you never know where your campaign will end up.

How does Black Geographers help students overcome some of the barriers they face?

We provide career resources, mentoring, networking and internship opportunities for the students and academics we work with. We also work with other educational institutions and geography organisations to improve representation, accountability and access across schools and universities.

For example, in 2020 we collaborated with Esri UK to create the Geospatial Scholarship Fund. The scholarship aims to:

- Help promote geography and geoscience as a positive life choice for students.
- Provide financial and other support for students throughout their studies.
- Increase the number of Black and mixed Black heritage students studying and working in these disciplines.

In your 2020 report: *Participation of Black students in geography,* it mentions that the geography curriculum does not engage with the issues Black students care about. What are those issues?

This statement is in reference to case studies that are used to increase people's understanding of social environmental issues. A question I have for curriculum leaders is whether the case studies being used are representative of the student cohort and the issues that are topical within the local area. For example, air pollution is a huge environmental issue in London. There are a range of case studies we can use when teaching students living in and around the M25 motorway that they can relate to because it is happening on their doorstep. This also encourages students to get involved in their local area.

There also needs to be an awareness of the type of case studies we use for different racial groups and the language we use to describe other cultures and countries in the global South. For example, we should not use the word 'slums' to describe informal settlements.

© Francisca Rockey

> **"WE PROVIDE CAREER RESOURCES, MENTORING, NETWORKING AND INTERNSHIP OPPORTUNITIES FOR THE STUDENTS AND ACADEMICS WE WORK WITH."**

Why are mentors so important?

Mentors are important because they offer guidance and insight into your chosen career path. If you don't have any friends or family working in a specific area, a mentor can connect you with people working in your dream job, assist you with job or internship applications, and offer one-to-one support on your journey, particularly if you're in the early stages of your career. There is a wealth of careers within the environment sector and it can be difficult to know where to start, or what is available to you, if you don't have a mentor or someone to guide you through your options.

What has been the best advice you have had from a mentor?

The most useful piece of advice I've had is to try everything, even jobs and sectors that aren't directly related to your dream career. You learn something from every job, and different sectors, which you can then take with you on your career journey. I was also told that my career is a journey. It might take several years to get to your ideal role but that doesn't mean you are on the wrong track.

> ***"I DON'T HAVE A CONCRETE PLAN FOR THE FUTURE OF BLACK GEOGRAPHERS BUT I HOPE IN 5 YEARS FROM NOW, WE ARE STILL SUPPORTING BLACK GEOGRAPHERS AND GEOSCIENTISTS AND BUILDING MEANINGFUL RELATIONSHIPS."***

What would you say to young people wanting to go further in geography?

As I'm sure you are aware, climate change and the future of our planet is a hot topic and if you would like to be at the forefront of climate discussions and working towards climate solutions, such as creating greener energy, rewilding to absorb more carbon or protecting our oceans and forests, then continuing your education in geography or geosciences, physical geography, Earth and environmental science or geology is the way to go. Everything I've been taught so far in my degree is relevant to current affairs, and by the time I finish my degree, I will be equipped with the tools to assist other scientists and researchers working to create a greener planet.

What is your vision for the future of Black Geographers?

I don't have a concrete plan for the future of Black Geographers, but I hope in 5 years from now we are still supporting Black geographers and geoscientists and building meaningful relationships.

© Francisca Rockey

Meet Francisca

Originally, I chose geography as a second option. I wanted to study history, but my favourite history teacher left in Year 9 and I knew it wouldn't be the same without him. What started as a second option to meet the requirements of the English Baccalaureate grew into a passion, far greater than I had for history, a strong emotion to know more about places and the relationships between people and our environment.

I remember writing my personal statement for my university application and being asked about my interest in geography and it came so naturally. I was intrigued by the natural features of the Earth and the dynamics of our changing world. Not only is geography relevant to current affairs, but we are surrounded by characteristics of physical geography in our everyday lives, from the type of soil found in your local park to the drainage of your nearest river. Understanding where things happen and the differences between places is important in many contexts, from agriculture to infrastructure, and housing to the environment.

Writing gives me the most joy, 100%. At the age of 14 (almost 10 years ago), I started a blog called 'Fran's World' to document my teenage years and get my writing 'out there'. What started as a hobby grew into something a lot bigger and I was

constantly looking for ways to make my corner of the internet bigger and better. On my blog, you would find lifestyle, travel and student-related content. I used to dabble in fashion, beauty and fitness from time to time; I wouldn't say they were part of my niche, though.

I used to publish a new post every Wednesday at 12pm. Writing was (and still is) something that comes naturally to me, so I didn't have to dedicate much time to it other than a few hours on a Sunday evening or a few hours before I was due to publish on a Wednesday. Having a schedule made it really easy to juggle my blog with studying and was how I managed to keep it going for several years. I no longer have a blog, but I do write for other publications such as gal-dem.

There are loads of different ways to use your passion to create change, you just have to find the right way for you. Ask yourself the following questions: What makes you curious? What are your passions and dreams? How can you combine your interests to change a certain issue you are passionate about?


© Francisca Rockey

> ***"I WAS INTRIGUED BY THE NATURAL FEATURES OF THE EARTH AND THE DYNAMICS OF OUR CHANGING WORLD."***

My advice is to seek out a support network, people who have similar passions and interests, with whom you can share ideas, have discussions or work together to achieve common goals. A great support network for young people is Transform Our World. It's an online community of educators empowering students to take climate action.

You could also try and find local community groups or projects related to the issue you're are passionate about. For example, if you're passionate about conservation and based in the UK, go to The Conservation Volunteers, enter your postcode and you'll find conservation activities happening in and around your local area. If, like me, you enjoy writing, you can set up a free blog on WordPress or Blogger and communicate your passions to others.

About Black Geographers

Black Geographers formed as a collective of Black geography students and graduates who have first-hand experience of the many barriers which prevent Black students from studying geography, and how isolating the field can be even after navigating these barriers.

Through collaborative work, Black Geographers aims to not only encourage more Black students to study geography, but to also begin transforming geography as a discipline, to make it more engaging and inclusive at every level of education.

The network, across Instagram, LinkedIn, Twitter and Black Geographer's newsletter, has grown to a community of 13K+ individuals.

ABOUT

Connect with Black Geographers and Francisca

- **blackgeogorg**
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- **blackgeographers**
- **www.youtube.com/channel UCKTcbVtv1DEsFr4M9Fd7AWg**
- **www.blackgeographers.com**

HOW CAN WE MAKE STEM SUBJECTS MORE ENGAGING FOR STUDENTS?

At **Point Park University** in Pittsburgh in the US, education researchers **Dr Ginny Chambers, Dr Kamryn York** and **Dr Mark Marnich** are helping pre-service teachers develop their skills in STEM subjects to make learning more enjoyable and effective for their future students. The team is using the principles of maker education to create hands-on, interactive STEM and maker experiences.

Dr Ginny Chambers

Associate Professor of Education

Dr Kamryn York

Assistant Professor of Education

Dr Mark Marnich

Professor of Mathematics

Point Park University, Pittsburgh, USA

Fields of research
Education, Teacher Training

Research project
Developing and transforming STEM teaching spaces and pre-service teaching programmes

Funder
US National Science Foundation (NSF) – Improving Undergraduate STEM Education Grant

PROFILES

TALK LIKE AN ... EDUCATOR

Collegiality — the cooperative relationship between work colleagues

Interdisciplinary — including two or more branches of knowledge

Learning styles — the preferred way that different students learn and absorb information

Pedagogy — the method and practice of teaching

Pre-service Teacher — a trainee teacher. This usually means a university student who is in training to become a teacher

Self-learning — an approach to learning where students teach themselves by following instructions and figuring out answers on their own

STEM — subjects related to science, technology, engineering and mathematics

When did you last make something in school? When have you taken a hands-on approach in a lesson? What skills does being creative in your learning demand of you and, more importantly, how does it enable you to develop them further?

Maker education, a term coined in 2013, is an approach to teaching where students are encouraged to try things themselves, share ideas, ask questions and make mistakes. "Maker education involves working with your hands and incorporating various tools, materials and technologies," says Kamryn. Makerspace teaching methods can be particularly useful for teaching STEM subjects. "This is because they require students to become more aware of the design of the world around them and see themselves as people who can test their ideas, make changes and improve their results," Kamryn explains.

Maker spaces are collaborative workspaces inside schools, libraries or public spaces, where maker-centred learning takes place. In a maker-centred classroom, maker spaces around the room might allow students to create small electrical circuits, figure out how to build bridges or create structures, or do similar activities that put what they have learnt into practice and build their problem-solving skills. "Maker education promotes creativity, collaboration and critical thinking skills through applying new ideas, asking questions and synthesising information," says Ginny.

How are maker spaces good for students?

Makerspace activities are student-led, which means that students do things themselves and can learn information in a way that suits their own learning style best. Students are also encouraged to ask a lot of questions during the activities. "Our research indicates students retain more information and are


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better at adapting that information when inquiry-based instruction is used," says Kamryn.

As students get older, maker education often results in them being better at applying their knowledge to the real-world. Since maker education activities show how information can be used in different scenarios, students can directly link what they are learning in the classroom with what they might need to know outside the classroom.

Maker spaces can be particularly beneficial for teaching mathematics as the fun, hands-on approach has been shown to increase children's confidence and lessen any anxiety they have surrounding the subject. Mathematical activities in maker spaces might include students designing and measuring things themselves or working out how to fit different shapes together to create new shapes. "Maker education develops skills in mathematics such as measurement, data analysis, spatial reasoning, counting and geometry," explains Mark.

Sounds great! How can maker spaces help teachers?

Teachers using maker spaces have said that it increased their confidence in their own understanding of STEM topics. In maker spaces, teachers listen to the questions their students are asking and see what their students come up with on their own. "Educators often become learners in a maker space," says Mark. "These new roles often help teachers gain insight into STEM pedagogy."

Maker space activities allow teachers to engage differently with STEM materials and connect better with STEM content. "Teachers using maker spaces indicated increased aptitude in self-learning, leadership, technological literacy, collegiality, adaptability, and ability to serve diverse groups of students," says Mark.

What is the Park Point team working on?

Despite the fact that makerspace education is becoming popular in schools across the US, teachers are still often underprepared to teach in maker environments as these are quite different from traditional teaching environments. To combat this problem, Ginny, Kamryn, and Mark started a project called T.I.M.E for STEM, where T.I.M.E stands for Transforming Integrative Makerspace Education. The project works with pre-service (student) teachers at Point Park University who are focusing on elementary education, with the goal to improve the way they teach STEM subjects and better prepare them for maker education methods.

"Our students participate in activities and design lessons that create a cooperative learning environment which integrates technology and connects learning outside of the classroom," says Kamryn. The students are also encouraged to do their own scientific investigations to help improve their understanding of STEM subjects. "Through these experiences, students gain a better understanding of how STEM education is an integrated, interdisciplinary and student-centred approach to learning that encourages curiosity, creativity, artistic expression, collaboration, computational thinking, communication, problem solving, critical thinking and design thinking!" says Kamryn.

Who else is the team working with?

The T.I.M.E for STEM project mainly takes place within the School of Education faculty at Point Park University, but it also works with various organisations such as the Children's Museum of Pittsburgh, Matt's Maker Space Organization, the local educational administration unit, the Natural Science, Engineering and Technology Department at Point Park University, Mount Lebanon School District and Manchester Academic Charter School. "Four classroom teachers from our project's partner schools participated in our training, and our pre-service students will soon visit and teach in their classrooms and maker spaces too," explains Ginny.

What has T.I.M.E for STEM achieved so far?

The partnerships that T.I.M.E for STEM have created have strengthened relationships both on campus and within the local community. "We have met so many people interested in our research, proud of what we are doing and keen to learn more about interdisciplinary STEM education for pre-service elementary teachers," says Ginny.

> **"EDUCATORS OFTEN BECOME LEARNERS IN A MAKER SPACE."**

As well as fostering links within the local community, the T.I.M.E for STEM project has run 14 professional development sessions for faculty and teacher participants. The sessions have been on a range of topics including Recyclable Materials, Fabrication, Metal Work, Technology Resources in Maker Labs, and Human-Centered Design Thinking. "Our research has shown that teachers are more confident in STEM questioning and assessment after doing these sessions," says Mark.

What are the next steps for T.I.M.E for STEM?

Throughout the next year, the programme's pre-service students will learn maker education pedagogy and curriculum development. "They will also have the opportunity to teach interdisciplinary STEM lessons in maker space classrooms at our partner schools," says Ginny.

Kamryn, Ginny and Mark will also talk to lots of different people – including teachers, administrators and educators – about makerspace education to find out what has been working in elementary STEM teaching and what could be improved. After this, they will develop a maker education planning template and observation rubric to serve as a guide for elementary teachers and teacher educators. This means that even those who are not enrolled in the programme at Point Park University will be able to benefit from their work and help make STEM subjects more interesting and engaging for more children.

Meet Sophie

"Sophie Jebose is a pre-service teacher at Point Park University from the Netherlands. Training in elementary education, she is using the maker space to develop her STEM teaching skills and prepare for her teaching career.

"When I left gymnastics after practising the sport for almost 10 years, I was asked to stay on to coach. I immediately fell in love with teaching and knew I wanted to do this for the rest of my life.

"I felt excited at the start of my teacher training. I am not nervous about speaking in front of people; I really get into a 'role', and it seems to flow naturally. However, when I started taking upper-level classes in college, I realised the responsibility that comes with teaching, which can be daunting at times.

"I think the challenges of teaching STEM subjects to children is sparking and then maintaining excitement for STEM. Often, I think that children are intimidated and think they are not good at math or science and, therefore, cannot like STEM. However, STEM is so much more than that! It is important to tackle this, so that every child knows they have a place within STEM.

I remember being one of those students who thinks they are not good at any of the STEM subjects and ruled it out before even giving it a shot. It's my goal to provide plenty of opportunities for my future students to become familiar with all aspects of STEM and help them discover their talents within the fields. Hopefully, that way, they will get excited about it!

"The maker space allows me to practise lessons exactly how I want to teach them because of the many materials available. This practice builds confidence and helps me when going into schools to work with students during field experiences. Also, it enables the professors to give us interactive and hands-on learning experiences, which makes learning fun.

> ***"YOU JUST HAVE TO HAVE THE PASSION TO WANT TO LEARN AND GROW, SO THAT YOU CAN TEACH STUDENTS TO LEARN AND GROW WITH YOU."***

Learning in the maker space with my classmates has helped me a lot. The room allows for a lot of flexible seating opportunities. As a result, I got to know and work with all my classmates. This creates supportive relationships and makes us more comfortable acting like children when participating in lessons that our classmates practice with us!

"For me, the highlight so far has been getting to learn in the maker space and seeing the professors make great use of the space by providing hands-on activities. I believe it is the future of teacher training, as it is helpful to learn about all the opportunities of a maker space before working as a teacher in a school. My favourite parts of the maker space at Point Park University are the white board tables. They allow for quick notes that really help during discussions and project planning.

"My proudest education achievement is passing the Teaching Certification Exam. This exam tests you on all the knowledge you have gained throughout your college career. At first, this sounded rather intimidating, but I knew that I could do it if I persisted, and I did!

"My ambitions for the future are to keep on studying to get my master's and my doctorate degree. I would love to be a university professor and teach students how to be great teachers.

"My advice to younger students considering a career in teaching is to follow your heart, and do not get discouraged. You do not have to be an expert in every single subject to be a great elementary teacher – you just have to have the passion to want to learn and grow, so that you can teach students to learn and grow with you."

ABOUT *EDUCATION*

Education is an area that is changing all the time. With the huge number of new technological advances, children entering school are tech-savvy in a way that they have never been before. "Teachers have a great opportunity to tap into these background experiences and use technology as a compliment to their lessons to make the content innovative, applicable and relevant," says Kamryn.

However, the advancement of technology brings challenges too! Many young students spend a lot of time on screens and find it difficult to be as engaged by anything else, and so choosing to work in education will mean finding ways to tackle these problems. "Teachers will need to offer their students a variety of classroom experiences that strengthen their collaborative and communication skills," explains Kamryn.

Working in education can be an extremely rewarding career as teachers have the opportunity to make massive differences in young people's lives. "Experiencing an authentic learning moment with a student is such a special experience," says Ginny. "Watching students learn, grow, and explore is truly fulfilling," agrees Mark.

"TEACHERS WILL NEED TO OFFER THEIR STUDENTS A VARIETY OF CLASSROOM EXPERIENCES THAT STRENGTHEN THEIR COLLABORATIVE AND COMMUNICATION SKILLS."

Explore careers in *education*

- If you are interested in teaching, Kamryn recommends having a look at your state's Department of Education website. "These webpages typically include information about certification, educational initiatives and resources for teachers and students," says Kamryn. "Other organisations that offer educational resources, conferences and networking opportunities include The National Education Association (**www.nea.org**), National Council of Teachers of Mathematics (**www.nctm.org**), Next Generation Science Standards (**www.nextgenscience.org**), and International Society for Technology in Education (**www.iste.org**)."
- If you are in the UK, advice for careers in teaching can be found at the government education site: **www.getintoteaching.education.gov.uk/train-to-be-a-teacher**
- Mark recommends talking to principals and teachers about their work. "These are the people who know about the everyday experiences of teaching," he says.
- Point Park University offers a pilot programme for high school students who are advanced in mathematics to take college math courses: **www.pointpark.edu/academics/undergraduateacademics/collegeinhighschool/index**
- Amongst other summer camps, it are also re-introducing its Engineering Summer Camp for high school students: **www.pointpark.edu/about/aboutpittsburgh/livingandlearninginpittsburgh/community-and-summer-programs/youth-and-high-school-students/index**
- According to USA Facts (**www.usafacts.org**), the average annual salary for a public-school teacher in the US is $65,000.

Pathway from school to *education*

- All certified elementary teachers in the US must have a bachelor's degree. Consider a degree in elementary education or a related field such as early childhood development. You could also study a subject specific degree (such as physics or English) and then enrol in a teacher education programme afterwards.
- To become a high-school teacher in the US, the most common route is to first earn a bachelor's degree in the subject you would like to specialise in and then earn a teacher certificate afterwards.
- To become an education researcher or professor like Ginny, Kamryn and Mark, it is likely you will need to complete a master's degree and a PhD.
- "Education students should be able to problem solve, demonstrate creativity and write clearly," says Ginny. When choosing a teaching programme, Ginny recommends looking for ones that have a detailed structure and allow for student choice. "Think about the subject and age level you might be interested in teaching and look for a programme that meets those needs," she says.
- "I recommend students take a mixture of courses that teach content and methods," says Kamryn. "It will be important for students to be competent in the skills needed to teach their future students in addition to pedagogical methods and strategies to best teach these skills."
- If you are interested in becoming a mathematics teacher, Mark recommends taking some data analytics and statistics classes at college, as well as traditional mathematics and education courses.

Meet *the T.I.M.E. for STEM team*

Q&A

Meet Ginny

What were your interests when you were growing up?

I have always been interested in sports, animals, art and travel.

Who or what inspired you to become an educator?

When I was young, I worked as a camp counsellor, and I knew I had a passion for working with young students. Working on my undergraduate degree, I connected well with my education professors, and I thoroughly enjoyed my time volunteering in the elementary classrooms. I also coached tennis, which made me realise that I enjoyed working with students of all ages.

> ***I LOVE ADAPTING MY TEACHING TO WHAT IS CURRENT IN EDUCATION. I ESPECIALLY LIKE USING MY CREATIVITY IN MY TEACHING AND COLLABORATING WITH COLLEAGUES AND EDUCATORS.***

What experiences have shaped your career?

When I was an elementary teacher, I had the opportunity to work with amazing teachers and administrators. I have taught in a large public school system and a small private school. Likewise, I have worked at a large university and a smaller university. All of these experiences have helped shaped who I am as an educator and a leader.

What attributes have made you successful?

As a former elementary teacher, and now as a college professor, I am always striving for excellence and trying to best meet the needs of my students. I am passionate about teaching and learning and am always interested in new ideas and research. I love adapting my teaching to what is current in education. I especially like using my creativity in my teaching and collaborating with colleagues and educators. Throughout my teaching career, I have always focused on the needs of the students. My courses incorporate collaboration, communication, creativity and growth-oriented learning. I implement a constructiveness approach to teaching, and attempt to present material in a structured, yet engaging manner.

What are your proudest career achievements so far?

I am proud of the work I have completed as a faculty member at Point Park University. I have learned about programme assessment, curriculum and programme development, and leadership roles within higher education. I am thrilled to be able to provide our students with unique opportunities as they complete their teacher certification programmes. Specifically, I am proud to offer our students enrichment opportunities such as student teaching abroad and creative learning experiences within maker education.

Ginny's *top tips*

1. Go for it! A career in education has proven to be the perfect balance of challenging and rewarding.

2. Find something that resonates with you in education and use that as a springboard for goal setting and achievements. As an elementary teacher, I fell in love with children's literature. I am passionate about finding the perfect book to open ideas to my students. This passion led me to both my master's and doctoral programmes. I currently focus on how literature can be used in maker education with STEM learning. Bring your own passion into your teaching!

Q&A
Meet Kamryn

What were your interests when you were growing up?
Sports, babysitting, leadership opportunities like the student council, band, spending time with family and friends, travelling and crafting!

Who or what inspired you to become an educator?
I always enjoyed working with children as a babysitter and camp counsellor. I had great teachers growing up that made school and learning enjoyable and fun, so I knew I wanted to contribute to the great field of education.

What experiences have shaped your career?
Throughout my career, I have been surrounded by good mentors. As opportunities presented themselves to me personally and professionally, I was willing to take risks and explore new experiences that stretched my skill set and deepened my understanding of innovative ideas. I value the gift of learning!

What are your proudest career achievements so far?
I am most proud of earning my doctorate in education and becoming an assistant professor. My faculty position allows me to contribute to the training of pre-service teachers as we get them ready to take on the role as a classroom teacher. I also have the privilege to work on innovative projects such as developing Point Park's student teaching abroad programme and our School of Education makerspace initiative. These experiences strengthen my love for learning and keep each day exciting as we establish new opportunities for our students.

Kamryn's *top tips*

1. Be open to change and new opportunities for learning.
2. Find good mentors throughout your career that will help guide your learning and facilitate new career opportunities.
3. Never be afraid to try – we learn from our experiences.
4. Discipline and hard work pay off!
5. If you become an educator, always stay focused on serving your students.
6. Never stop learning – it is important to stay relevant in your teaching practices and methods to best meet the needs of students.

Q&A
Meet Mark

What were your interests when you were growing up?
Sports, mechanical devices (cars, motorcycles, lawnmowers, etc.) and history.

Who or what inspired you to become an educator?
I guess for twelve of my first eighteen years of life education was the focus and what I knew best!

What experiences have shaped your career?
The teachers I have had (good and bad), colleagues I have worked with (again, good and bad) and taking advantage of every opportunity that has come my way.

What attributes have made you successful?
My willingness to help, remembering what it was like to be a student and working harder than expectations have helped me as an educator.

What are your proudest career achievements so far?
Helping students who never thought they could earn a degree achieve their goals, earning a doctorate and becoming a professor.

Mark's *top tips*

1. Don't follow in my footsteps, blaze your own path.
2. Learn from mistakes and successes along the way.
3. Be kind to people along your journey – bring others along with you.

CAN GARDENING HELP CHILDREN GROW?

Founded by **Professor Sallie Marston** and led by former school counsellor **Moses Thompson**, the **University of Arizona's School Garden Workshop** creates and maintains gardens for schools in Tucson. Not only do gardens provide sites for practical learning, but Sallie and Moses believe they help children improve their social competencies and emotional well-being.

Professor Sallie Marston

School of Geography, Development and Environment, University of Arizona, USA
Founder, School Garden Workshop

Field of research
Human Geography

Moses Thompson

Director, School Garden Workshop

Research project
Investigating school gardens as sites of psychological resilience

Funder
US National Science Foundation (NSF)
NSF Award Number (FAIN): 2146751

PROFILES

TALK LIKE A ...

SCHOOL COUNSELLOR AND GARDENER

Aquaponic — a system of jointly farming fish and plants, in which water and nutrients are cycled between the fish and plants

Emotion regulation — the ability to control your emotions

Ethnographic observation — an anthropology research method in which the researcher observes humans in their cultural setting

Raised bed — a gardening technique in which soil is raised above the ground-level, usually enclosed in a large container

Resilience — the ability to bounce back to a pre-crisis state after experiencing severe stress. It includes capacities such as adaptability and persistence

Title I school — in the US, a designation for schools where most students come from households at or below the federal poverty level

The Sonoran Desert in Arizona, USA, may seem an unlikely place for a garden to flourish. However, it is the most biodiverse desert in North America and Indigenous peoples have been growing food here for 4000 years. Despite the harsh climate, school yards in Tucson, a city in this desert landscape, are bursting with colour. Flowers bloom, vegetables grow and children experience the wonders of nature in over 70 school gardens in the district, thanks to the work of Professor Sallie Marston, Moses Thompson and the University of Arizona's School Garden Workshop.

Why do school gardens matter?

Garden-based therapy, the use of gardening activities as a treatment for mental and physical ailments, is a well-established tool for lowering stress levels and encouraging physical exercise. In his work as a school counsellor, Moses used garden-based therapy to help children with adverse childhood experiences. "I noticed that working in the garden reduced children's anxiety, fear and anger," he says. "Most importantly, through working in the garden, students came to understand how to manage these emotions."

Garden-based learning, in which educators use gardening as an instructional tool, engages students in practical, outdoor, hands-on projects, in contrast to the theoretical, indoor nature of much conventional teaching. For example, students can conduct scientific

Students in Tuscon harvest oranges from their school garden

experiments to explore how plants grow under different conditions. The gardens themselves can be used as outdoor classrooms where students can monitor weather conditions, learn about traditional uses of different species and create artwork inspired by their natural surroundings. "School gardens are places of wonder," says Moses. "When students are curious, the motivation to learn is intrinsic, so the learning is deeper and more sustained."

Tucson, Arizona

In Tucson, around one in four children live below the federal poverty line. All schools participating in the School Garden Workshop are Title I schools, meaning that most students come from households in poverty. Typically, Title I schools are also more racially diverse than other schools. "Title I schools in the Tucson Unified School District (TUSD) have a high percentage of Hispanic students," explains Sallie. "On average, 60% of students are Hispanic, 20% are non-Hispanic White, and the remainder are Native American, Asian American and multi-racial." In this context, school gardens not only benefit individual students, but also bring disparate groups of people together and provide important community spaces for the residents of Tucson.

How are school gardens used in Tucson?

The School Garden Workshop helps create and maintain gardens in the TUSD, as well as training educators and students in how to use the gardens as learning and community resources. As every school yard and school community is different, every school garden is unique. Some have raised beds, some have greenhouses and some have aquaponic systems. The produce also varies, with different trees, flowers and vegetables grown. Some school gardens even contain chicken coops and tortoise habitats.

"Beyond being an outdoor classroom, school gardens provide opportunities to improve nutrition among students from families where incidences of Type 2 Diabetes are high," says Sallie, as the produce grown in gardens is served in school cafeterias. "Through food literacy lessons and take-home meal kits, students can learn about healthy eating and take those lessons home to their families."

School gardens promote problem solving and collaboration (for example, students must work together to catch escaped chickens!), and they support emotional well-being by providing opportunities for yoga or simply to enjoy the sights, sounds, smells and tastes of the garden. They also increase connections with the community, as neighbours and family members share their skills (e.g., stone masonry and construction) and knowledge (e.g., Indigenous planting calendars) with teachers and students.

Do school gardens increase resilience?

Having witnessed the benefits school gardens bring to students, teachers and communities, Sallie and Moses wanted to investigate these impacts from a scientific viewpoint. To do this, they focused on the psychological concept of resilience, and whether students in Tucson displayed greater resilience following the COVID-19 pandemic lockdowns if they attended a school with a garden. "Psychological resilience is founded on two different constructs: adversity and positive adaptation," explains Sallie. "Children are resilient when they possess the ability and personal assets to endure the negative effects of stresses and can 'bounce back' to their pre-crisis status. With respect to learning, resilience is the ability to be mentally 'present' to learn."

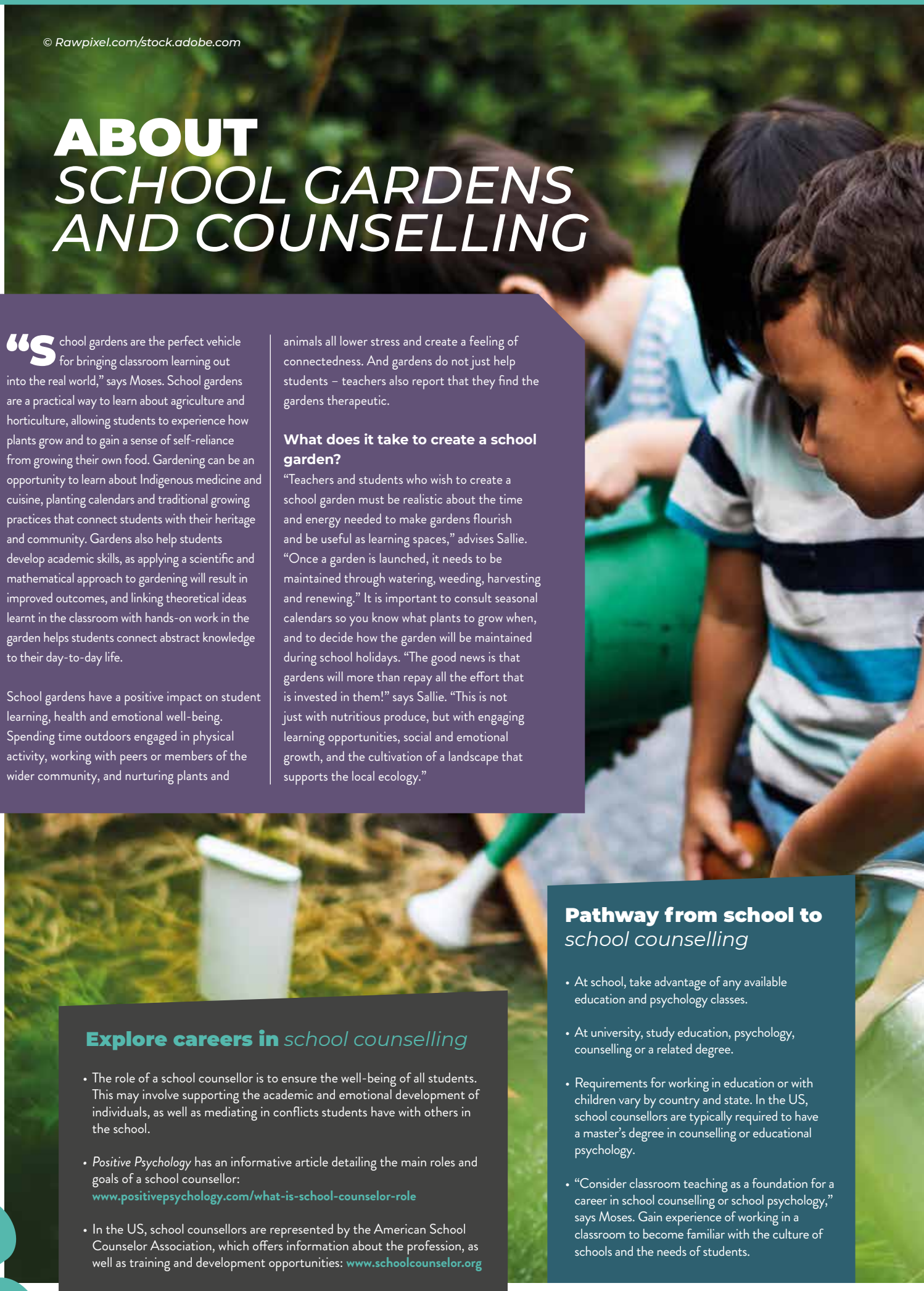
An initial key finding was that the concept of resilience was a poor fit for their study. As most of the students in the TUSD come from households in poverty, there was no true 'pre-crisis' state for them to return to after the lockdowns. While Sallie and Moses found evidence of self-reliance, emotion regulation and perseverance in the students, the psychological tools used to measure resilience could not adequately capture these.

> **"SCHOOL GARDENS PROMOTE PROBLEM SOLVING AND COLLABORATION, AND THEY SUPPORT EMOTIONAL WELL-BEING..."**

Instead, Sallie, Moses and the team conducted ethnographic observations in different schools. This involved observing lessons held in classrooms and gardens over the course of seven months and taking detailed notes. "Our field notes resulted in a complex assembly of descriptive and analytical material that provided a deep and expansive foundation for understanding how gardens have been of value in what we are now calling 'self-determination', rather than resilience," Sallie says.

This data analysis involves statistically comparing the well-being and self-determination of students exposed to school gardens with students attending schools without gardens. The observational notes are coded by applying a word or phrase that best describes the recorded behaviour. The codes are fine-tuned and ultimately provide a rich dynamic assessment.

Although they are still waiting to draw scientific conclusions from their research study, over their years of working with the School Garden Workshop, Sallie and Moses have observed first-hand how school gardens are helping not only flowers, but also children, bloom in the desert.



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ABOUT *SCHOOL GARDENS AND COUNSELLING*

"School gardens are the perfect vehicle for bringing classroom learning out into the real world," says Moses. School gardens are a practical way to learn about agriculture and horticulture, allowing students to experience how plants grow and to gain a sense of self-reliance from growing their own food. Gardening can be an opportunity to learn about Indigenous medicine and cuisine, planting calendars and traditional growing practices that connect students with their heritage and community. Gardens also help students develop academic skills, as applying a scientific and mathematical approach to gardening will result in improved outcomes, and linking theoretical ideas learnt in the classroom with hands-on work in the garden helps students connect abstract knowledge to their day-to-day life.

School gardens have a positive impact on student learning, health and emotional well-being. Spending time outdoors engaged in physical activity, working with peers or members of the wider community, and nurturing plants and animals all lower stress and create a feeling of connectedness. And gardens do not just help students – teachers also report that they find the gardens therapeutic.

What does it take to create a school garden?

"Teachers and students who wish to create a school garden must be realistic about the time and energy needed to make gardens flourish and be useful as learning spaces," advises Sallie. "Once a garden is launched, it needs to be maintained through watering, weeding, harvesting and renewing." It is important to consult seasonal calendars so you know what plants to grow when, and to decide how the garden will be maintained during school holidays. "The good news is that gardens will more than repay all the effort that is invested in them!" says Sallie. "This is not just with nutritious produce, but with engaging learning opportunities, social and emotional growth, and the cultivation of a landscape that supports the local ecology."

Explore careers in *school counselling*

- The role of a school counsellor is to ensure the well-being of all students. This may involve supporting the academic and emotional development of individuals, as well as mediating in conflicts students have with others in the school.
- *Positive Psychology* has an informative article detailing the main roles and goals of a school counsellor: **www.positivepsychology.com/what-is-school-counselor-role**
- In the US, school counsellors are represented by the American School Counselor Association, which offers information about the profession, as well as training and development opportunities: **www.schoolcounselor.org**

Pathway from school to *school counselling*

- At school, take advantage of any available education and psychology classes.
- At university, study education, psychology, counselling or a related degree.
- Requirements for working in education or with children vary by country and state. In the US, school counsellors are typically required to have a master's degree in counselling or educational psychology.
- "Consider classroom teaching as a foundation for a career in school counselling or school psychology," says Moses. Gain experience of working in a classroom to become familiar with the culture of schools and the needs of students.

Q&A

Meet Sallie

What motivated your interest in human geography?

As a teenager, I was interested in psychology and what influences people to do what they do and be who they are. At university, I studied psychology and geography, because geographers aim to understand how where you are shapes who you are, and that connection was very appealing to me. These two subjects allowed me to combine geography's focus on place and space with psychology's focus on people. Spaces shape people; but of course, people also shape spaces.

What do you most enjoy about your work?

I enjoy turning the geography-psychology lens onto the relationship between people and environments in different situations. The work I am currently doing with school gardens is the most rewarding I have ever done. It draws from my research interests in place and society and engages me with interesting young people and exciting research questions about the power of transformative education.

> ***"SPACES SHAPE PEOPLE; BUT OF COURSE, PEOPLE ALSO SHAPE SPACES."***

Why should people spend time in gardens?

I enjoy gardens as spaces of respite from the challenges of my everyday life. They provide an opportunity to tune out stresses and focus on the marvels of nature. It is exciting to watch things grow and feel a sense of accomplishment in helping make that happen. School gardens are places where important research on climate change is occurring, forgotten relationships with local and Indigenous knowledge are being rekindled and challenges about food security and social justice are being met. I'd recommend spending some time in a garden making things grow. It's exhilarating!

Sallie's *top tips*

If you are interested in connecting geography and psychology:

1. Get to know each discipline, so you can appreciate their unique contributions to science and daily life.
2. Consider your strengths, interests and what you could bring to this exciting relationship.

Q&A

Meet Moses

What did you most enjoy about your work as a school counsellor?

I enjoyed connecting with kids and families and having the opportunity to create moments of joy for students. So many kids come to school with the emotional weight of things that happen outside school that are beyond their control. It is a very special thing to be someone who listens, helps kids make sense of their feelings, helps them see a path forward, and who brings them joy in the middle of a stressful school day.

What have been the highlights of the School Gardens project?

Where do I start?! The early years, when I was gardening with kids and families as a school counsellor, were the golden years. We were learning to garden together and transforming the school yards. Students who struggled in the classroom would thrive in the gardens. Parents would work with us and talk about how gardening reminded them of growing up.

A second highlight would be right now, as I'm surrounded by an amazing team in this successful programme. We're working on our third school garden almanac, a place-based gardening handbook of local knowledge. It's emblematic of all the good things school gardens are capable of, and it's going to be the best almanac yet!

Why do you enjoy gardening?

Every day, when I drop my 7-year-old off at school, I spend 20 minutes in his school garden which sets my trajectory for the day. A lot of things happen when I do gardening – I take my mind off stressful things and connect and with people and nature. It's centering, and I enjoy seeing spaces transformed.

Moses' *top tips*

If you would like to work professionally in school gardens:

1. Build foundational knowledge of human development and education by spending time in classrooms to learn the culture of school buildings.
2. Study education, teaching or school counselling, with a focus on social and emotional learning in gardens.

WHAT SKILLS DO YOU NEED TO SUCCEED IN SCHOOL?

Your academic identity plays a key role in your education. Students with low self-confidence in their abilities are more likely to struggle in school and withdraw from university. To address this, **Dr Cheryl Talley** founded **Project Knowledge,** a research project and academic intervention at **Virginia State University,** USA, which has since expanded to a local high school. Using psychology theories and methods, this landmark programme provides students with the skills and confidence they need to succeed.

Project Knowledge

Virginia State University, USA

Field of research
Psychology

Research project
Using psychology to explore the best methods for instilling good academic habits in students and encouraging them to continue in higher education

Funder
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PROFILE

TALK LIKE A ... PSYCHOLOGIST

Academic identity — how a person views themselves within their educational environment

Emotion regulation — the ability to control your emotions

Future Time Perspective (FTP) — a belief that doing things now will result in future rewards

Historically Black College/University (HBCU) — in the US, a school of higher learning that was accredited and established before 1964, whose principal mission is the education of African Americans

Intervention — an action or activity used to change a person's behaviour or feelings

Near-peer — someone who is close to you in age

Past Negative Time Perspective (PNTP) — a belief that the present is influenced by bad things that happened in the past

Protective factor — a characteristic that increases the likelihood of positive outcomes

Risk factor — a characteristic that increases the likelihood of negative outcomes

Semester — half an academic year

STEM — Science, Technology, Engineering and Mathematics

What is your favourite subject, and which subject do you find most challenging? Where do you think your strengths lie in these subjects, and where do you feel you struggle? We all have a sense of academic identity, a perceived idea of who we are within our educational surroundings. While a positive academic identity can lead to success in school, a negative academic identity can become a self-fulfilling prophecy – students who tell themselves "I can't do mathematics" are likely to struggle in mathematics classes due to a lack of self-confidence in their abilities.

"I heard so many of my students say that they hate science or that they can't do science," says Dr Cheryl Talley, a psychologist at Virginia State University (VSU). "This didn't sit well with me." Some years ago, she became aware that as many as 60% of students failed to receive a degree within six years, with the majority of those students dropping out before completing all of their required introductory courses.

VSU is a Historically Black College/University (HBCU). Many of its students qualify for federal financial aid. The need for income-based financial assistance often translates to being under-prepared for the challenges of college and a greater chance of dropping out before the end of the third semester.

This attrition problem is not unique to VSU. However, Cheryl was appalled by the prospect of contributing to an HBCU student leaving university with debt and no degree.

In response to this, Cheryl founded Project Knowledge in 2011. Project Knowledge (PK) is a research project, drawing on theories and methods from psychology to discover what techniques work best for encouraging students to stay in university. A key aspect of PK is the

> ***"THE GOAL OF PK IS TO PROVIDE EXPERIENCES THAT BOLSTER THE FEELINGS ASSOCIATED WITH ACADEMIC ACCOMPLISHMENT. WE BELIEVE THAT POSITIVE FEELINGS ABOUT LEARNING STRENGTHEN A STUDENT'S ACADEMIC IDENTITY."***

intervention, in which older VSU students mentor first-year students, encouraging them to develop their confidence and providing tools for a more robust learning mentality. As a result of PK's success at VSU, the intervention has since been expanded to a local high school, where students are taught the skills needed for academic success.

Project Knowledge's aims

"The goal of PK is to provide experiences that bolster the feelings associated with academic accomplishment," says Dr Victoria Davis, PK's Program Manager. "We believe that positive feelings about learning strengthen a student's academic identity."

Studying the traits of STEM students who did not drop out of university, the team discovered they shared common characteristics that lend themselves to academic achievement. The team identified two principal groups of factors that affect whether or not students stay in university. Protective factors (e.g., self-confidence, aspirations for the future, strong learning habits) encourage students to persevere, while risk factors (e.g., perceived failure, lack of motivation, poor learning techniques) decrease a student's engagement and increase their likelihood of leaving.

"The focus of PK's intervention is to increase protective factors and decrease risk factors," says Meya Mongkuo, PK's Wellness Coordinator and Research Analyst. "It is important that the intervention is not seen as remedial, as once students are labelled as needing academic help, the associated stigma can demotivate them."

The importance of identity

A positive sense of academic identity is key to realising PK's vision. "According to the theories behind this research, students who identify as 'smart' commonly exhibit behaviours that correspond with academic achievement," says Jordan Windley, PK's Program Manager. "This self-identification is thought to be associated with good academic habits and behaviours, such as emotion regulation and organised note-taking, that reinforce this identity."

Your self-identity is, in a large part, dependent upon the relationships you have with those around you. For this reason, building trusting relationships between mentors and mentees lies at the heart of PK. "We use near-peer mentoring activities to provide experiences that associate positive feelings, such as self-confidence, with schoolwork, while diminishing negative feelings that may be associated with past academic experiences," explains Jordan.

Project Knowledge in action

For the intervention at VSU, first-year students are assigned to a small group led by an older student, who also acts as their personal mentor. The groups meet formally every week and informally on a more frequent basis, and mentees also receive one-to-one training from their mentor. The small group sizes and close connections between mentor and mentee mean strong relationships develop over the course of the year.

Many students report that in high school, memorisation of facts is more important than understanding of concepts, and so they lack the skills needed to succeed in university. "Students feel the process of 'learning how to learn' was always assumed, but never actually taught," explains Meya. The intervention focuses on providing students with the skills and resources required for successful learning.

Mentoring sessions teach techniques such as using a calendar to improve time management, reviewing class notes within 24 hours to increase retention, and active studying to ensure understanding. Rather than passively rereading textbooks and reciting facts, active studying involves engaging with the material, for example, by explaining concepts in your own words.

The informal sessions led by mentors often take place as study groups, where mentees can witness good academic practices in action. "We have realised that students learn through seeing behaviours modelled and reinforced by other students," says Meya.

Perspectives of time

To dig deeper into the psychology behind academic success, Victoria has been researching how students perceive time, which appears to strongly influence whether they stay in university. "In essence, academia rewards people who have a

The Project Knowledge professional leadership team (clockwise from bottom: Dr Cheryl Talley, Dr Reginald Hopkins, Dr Bernice Carson, Dr Oliver Hill Jr.)

Above: The 2021-2022 cohort of Petersburg High School Project Knowledge mentors and mentees

> **"BY ACTING AS ROLE MODELS, MENTORS PROVIDE MENTEES WITH A VISION OF THEMSELVES AS SUCCESSFUL STEM STUDENTS, WHILE ALSO STRENGTHENING THEIR OWN ACADEMIC IDENTITY THROUGH THE PROCESS OF HELPING OTHERS TO ACHIEVE."**

Future Time Perspective (FTP), who believe that doing things now will result in future rewards," she explains. "However, most VSU students do not have an FTP, but a Past Negative Time Perspective (PNTP), in which they believe the present is influenced by bad things that happened in the past."

Your perspective of time has an impact on your behaviour. "A PNTP means many students don't prepare for assignments until the deadline has almost arrived," says Victoria. "Then, when they inevitably don't do well, they see that failure as more significant than it ought to be." A PNTP therefore acts as a risk factor, while an FTP can act as a protective factor against the challenges of education.

This is an important insight as it indicates where interventions should be focused. "It is important to encourage students to relate to school from the perspective of their future self," explains Victoria. "This shift of perspective from your present circumstances to your future self is more likely to occur inside of trusting relationships." Such relationships form the backbone of PK.

From university to high school

As PK grew from strength to strength, the team realised there could be value in instilling good academic habits and mindsets earlier in a student's educational journey, and so the intervention was expanded from VSU to Petersburg High School (PHS) in 2019. "The aim was to create high school students who are university-ready, while also increasing the number of students aspiring to attend university," says Cheryl.

In the PHS version of the intervention, mentors are first-year VSU students, in a role reversal from their position as mentees in the VSU intervention. "The idea is that the mentoring experience itself provides an intervention for these university students," says Jordan. "The motivation to adopt successful academic habits would be driven by their desire to serve others, rather than by participating in a programme where they could be identified as in need of help."

When the PHS intervention was forced to move online during the COVID-19 pandemic, the VSU mentors responded to the challenge by displaying greater levels of creativity, discipline and commitment. "PK served as a protective factor against loneliness and isolation, and PHS students involved in PK had improved mental and emotional health," says Victoria.

Faced by the society-wide challenges of the pandemic, mentors did not limit their teaching to academic habits. "Mentors also delivered training on coping with anxiety and depression, expressing gratitude, and meditation," says Meya. Being able to deal with and flourish within such challenging conditions shows the value of PK for building resilience within mentees and mentors alike.

> **"FROM 2011 TO 2019, OVER 80% OF THE 200 STUDENTS THAT PARTICIPATED IN PK PERSISTED IN THEIR STEM DEGREE. THIS IS GREATER THAN THE NATIONAL AVERAGE AND DOUBLE THE PREVIOUS VSU STEM PERSISTENCE RATE."**

Benefits of bi-directional relationships

The results of the PK research clearly show that benefits go both ways, with both mentors and mentees displaying enhanced academic outcomes. "Near-peer mentoring not only sharpens mentees' academic identity, but gives mentors motivation to continue to improve," says Jordan. "By acting as role models, mentors provide mentees with a vision of themselves as successful STEM students, while also strengthening their own academic identity through the process of helping others to achieve." This fostering of relationships, rather than a direct focus on academic ability, can pave the way for a more inclusive and supportive academic community.

Project Knowledge successes

Given its core research aim, the impacts of PK have been carefully monitored and have shown great success. "From 2011 to 2019, over 80% of the 200 students that participated in PK persisted in their STEM degree," says Cheryl. "This is greater than the national average and double the previous VSU STEM persistence rate."

The team now hopes the lessons learnt in PK can be applied to HBCUs and minority serving institutions across the country, thereby equipping students with the skills and confidence needed to achieve success, allowing them to go far in life. •

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ABOUT *PSYCHOLOGY*

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Psychology aims to understand why people think and behave the way they do. There are many branches of psychology, including fields examining the biological, social and developmental influences on human thoughts and behaviours. This section explores the branches of psychology studied by Project Knowledge team members.

Biological psychology investigates how biological processes impact behaviour. Cheryl initially trained in neuroscience, but now addresses larger psychological questions. "Neuroscience focuses on cellular mechanisms to explain behaviour," she says. "In the real world, human activity is influenced by biological, mental and emotional processes, as well as social environments. It is only by combining knowledge from different fields that we can tackle complex problems such as a student's identity."

Clinical health psychology uses psychological knowledge to provide mental and behavioural healthcare. "Clinical health psychology focuses on both the mind and body," says Victoria. "Since they are connected and affect one another, this field teaches us to view individuals as a whole and to use dynamic, holistic approaches to healing." Clinical health psychology has practical applications in all aspects of healthcare. "Its distinction is to assess and manage severe illness and disability," explains Meya.

Behavioural psychology focuses on the impact of people's environments, such as community settings, on their thoughts and behaviours. "This mostly involves research into health promotion and disease prevention," Jordan says. "This is done by examining related psychological, social, emotional and behavioural factors in physical and mental health."

Pathway from school to *psychology*

- Mathematics and science are important for developing analytical thinking and problem-solving. "Science requires imagination and creativity," says Cheryl, who also recommends studying art, literature and music.
- Study English and develop your communication skills, as Jordan emphasises that psychology involves a lot of reading and writing.
- Victoria recommends interviewing local psychologists, getting involved with psychology organisations and seeking experience in a research lab. These will build your skills and inform your decisions on what branch of psychology to pursue.
- Most universities offer degrees in psychology, where you will be able to specialise in the field that most interests you as you progress through your studies.
- Alongside your psychology classes, Meya recommends taking classes in statistics and the philosophy of ethics.

Explore careers in *psychology*

A degree in psychology does not limit you to being a psychologist, as it will equip you with a range of skills that can be applied to any career. Some examples include:

- **Academia –** research is integral to learning more about psychology and teaching is essential for passing this knowledge to the next generation
- **Clinical work –** the interactions between physical and mental health means knowledge of psychology will help in organising clinical programmes and the diagnosis of psychiatric disorders
- **Community work –** psychology will give you the skills to help communities and organisations become more effective and take care of their members
- **Law –** forensic psychology applies psychology within the legal system, and all aspects of law require an understanding of how people think and behave
- **Marketing –** every advert relies on psychology to persuade a consumer to buy or do something
- **Policy –** developing effective, people-focused policies involves an understanding of how people think
- **Technology –** user-friendly technologies can only be produced if computer science and engineering are combined with psychology
- **Therapy –** you can help others improve their own mental health by teaching them how to change their thought patterns

Meet *the team*

Dr Cheryl Talley

Project Knowledge role: Principal Investigator

Fields of research: Biological Psychology, Neuroscience

When I was young, I wanted to be a doctor until I realised I didn't like seeing people in pain. I became interested in psychology as an undergraduate but wondered why the textbooks all referred to white people as 'normal'.

I was inspired to go into research because I wanted to make a difference. I have been motivated by curiosity and dogged determination. Along the way, I've learned that it's less important to have a determination to succeed, but rather the determination not to quit.

Every step of my educational journey has been about not quitting. I left college in my third year when I had a baby, and then waited ten years before completing my bachelor's degree. I was often tempted to give up on my education, but I kept telling myself, "Next year, I'll be in school". And eventually, I was. I returned to college as a wife and mother of four children.

During graduate school, I had an hour-long commute across the Blue Ridge Mountains. I started to turn off the music and began to use that hour to have time with myself. The realisation of my own power provided me with the confidence to seek the help I needed, and I graduated with a PhD in psychobiology.

As a neuroscientist, I worked in a rat lab studying basic mechanisms that did not have direct clinical applications. I had a spiritual epiphany, became a vegetarian, and could no longer justify the killing of lab animals. However, I enjoyed research so decided to apply my investigative skills to the science of teaching and learning.

My biggest motivator is to know myself. The motto behind Project Knowledge ('The greatest knowledge is self-knowledge') has come from my own journey. Our goal is for students to know that they are capable of learning. Once students understand their own power, they will have the motivation to succeed.

My ambition is to grow our educational technology company, Phygital Learn LLC, through which we are applying the principles we're learning in Project Knowledge to early readers. We have created a tablet-based reading programme that teaches reading fluency through stories containing pictures and dialogues recognisable to African American children.

Cheryl's *top tips*

1. Be observant and curious. Observe yourself and be curious about how you can improve. If you learn to be the best version of yourself, you will succeed in life.
2. Never stop learning. Choose something you are interested in, and challenge yourself to learn more. Choose a skill and practise until you have mastered it.
3. Consider failure your best teacher. Change directions if you need to, but never quit.

Jordan Windley

Project Knowledge role: Program Manager

Field of research: Behavioural and Community Health Psychology

I've always been interested in human behaviour. If I hadn't become a psychologist, I would have been a lawyer. I loved law movies as a kid and always dreamed of defending a client.

In sixth grade, I read a book called *Hitler: The Pathology of Evil*, which interested me in the criminally insane. I wanted a deeper understanding of what could drive evil behaviours, so I set my sights on becoming a forensic psychologist, hoping to criminally profile someone someday.

I joined Project Knowledge because I wanted to be part of a programme that makes a difference in the lives of adolescents. I am excited by the opportunity to build relationships with the youth in our community. Our mentoring not only helps the teens form responsible, healthy relationships, but has been shown to improve their mental health.

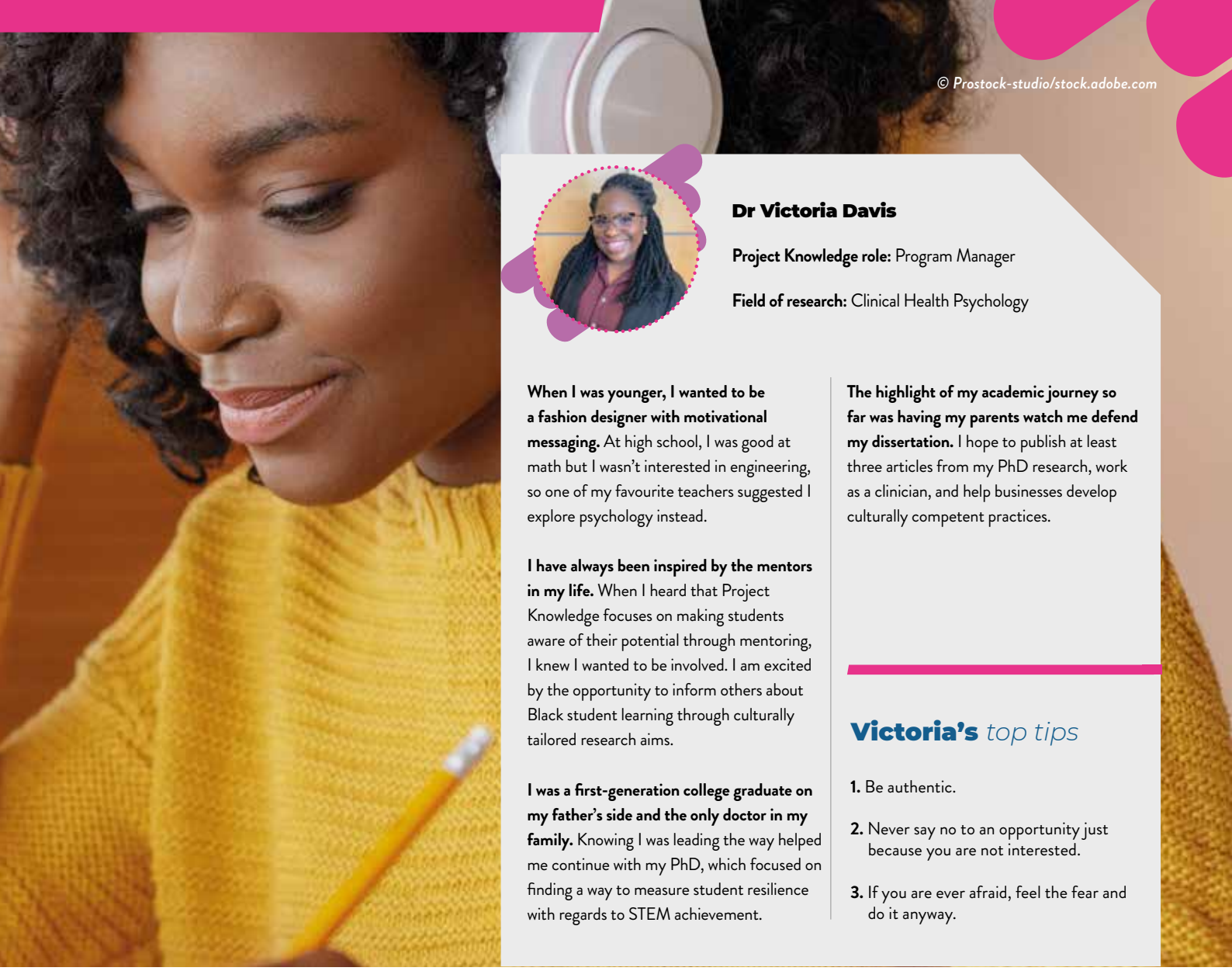
My PhD research will involve exploring where thoughts of suicide come from in African American adolescents. This idea came about while working with some students in Project Knowledge. I hope to do research into prevention models for these adolescents struggling with concepts of suicide or violence in their communities.

It has been a long journey to get where I am now, and I still have a way to go. I've changed my mind several times about what career path to follow, as I've been exposed to many different facets of psychology. I also serve as an in-home counsellor for children, and community work has kept me motivated throughout this journey.

Completing my master's degree was a big highlight. It was a difficult responsibility and took longer than it should have, as some of my mentors left the university part way through my degree and it was during the height of the pandemic. But it all felt worth it once it was completed.

Jordan's *top tips*

1. Ask everybody questions. When you meet interesting people in different positions, ask how they got there. This could help you along your journey.
2. Try everything at least once. There are lots of options available for psychology students, so gain experience to discover what you do and don't enjoy.
3. Make friends and network. It's important to have people you can learn from and who can offer you opportunities in the future.



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Dr Victoria Davis

Project Knowledge role: Program Manager

Field of research: Clinical Health Psychology

When I was younger, I wanted to be a fashion designer with motivational messaging. At high school, I was good at math but I wasn't interested in engineering, so one of my favourite teachers suggested I explore psychology instead.

I have always been inspired by the mentors in my life. When I heard that Project Knowledge focuses on making students aware of their potential through mentoring, I knew I wanted to be involved. I am excited by the opportunity to inform others about Black student learning through culturally tailored research aims.

I was a first-generation college graduate on my father's side and the only doctor in my family. Knowing I was leading the way helped me continue with my PhD, which focused on finding a way to measure student resilience with regards to STEM achievement.

The highlight of my academic journey so far was having my parents watch me defend my dissertation. I hope to publish at least three articles from my PhD research, work as a clinician, and help businesses develop culturally competent practices.

Victoria's *top tips*

1. Be authentic.
2. Never say no to an opportunity just because you are not interested.
3. If you are ever afraid, feel the fear and do it anyway.

Meya Mongkuo

Project Knowledge roles: Wellness Coordinator and Research Analyst

Field of research: Clinical Health Psychology

When I was younger, I just wanted to be happy. I enjoyed dancing to Afro-Cuban music, swimming in the ocean, and having barbecues at the beach with family.

I took a psychology class in college, while I was failing miserably in my chemistry and pre-medicine courses. A lightbulb ignited when I was in that class – it just clicked, and the concepts made sense to me. I started taking more classes in psychology and that's when I knew it was my path.

I attended the Black Psychology Conference at VSU, which inspired me to enrol at VSU for my PhD. It is very rare to see a clinical health psychology programme at an HBCU. I was hooked by the opportunity to sit at the feet of giants in the field of psychology who were African American, and I was motivated by having mentors who were open to me asking questions and who gave me space to learn and inquire.

Having a mentor who looks like you and who can relate to what you are going through makes navigating life a bit easier. You don't feel as alone when you face difficult situations.

My father was a professor and having the opportunity to work with him and present our research together was an honour. We won the Best Paper Award at an international conference, with my mother cheering us on, which is a highlight of my academic journey and a symbol of redemption for my family. It was an honour to continue his legacy as, unbeknownst to us, this was one of his last publications before his passing.

My PhD research involves mindfulness practices for Black, Indigenous and People of Colour (BIPOC) and how they affect health and well-being. In the future, I hope to curate healing spaces for BIPOC people to reconnect with their ancestral wisdom, and, as in the past, I just want to be happy.

Meya's *top tips*

1. Allow time to know yourself.
2. Humbly learn from the feet of Elders. Commit to continue their legacy and pass it forward to future generations.
3. Seek mentors who can help guide you along your path.

BUILDING AND TRAINING HUMAN TENDONS IN THE LAB

Tendon issues affect millions of people worldwide, and treatment options are far from guaranteed to be effective. Tissue engineering involves building human tissues in the lab, which can then be used to replace faulty tissues in patients. **Professor Pierre-Alexis Mouthuy**, based at the **University of Oxford** in the UK, is taking this a step further with tendon building, by using humanoid robotic arms and soft bioreactor chambers to 'train' tendons to deal with the stresses they will encounter in the human body.

Professor Pierre-Alexis Mouthuy

Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, UK

PROFILE

Field of research
Bioengineering

Research project
Developing a humanoid bioreactor for tendon tissue engineering

Funders
Engineering and Physical Sciences Research Council (UKRI-EPSRC)
(grant number EP/S003509/1)

TALK LIKE A ... BIOENGINEER

Bioengineering — the application of engineering principles to the fields of medicine and biology

Bioreactor — equipment within which a biological process is carried out

In vitro — (Latin for 'in the glass') used to describe processes taking place in the lab

In vivo — (Latin for 'in the living body') used to describe processes which happen within living organisms

Mechanical — in a bioengineering context, something involving movements, such as rotations, stretches, compressions or twists

Musculoskeletal — relating to muscles and skeletons, especially regarding their interactions

Orthopaedics — the branch of medicine concerning correcting structural issues with the musculoskeletal system

Polymer — a large molecule composed of repeated chains of smaller molecules

Stem cell — a cell that has not yet become specialised and has the potential to become one of many different types of cell

Tendon — soft connective tissue made, mainly, by collagen that attaches a muscle to a bone

Tenocyte — a tendon cell

Tissue — a collection of specialised cells and their products making up a functional part/structure in a living organism

Tissue engineering — a type of bioengineering involving creating in vitro tissues with the intention of restoring or improving tissues in living organisms

Our tendons are strong cords that connect our muscles to our bones, allowing us to move our limbs and absorb some of the impact of movement. While they are extremely tough tissues, their lack of elasticity means they can be relatively easily damaged through intensive exercise and can take a long time to heal. "In the UK, tendon issues are the most common type of musculoskeletal condition for which patients seek medical treatment," says Professor Pierre-Alexis Mouthuy. "They often lead to pain and prolonged periods of disability."

Pierre works at the Nuffield Department of Orthopaedics at the University of Oxford, where his team is working on a pioneering solution to tendon diseases and injuries. He is focusing on the tendons present at the shoulder joint, where current surgical repairs have failure rates of around 40%. In cases where full replacement is needed, tendon tissue may be taken from other parts of the patient's body and grafted in, but this can cause complications at the donor site. Pierre believes that tissue engineering could hold the solution to significantly more successful tendon repair or replacement procedures. "Tissue engineering is a promising strategy that aims to generate grafts for tendons and other tissues in vitro," he says. "This field is still mainly

Presentation of the humanoid bioreactor system during the official opening of the new Biomaterial wing of the Botnar Research Centre by the Queen Consort (formally HRH the Duchess of Cornwall) in January 2022 © Royal Press Office

at the research stage, as we are limited by the replication capacities of existing technologies, but, if successful, it could overcome the problems of tissue grafting from existing donor tissue."

How to build a tissue

Building human tissue from scratch is no simple task. "The first stage involves choosing a type of cell," says Pierre. "This can be either existing tendon cells (called tenocytes) extracted from patients, or stem cells which are then exposed to specific conditions that lead them to become tenocytes." Once the cells are selected, they are encouraged to grow and multiply on a 'scaffold' made of synthetic or natural polymers. "In our research group, we often use a technique called 'electrospinning' which uses electrical charges to create very fine fibres that resemble the natural structure that holds together the tenocytes in tendons in the body," explains Pierre.

An important consideration for growing tissues in vitro is providing an environment that mimics in vivo conditions. This involves the creation of 'bioreactors', which attempt to provide the same chemical and physical properties as the tissue site in the body. Given the role of tendons in movement, creating effective tendon tissue involves a further step. "Cells are able to sense mechanical stresses, and this affects the genes they express, which in turn influences the proteins they produce for both internal use and external secretion," says Pierre. "Adding simple, linear mechanical stimulation to tendon bioreactors is known to improve both the tenocytes and their contribution to their surrounding structure." However, the body's movements – especially at complex joints like the shoulder – do not just happen in one direction. Addressing this is the principal focus of the team's research.

Robot shoulders

"We don't know yet to what extent we need to mimic the body's mechanical conditions to optimise the bioengineering of tendon tissue," says Pierre. "Existing evidence suggests that matching in vitro mechanical conditions more closely to the body is likely to improve the quality of the tendon tissue produced." Mimicking these conditions as closely as possible means building a working shoulder joint, which is where robotics enters the stage.

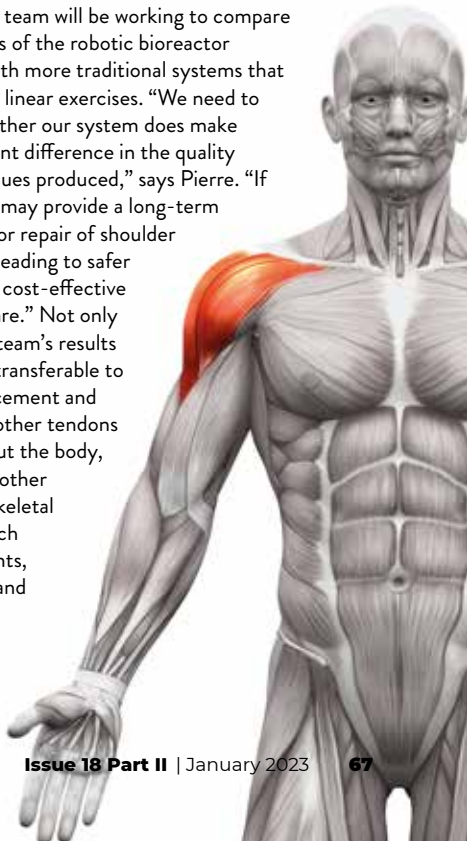
> **"THIS FIELD IS STILL MAINLY AT THE RESEARCH STAGE, AS WE ARE LIMITED BY THE REPLICATION CAPACITIES OF EXISTING TECHNOLOGIES, BUT, IF SUCCESSFUL, IT COULD OVERCOME THE PROBLEMS OF TISSUE GRAFTING FROM EXISTING DONOR TISSUE."**

"We partnered with robotics company Devanthro, which specialises in humanoid robots," explains Pierre. "The main challenge for our team has been to develop a bioreactor chamber that can be combined with a robotic shoulder." To work effectively, the chamber has to be flexible and undergo mechanical stresses in different directions as the shoulder joint moves. "We went through a lot of prototyping to ensure the chamber didn't break and remained sterile during use," says Pierre. "We also had to adapt the robotic shoulder, which was not intended for this kind of application at all!"

Progress and next steps

"So far, we have demonstrated that we can successfully combine bioreactors and mechanical exercise, and that the forces involved do impact the growth and gene expression of the cells," says Pierre. "While this is very preliminary work, the opportunities that this proof-of-concept study opens up are huge." As well as practical experiments, the team has also collaborated with mathematicians and computational engineers to develop computational models that predict the effects of adjusting different parameters, without taking up the time and expense that testing these adjustments in the real world would need.

Next, the team will be working to compare the results of the robotic bioreactor system with more traditional systems that offer only linear exercises. "We need to show whether our system does make a significant difference in the quality of the tissues produced," says Pierre. "If it does, it may provide a long-term solution for repair of shoulder tendons, leading to safer and more cost-effective patient care." Not only that, the team's results could be transferable to the replacement and repair of other tendons throughout the body, as well as other musculoskeletal tissues such as ligaments, cartilage and bone.



ABOUT *BIOENGINEERING*

Bioengineering is where engineering meets medicine. It involves taking the principles of biology and the tools of engineering to create useful products for a variety of applications. As well as tissue engineering, as in Pierre' research, there are many other areas to the discipline, such as:

- Developing prosthetic limbs and other body parts
- Developing pharmaceuticals from biological origins, such as vaccines
- Building medical imaging technology or disease diagnostic devices
- Engineering bacteria to produce specific useful chemicals

"Bioengineering is a broad and ever-expanding field," says Pierre. "I believe there will be an increasing number of opportunities for bioengineers in the future. There is still so much to explore, discover and invent!"

"I BELIEVE THERE WILL BE AN INCREASING NUMBER OF OPPORTUNITIES FOR BIOENGINEERS IN THE FUTURE. THERE IS STILL SO MUCH TO EXPLORE, DISCOVER AND INVENT!"

Pathway from school to *bioengineering*

Pierre recommends considering subjects such as physics, maths, biology and chemistry in school and college. A number of universities run undergraduate courses in bioengineering or biomedical engineering, and careers in the field are also often accessible with relevant qualifications in medicine, engineering or biology.

Pierre suggests talking to people who have studied bioengineering or work in the field to gain a deeper insight into the subject and related career paths. At university, he recommends gaining research experience through lab visits and internships. Reading articles or books related to life sciences will also help develop your interests.

Nicole, a PhD student working with Pierre, recommends looking into opportunities to study abroad. She suggests researching relevant charities, as well as funding specific to certain countries or circumstances. She says you should not be afraid to reach out to research groups in search of practical experience.

Explore careers in *bioengineering*

- There are many resources online exploring possible careers in the field of bioengineering. This page from Imperial College London provides a useful overview: **www.imperial.ac.uk/bioengineering/study/career**
- Pierre' department runs work experience annually, in the summer term, for Year 12 students (mostly from Oxfordshire state schools), with applications open from November to January: **www.ndorms.ox.ac.uk/get-involved/work-experience**
- Pierre' department also runs a monthly online talk about careers in medical research, which are later available on YouTube: **www.ndorms.ox.ac.uk/get-involved/schools**
- According to Prospects, the average entry-level UK salary for a biomedical engineer is around £25,000 to £30,000, rising up to £45,000 or beyond with experience.

How did Pierre become *a bioengineer?*

As a kid, I enjoyed playing sports, board games, guitar and many other things. I grew up in Belgium, so I also spent a lot of time reading comics (which are very popular there), especially those based on science fiction and fantasy. Later, as a teenager, I developed interests in life sciences and astronomy, although I was most interested in spending time with friends!

Science fiction has been a major source of inspiration for me. I have always been fascinated by innovations and visionary ideas around engineering and medicine, regardless of whether they were real or not.

I always remember the advice to "do what you love" when making career choices. Of course, it doesn't mean that you won't have to do some things that you dislike or are difficult, but if you enjoy most of what you do, the rest is manageable!

> **I ALWAYS REMEMBER THE ADVICE TO "DO WHAT YOU LOVE" WHEN MAKING CAREER CHOICES.**

When looking for university courses, I looked for studies in between engineering and medicine, which is how I discovered bioengineering. Following my degree, I gained research experience in biomaterials and tissue engineering through a master's degree and then a PhD. Since then, I've been continuing my journey in research and academia.

My greatest hope for my work is that one day it can be helpful for patients. I enjoy developing new technologies for healthcare applications and have been fortunate to contribute to a few already, even if they are yet to reach clinics. I am also very lucky to have a wonderful team of researchers to work with.

Pierre's *top tip*

Keep the 'beginner's mind', as my Aikido teacher would often say. Experience, knowledge and critical thinking are essential in science, but keeping an attitude of openness, excitement and willingness to learn without preconceptions is also crucial. This can be easily lost as you gain expertise!

Meet Nicole

Nicole Dvorak
PhD student, Nuffield Department of Orthopaedics, Rheumatology and Musculoskeletal Sciences, University of Oxford, UK

I am a final year PhD student in Professor Pierre Mouthuy's research group. Using computational models and in-vitro, I look into the behaviour of the tendon cells within our tissue cultures, focusing on what they consume, whether they have enough oxygen and what happens if we stretch, twist or bend the structures that the cells hold onto.

In school, I disliked physics and was bad at maths. I am dyslexic, so combinations of letters and numbers confused me. It's funny that I now deal with both daily! I liked biology and medicine but never aspired to become a doctor, as I wanted to find a cure rather than administer it. Outside of school, I loved sports and movies. I did not read much, but I loved watching documentaries on TV.

I attended a school focusing on foreign languages. Science only interested me via TV, until my final year when I wrote a small thesis on genetic disorders; that was when the spark turned into a flame. I went on to do a bachelor's and master's degree in medical and pharmaceutical biotechnology in Austria. These courses each included a research semester, so I went to the University of California San Francisco (UCSF), in the US, to do transplant research and the Queensland University of Technology (QUT), in Australia, to do tissue engineering. The latter topic fascinated me because of the body's ability to heal and because it involved engineering.

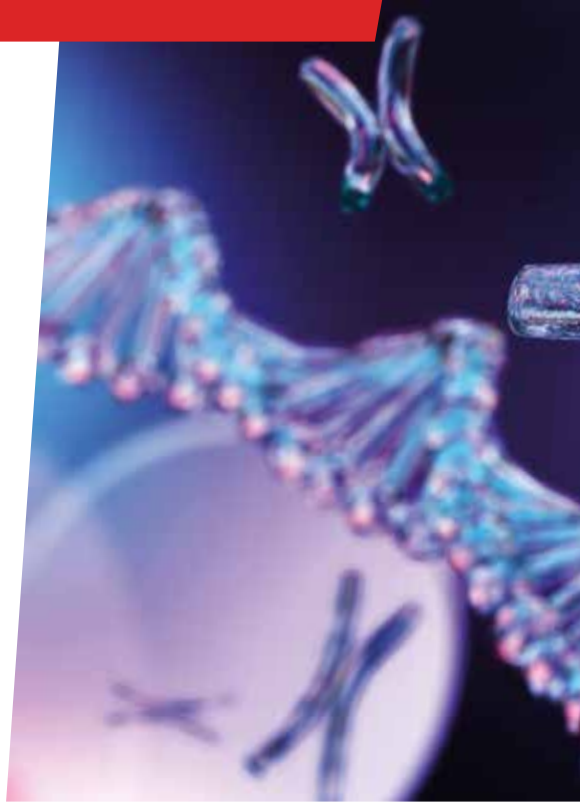
Some days, I get up at 5am to go rowing, before going to work at 9am. Other days, I work from home. I have a disability, which means I need to be flexible and listen to my body. My days include planning and conducting experiments, analysing data, writing scientific papers about our results and writing my PhD thesis. I am also on committees to spread awareness of disability issues within the university.

Whether because of a question from a colleague or some unexpected experimental results, every day is challenging in a different way. That is the nature of research; we are working at the edge of our knowledge, which is what makes it exciting and rewarding.

I'm very proud of where I am now. The odds of me getting into university were not high, but I've always found science inherently fascinating. After I was diagnosed, I found Stephen Hawking especially inspirational.

Nicole's *top tips*

1. Everyone's timeline is different. Do it your way**.**
2. Be ambitious.
3. Ask questions unapologetically.



WHY DO MALES AND FEMALES HAVE DIFFERENT RISKS OF DISEASE?

While males are more likely to develop cancer than females, most autoimmune diseases are more prevalent in females. For cardiovascular diseases, not only do males have a higher risk, but how the diseases present is also different than in females. **Dr Nora Engel**, a molecular geneticist at **Temple University School of Medicine** in the US, is examining sex differences in gene expression and DNA modifications to determine why this is the case.

Dr Nora Engel

Associate Professor, Department of Cancer Biology, Fels Cancer Institute for Personalized Medicine, Temple University School of Medicine, USA

PROFILE

Field of research
Molecular Genetics

Research project
Investigating the genetic and epigenetic differences between males and females

Funder
US National Science Foundation (NSF)

This work is supported by the NSF, under award number 330588. The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NSF.

TALK LIKE A ...

MOLECULAR GENETICIST

Autoimmune disease — a disease in which the immune system attacks healthy cells

DNA — the molecule that stores genetic information in living cells

Epigenetic mark — a process that alters gene expression but does not change the DNA sequence

Gene — a section of DNA

Gene expression — the process by which an organism's genetic information is used to produce end products, such as proteins, that influence the functioning and physical characteristics of the organism

Genomic — relating to the genome (the complete set of genetic material in an organism)

Hormone — a chemical messenger in an organism

Protein — a complex biological molecule, playing a variety of essential roles in living organisms

RNA — the molecule produced during gene expression that contains copies of a gene

Sexual dimorphism — when an animal species displays physical differences (not including the reproductive organs) between the sexes

Stem cells — non-specialised cells that, in an organism or in a lab, can grow into specialised cells

Transcription — the process of converting genes from DNA into RNA

Transcription factor — a protein that enables transcription

Have you ever wondered why male ducks are brightly coloured, while females are drab and brown? Although the aim of both sexes is to reproduce, the male's role is to attract a mate, requiring it to be colourful and attractive, while the female's role is to safely raise the young, requiring it to be camouflaged from predators. This is an example of sexual dimorphism, where there are physical differences between males and females of the same species, and it results from genetic differences between the sexes.

Lions are another example of a species that displays clear sexual dimorphism. A male lion's genes cause it to grow a mane, while a female lion's genes do not. Like all mammals, every cell in the human body has differences in gene expression between males and females. "Depending on the tissue, these differences can be subtle or substantial," says Dr Nora Engel, a molecular geneticist at Temple University School of Medicine. "There are striking sex differences in gene expression in the brain, liver and muscles, but male and female gene expression is less divergent in the heart." Nora is leading a team of researchers to uncover the genetic differences between males and females, and she hopes her research will help scientists understand how these differences impact sex-specific differences in health.

How do male and female genes impact risk of disease?

Males are at higher risk of certain diseases than females, while females are more likely to develop other conditions than males. For example, a male has a one in two chance of being diagnosed with cancer during their lifetime, while for females, the chance is one in three. However, lupus (an autoimmune disease)

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is more common in females; nine out of ten lupus patients are female.

"Unfortunately, we know very little about the impact that gene expression sex differences have on the risk of specific diseases," says Nora. "A major goal of our lab is to bridge the gap between the molecular differences between males and females and the well-established sex biases in disease."

What influences gene expression?

All living organisms have genes, which are responsible for the characteristics of that organism. DNA, the molecule that instructs cells how to function, is composed of these genes, and humans have over 20,000 genes inside every cell. The process of gene expression enables the genetic information stored in DNA to be converted into functional products, such as proteins, that influence the organism's physical traits. Gene expression occurs by transcription, in which genes are copied from the DNA into molecules called RNA, by proteins known as transcription factors.

One process that regulates gene expression is DNA methylation, whereby a methyl group (one carbon atom and three hydrogen atoms) is added to a DNA molecule. "DNA methylation determines whether DNA is available for binding to transcription factors," explains Nora. If the protein cannot bind to the DNA, then transcription of certain genes will be hindered.

DNA methylation is an example of an epigenetic mark, as it changes the DNA structure and the physical trait outcomes, but it does not alter the DNA gene sequence. Scientists have observed that DNA methylation varies widely between males and females, resulting in epigenetic differences between the sexes. "However, there is a huge gap between characterising sex differences in gene expression and epigenetic marks, and tying them to specific sex disparities in disease," says Nora. As yet, scientists do not know how soon after fertilisation these molecular differences appear, or how they vary across a person's lifespan.

> **"A MAJOR GOAL OF OUR LAB IS TO BRIDGE THE GAP BETWEEN THE MOLECULAR DIFFERENCES BETWEEN MALES AND FEMALES AND THE WELL-ESTABLISHED SEX BIASES IN DISEASE."**

"Therefore, our goal is to characterise sex differences in gene expression, from the earliest stages of embryonic development all the way to adulthood," says Nora. "Our hypothesis is that some of the sex differences we see in adult diseases will be explained at the molecular level, and that some of these molecular differences are established in the early stages of embryonic development and then persist into adulthood."

What challenges must Nora overcome?

Nora's experiments cannot be conducted in humans, so she uses animal models instead. "A key part of our research involves working with male and female mouse embryonic stem cells," she says. By manipulating the genes of these mouse cells, Nora and her team of molecular geneticists have shown that male and female cells express RNA in different ways, and they are now testing how these differences affect epigenetic patterns. However, although embryonic development is similar in all mammals, some of the team's findings may not be translatable from mice to humans.

Moreover, an obstacle to understanding sex differences is that there are two factors that contribute to them: the difference in sex hormones between males and females, and the genetic differences arising from the sex chromosomes, i.e., XX in females and XY in males. Disentangling these two components is a major challenge and requires using genetically engineered mice.

Another challenge is that Nora and her team conduct a lot of DNA and RNA sequencing, allowing them to establish which genes are expressed in male and female mouse cells. Despite being much smaller than humans, mice have a similar number of genes to us, meaning that each DNA sequence contains a huge amount of data. "This genomic data must be analysed by a bioinformatician, but there are very few of these highly specialised scientists," explains Nora. "This means we have a long wait each time we need to get data analysed."

What has Nora discovered?

Nora has initially focused on studying the differences in the hearts of male and female mice. "We have found sex differences in gene expression and epigenetics across all stages of life," she says of this work. While some of these differences begin early in embryonic development and persist into adulthood, other differences disappear later in life. Some of the molecular differences between males and females do not occur until the mouse has grown and sex hormones start to circulate.

The team is now analysing the data to determine what sex-specific networks are driving the differences between male and female cells and how they relate to heart physiology and vulnerabilities. "We are also about to start a new project investigating sex differences in cancer," says Nora.

After establishing the genetic and epigenetic differences between male and female mouse cells, Nora's next challenge will be to determine how this knowledge relates to humans, helping scientists uncover the reasons behind sex disparities in disease.

ABOUT *MOLECULAR GENETICS*

Molecular genetics involves studying the molecular structure of genes. If the molecular structure of a gene, or the protein it produces, is different to what it should be, then it will not function correctly in the body. This results in disease. For example, cystic fibrosis, congenital deafness, sickle cell anaemia and many types of cancer are all caused by mutations in a person's genes. The field of molecular genetics is, therefore, essential for human health and well-being.

What do molecular geneticists do?

While Nora is applying her skills to investigate the genetic differences between males and females, other geneticists explore how genetic mutations result in the symptoms observed in genetic diseases. The development of molecular techniques and genetic engineering means that scientists can now genetically manipulate cells and artificially modify an organism's DNA, enabling them to understand the molecular mechanisms by which genes are regulated. Advances in genomics have allowed scientists to determine the underlying causes behind diseases, paving the way to a greater understanding and treatment of genetic conditions.

The joys of genetic research

According to Nora, the best thing about her job is that no two days are the same. "I love inspiring the people in my lab and seeing the spark in their eyes when they become infected with the urge to dive into research!" she says. Nora also likes running her lab and training the next generation of scientists. "I enjoy being a small part of the incredibly exciting enterprise that is science, especially in a new field that is full of exciting questions and discoveries."

What does the future hold for molecular geneticists?

"Traditional genetics has undergone an incredible transformation," says Nora, referring to the advances in technology that have revolutionised the field in the last couple of decades. "This transformation will require the next generation of scientists to have the skills to deal with the huge amounts of data being generated. It will also open amazing opportunities for new hypotheses to be tested."

Pathway from school to *molecular genetics*

- At school, biology classes will introduce you to the fundamentals of genetics, mathematics classes will teach you about statistics and you will learn coding in computing classes, all of which is key knowledge for molecular geneticists.
- Post-16 and at university, consider studying biology, molecular biology, genetics or human biology if you are interested in a career in molecular genetics.
- "Most importantly of all, find work experience in a lab with a good leader," advises Nora. "See how you feel when conducting real experiments."

Explore careers in *molecular genetics*

- As a geneticist, you could find yourself working in a research lab conducting genetics experiments or in a clinical lab testing patients for genetic conditions.
- The National Human Genome Research Institute (NHGRI) provides a wealth of information about genetics and genomics and the research currently being conducted (**www.genome.gov/About-Genomics/Introduction-to-Genomics**). NHGRI also has numerous educational resources for students and teachers (**www.genome.gov/About-Genomics/Educational-Resources**) and provides information about careers in the field (**www.genome.gov/careers-in-genomics**).
- The Genetics Society of America (GSA) blog, *Decoding Life*, features geneticists following a diverse range of career paths (**www.genestogenomes.org/tag/decoding-life**). GSA also provides educational resources, including classroom- and lab-based genetics activities for schools (**www.genetics-gsa.org/education**).
- The University of Utah has produced tutorials about genetics (**learn.genetics.utah.edu**).

Q&A

Meet Nora

What inspired you to become a scientist?

While studying at university, I loved genetics and biochemistry, but I never considered a career in research until after I graduated. I took an opportunity to work in a lab, even though I wasn't specifically interested in the project. Working alongside the project leader, getting involved in the day-to-day running of experiments and fitting our results into the bigger picture sparked my curiosity in a way that nothing else ever had. So, I channelled my energy into finding a path that would allow me to combine my newfound passion with my interest in genetics.

Who has been influential in shaping your career?

My thesis director, Dr Elena Rivera, was an amazing role model. She was calm and dedicated, and has been essential in my career path. I worked in Dr Francisca Sanchez-Jimenez's lab in Spain, where both she and Dr Miguel Angel Medina were instrumental in giving me the confidence to become a scientist. I then worked in Dr Marisa Bartolomei's lab in the US. Marisa gave me the opportunity to work in the field I was passionate about, showed me how to do excellent science and was an incredible mentor. Throughout my career and to this day, Dr Rosa Bergoc of the University of Buenos Aires in Argentina has been my ultimate role model, as a consummate scientist, passionate teacher, and kind and skilful leader.

How do you overcome obstacles in your work?

When an experiment fails, or my papers or grants get rejected, I allow myself to get angry and maybe even cry for one day, and then I move on and ask my colleagues for advice to figure out the solution. Research comes with uncertainty and setbacks, so scientists must be resilient to overcome rejection and failure.

What are your proudest career achievements, so far?

I am proud of my time in the Genetics Department at the University of Buenos Aires, Argentina. Against all odds, I managed to start a lab, recruit fun and driven students, design a research project and see it come to fruition. I am also proud to be working at the forefront of the new scientific field of sex differences and to be one of its pioneers.

What are your ambitions for the future?

In my research lab, I hope to train new generations of scientists and constantly have interesting questions to investigate.

What makes a successful scientist?

In my opinion, the best scientists are not necessarily the ones who make the best discoveries but are the ones who ask the best questions. New research fields are opened when people ask interesting questions that have never been asked before.

> **THE BEST SCIENTISTS ARE NOT NECESSARILY THE ONES WHO MAKE THE BEST DISCOVERIES BUT ARE THE ONES WHO ASK THE BEST QUESTIONS.**

I am inspired by the following quote from Sir Peter Medawar (a Brazilian-born British scientist) as it encapsulates the broad range of possibilities in science: "There is no single 'scientific mentality'. Among scientists, there are collectors and classifiers, many are detectives, many are explorers, some are artists and others are artisans. There are scientists who are poets and scientists who are philosophers, there are even some mystics. Most scientists could easily have been of another profession."

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Nora's *top tips*

1. Always ask questions, and try to think of new questions that have not yet been asked.
2. Read broadly, and keep an open mind. Many new ideas come from reading outside your own field.

LIGHTING UP CANCER: INNOVATION IN PAEDIATRIC SURGERY

Surgically removing cancer tumours can be a risky procedure – bodily tissues that the cancer grows on can be damaged in the process, and leaving any part of the tumour behind can lead to the cancer coming back. **Dr Stefano Giuliani** and his team at the **University College London (UCL) Great Ormond Street Institute of Child Health** in the UK are developing a ground-breaking technique that literally 'lights up' the cancer cells, making removal much easier.

Dr Stefano Giuliani

Consultant Neonatal and Paediatric Surgeon at Great Ormond Street Hospital, Associate Professor at UCL Great Ormond Street Institute of Child Health, Co-Investigator at the Wellcome/EPSRC Centre for Interventional and Surgical Sciences (WEISS), London, UK

PROFILE

Fields of research
Neonatal and Paediatric Surgery, Cancer Research

Research project
Using fluorescent antibodies to clearly distinguish tumours, allowing safer and more precise surgery for treatment of neuroblastoma in children

Funders
Medical Research Council (grant reference MR/T005491/1), Wellcome Trust-Innovator Award (grant reference 222111/Z/20/Z) Wellcome/EPSRC Centre for Interventional and Surgical Sciences at University College London (WEISS, grant number 203145Z/16/Z), GOSHCC cancer infrastructure award

TALK LIKE A ...
NEONATAL AND PAEDIATRIC SURGEON

Antibody — protein molecules found in the blood that aid the recognition of pathogens and other harmful substances

Biomedicine — the branch of medicine that involves applying biological and biochemical research to medical research and practice

Cancer — a disease in which certain cells in the body grow uncontrollably and spread to other parts of the body

Fluorescence — the emission of light by a substance that has absorbed light or other electromagnetic radiation

In vitro — a process that takes place outside of a living organism (e.g., in a tissue culture dish)

Neonatal — relating to newborn children

Neuroblastoma — a type of cancer that forms from certain immature nerve cells

Paediatric — the branch of medicine relating to children and the diseases that affect them

Tissue — any of the materials that make up the body (e.g., specialised cells and their products)

Tumour — a mass of tissue formed when cells grow uncontrollably and which can be benign or malignant

Cancers come in a wide array of shapes and sizes and can affect different parts of the body in different ways. High-risk neuroblastoma is a type of cancer that occurs principally in babies and young children. It affects around 100 children every year in the UK and in its more aggressive form has a low survival rate. Neuroblastoma occurs when specialised nerve cells, called neuroblasts, are left behind from the child's time in the womb and become cancerous. "High-risk neuroblastoma is an aggressive cancer, which has often spread to multiple organs by the time of diagnosis," says Dr Stefano Giuliani. Stefano is a surgeon at UCL Great Ormond Street Institute of Child Health (ICH) in London. He is working on a pioneering research study that could dramatically improve survival rates for children with this cancer.

Challenges of surgery

Treatment for neuroblastoma involves surgically removing the entire tumour, but this is a challenging task even for the most experienced surgeons. "The neuroblastoma grows around the largest and most critical vessels, nerves and organs in the body," explains Stefano. "This raises the risk of damaging these tissues during surgery, which can lead to dangerous situations such as severe bleeding."

Currently, it is not easy to tell the difference between cancerous tissue and normal healthy tissues during surgery, which is why this procedure is so challenging. "There is a need to develop a tumour-specific detection strategy

> **THERE IS A NEED TO DEVELOP A TUMOUR-SPECIFIC DETECTION STRATEGY TO HELP SURGEONS EASILY SEE TUMOUR CELLS VERSUS NORMAL ANATOMICAL STRUCTURES.**

to help surgeons easily see tumour cells versus normal anatomical structures," says Stefano. This need forms the foundation of his research project.

Fluorescence-guided surgery

Fluorescence-guided surgery (FGS) could provide the solution to solving this issue. "FGS is possibly one of the greatest innovations in surgery," says Stefano. "We are developing specific fluorescence probes which can clearly highlight cancer cells." Fluorescent molecules are those that 'light up', emitting a certain wavelength of light when exposed to either visible light or other wavelengths such as ultraviolet or infrared.

These fluorescence probes are formed using a clever biochemical technique. The main way the body's immune system naturally detects pathogens or cancers is via the use of antibodies – molecules whose shape matches other molecules only found on the surface of specific harmful cells. Biomedical scientists have found the antibody specific to neuroblastoma and can modify this in the lab to attach a fluorescent particle to it.

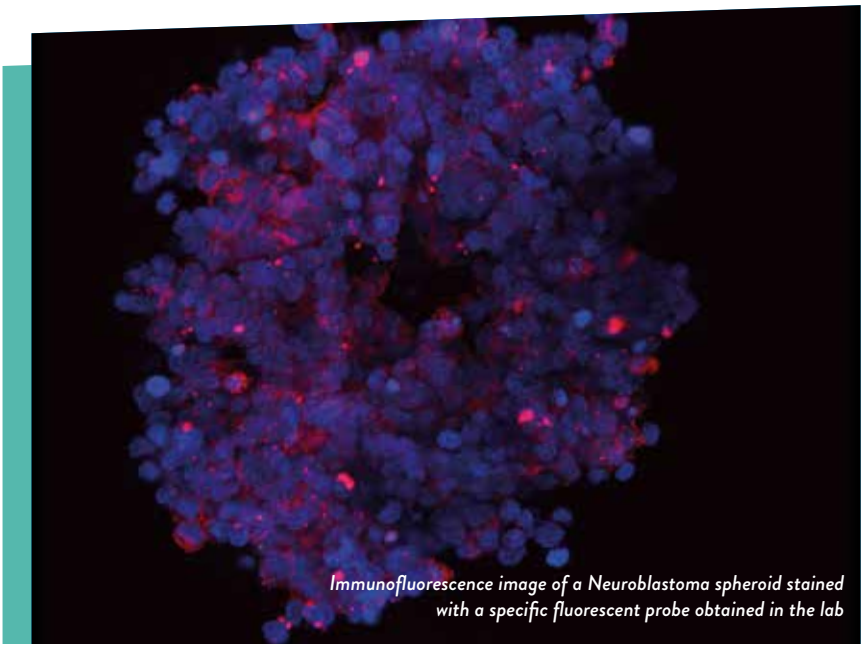
When these modified antibodies are introduced to the body, they attach to the neuroblastoma cells and nowhere else. This means that when the tumour is exposed during surgery, it is literally 'lit up' against surrounding tissue by all the fluorescent molecules attached to it. For surgeons, this makes it much easier to distinguish cancerous cells from healthy cells and remove the tumour accurately. High-resolution scanners can be used to detect any leftover cancer cells not visible to the naked eye, making surgery as comprehensive as possible.

Progress and next steps

"We have obtained good data in vitro and in animal models for this technique," says Stefano. "We are about to submit an important paper to publish these results." 'In vitro' refers to experiments not performed on living organisms, using cancer cells grown in the lab. Typically, this is the first step of testing new medical techniques, which precedes testing on animals, which precedes testing on humans.

Once in vitro experiments had been completed, the team moved on to using FGS to remove neuroblastoma in mice. "Animal models are essential to obtain meaningful data before using the same technologies in humans," says Stefano. "Now, the next step will be to translate our findings to humans in a clinical trial."

The team hopes this new technology will be saving children's lives within five years. "Surgery will be more precise, leaving less cancer behind and bringing benefits to rates of survival and recovery from surgery," explains Stefano. "Patients will receive less extensive and more targeted surgery, with less risk of complications." By removing the smallest parts of the tumours, it is expected that recurrence will be much reduced. In time, this technique could be extended to treat many different types of cancer, potentially saving many lives worldwide.



Immunofluorescence image of a Neuroblastoma spheroid stained with a specific fluorescent probe obtained in the lab

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ABOUT *NEONATAL AND PAEDIATRIC SURGERY*

Neonatal and paediatric surgery involves surgery specific to babies and children. Often, the conditions they face, and the appropriate treatments, differ to those for adults, which has led to the development of these specialised fields. Like many medical professionals, the work of neonatal and paediatric surgeons like Stefano is typically split between treating patients and performing research.

"A particularly skilled professor of surgery inspired me when I was a medical student in Italy. His surgical skills, humanity and determination made me willing to pursue a career in academic surgery," says Stefano. "I love my job, and I believe passion and dedication are essential to succeed in any career."

The Great Ormond Street ICH is world-famous for leading the way in paediatric care, and Stefano's work is contributing to this reputation. "One of my proudest achievements is having developed an independent research group on image-guided surgery," he says. "This has been my dream for many years, and I obtained it with the support of ICH and my academic mentors, Professor Anderson and Professor De Coppi."

Though there have been many advances in the field, both in terms of knowledge and technologies, Stefano believes there is a lot more progress to be made, presenting exciting opportunities for the next generation. "Paediatric and neonatal surgery is one of the most fascinating fields in medicine," he says. "There is a lot to discover in complex fields such as foetal development, congenital anomalies, rare diseases and cancers."

"PAEDIATRIC AND NEONATAL SURGERY IS ONE OF THE MOST FASCINATING FIELDS IN MEDICINE."

Pathway from school to *neonatal and paediatric surgery*

"A strong foundation in biology, mathematics and computing is essential for the medical careers of the future," says Stefano. "Artificial intelligence, digital surgery and rapid pace innovations are increasingly driving forward medicine and biomedical research."

"A strong background in biology is a must," says Laura. "I would also encourage broadening your knowledge of statistics, chemistry and physics."

"The lines between the traditional science subjects are becoming increasingly blurred," says Dale. "Most challenges require expertise from multiple disciplines, so I would recommend taking a broad range of subjects. Learning maths and learning to code are becoming especially central to all scientific endeavours."

Explore careers in *neonatal and paediatric surgery*

- Stefano recommends shadowing a paediatric surgeon to see whether you like the type of work they do, and then ask for research projects in the field. He suggests contacting a local academic paediatric surgeon to kickstart this process. The British Association of Paediatric Surgeons has a public directory: **members.baps.org.uk/search/custom.asp?id=5498**
- Dale emphasises the importance of communication for any area of science. He recommends learning to communicate with others, both within your area of expertise and those in the wider world. This podcast from THIS.Institute explains more: **www.thisinstitute.cam.ac.uk/podcast/communicating-and-disseminating-research**
- Laura points to PubMed (**pubmed.ncbi.nlm.nih.gov**) as the go-to resource for researching specific medicine-related topics. She also recommends following blogs and watching webinars to keep up-to-date with the latest advancements in the field.
- UCL Great Ormond Street Institute of Child Health offers work experience, talks for medical students and engagement sessions with patients and parents. Find out more: **www.gosh.nhs.uk/working-here/gain-experience-us**

Meet *the team*

Dale and Laura both work in Stefano's research group. They talk about their roles on the project and how their backgrounds led them to their current positions.

Dr Dale Waterhouse

Wellcome / EPSRC Centre for Interventional and Surgical Sciences (WEISS), London, UK

My role in the group is to help develop biomedical imaging devices (specialised cameras). Elsewhere, my biomedical imaging work leads to me contributing to research into neurosurgery, laparoscopic surgery and endoscopy.

I didn't really enjoy science until I was in my final year of school. Around this time, scientists in Geneva were planning to switch on the newly constructed Large Hadron Collider; in my

A-level science class there was an uncharacteristic buzz of excitement. My passion for science grew as I read popular science books. These revealed new realms of science – time travelling twins, evolutionary battlefields, warping fabrics of reality – concepts absent from the relatively dry school curriculum. From then, I knew I wanted to learn more.

I've tended to seek projects I enjoy and work with people I get along with, trust or admire. Following my degree, I applied for a prestigious PhD programme in particle physics, but I didn't get a place. In retrospect, this was a fortuitous 'failure'. It led me to a PhD position with a young, upcoming professor I respected and admired – in her lab, I found opportunities to grow and develop into a better scientist. For this, I am very thankful.

Research is time consuming, and things don't always work as initially planned. I am constantly challenged to evolve my thinking and generate new approaches to solving problems. Sometimes these challenges are scientific, but often they are operational challenges like acquiring funding, troubleshooting equipment failures or finding a bug in my code.

Learning about a clinical challenge and then working with a team to generate bold new ideas is the most engaging part of my work. It takes many months, sometimes years, of hard work for these ideas to become reality, but when they finally do, it is very rewarding. The most rewarding is yet to come, when one day, hopefully, these advances make their way into routine care and change the lives of patients.

My proudest career achievement, so far, is when my PhD thesis was published as a book.

In the long term, I would like to be a professor of biomedical imaging, leading a multidisciplinary research team towards advancing surgical imaging techniques.

A typical day for me in three words? "That was unexpected!"

Dr Laura Privitera

UCL Great Ormond Street Institute of Child Health, Developmental Biology & Cancer Department, London, UK

Centre for Interventional and Surgical Sciences (WEISS), London, UK

I initially joined the group as a Clinical Research Fellow, and I have very recently embarked on a three-year PhD on image-guided surgery. I have only been working in this field for two years, so the biggest asset I bring to the group is my passion and determination.

During my final year at university, I had the amazing chance to work at the Great Ormond Street Hospital. It was the academic clinicians that I had the opportunity to work alongside during my internship that really inspired me to pursue a career in research. The people I worked with are internationally renowned, and this was an incredibly important opportunity for my personal and academic growth. I enjoyed the experience so much that I applied for a research position after graduating. I am only at the beginning of my research career, but I believe that what we are working on is truly ground-breaking.

In this line of work, you are challenged daily. There is always a new experiment or a new procedure to learn, and this can be both exciting and overwhelming at times!

Being part of a multidisciplinary team like ours has given me the opportunity to be involved with different projects that have resulted in publications and presentations at conferences. It has also been an exceptional opportunity to create new connections and expand my knowledge.

I am proud of being awarded the "Peter Paul Rickham prize for the best basic science paper" at the international congress of the British Association of Paediatric Surgeons (July 2022).

My ambition is to be an academic paediatric surgeon with a special focus on innovation in cancer surgery. I believe the field of surgical oncology will experience significant advances, and I want to be ready for this change.

The three words that describe a typical day for me are engaging, challenging and rewarding!

The team's *top tips*

1. Try to pursue the things you love. If you don't love it, you won't spend time on it.
2. You will inevitably encounter obstacles and bad days along the way. Always keep in mind the end goal to never lose focus.
3. Study hard and dream big. You cannot do high quality research unless you are a dreamer.

HOW CAN SCIENTISTS IMPROVE THE WELL-BEING OF PATIENTS WITH LUPUS?

Systemic lupus erythematosus (SLE) is a disease without a cure. But, thanks to discoveries by **Professor George C. Tsokos**, a rheumatologist at **Harvard University** in the US, new treatments are on their way to improve the quality of life for patients.

Professor George C. Tsokos

Chief of Rheumatology and Clinical Immunology, Beth Israel Deaconess Medical Center, Boston, USA

Professor of Medicine, Harvard Medical School, USA

PROFILE

Field of research
Rheumatology

Research project
Uncovering the molecular mechanisms that cause lupus in order to find new treatments for the disease

Funders
National Institutes of Health (NIH), Alliance for Lupus Research

TALK LIKE A ...

RHEUMATOLOGIST

Autoimmunity — when the immune system attacks healthy cells in the body

Epigenetic — environmental (rather than genetic) factors that affect how genes function

Immune system — your body's defences against infection

Inflammation — a process by which the immune system fights invaders. Symptoms may include swelling and pain

Pathogen — something that causes disease, such as bacteria and viruses

Protein — a complex biological molecule that performs specific functions in the body

Rheumatology — the branch of medicine that studies and treats diseases that affect the muscles, bones, ligaments and tendons

T cell — a part of the immune system, trained to attack a specific pathogen

Tissue — a group of similar cells that work together as a unit, e.g., muscle tissue

Imagine your body is a castle. Your immune system is a team of guards, carefully patrolling the corridors to check for intruders. These guards are highly trained and know how to spot invading enemies, such as viruses or bacteria, and distinguish them from those who live in the castle, i.e., your own organs. When the guards encounter someone who should not be there, they quickly learn how to neutralise the threat, keeping the castle safe and secure.

But what if your guards turned against you? Imagine if, instead of attacking intruders, the guards started to fight the castle occupants. Not only would this cause damage and destruction to the castle, but it would leave the door open for enemies to sneak in.

Something similar can happen to a real human immune system, in a process known as autoimmunity. Instead of just attacking harmful viruses and bacteria, the immune system will sometimes turn on healthy cells in the body and attack them, too. This can result in autoimmune diseases such as Type 1 diabetes, rheumatoid arthritis and multiple sclerosis. Professor George C. Tsokos, a rheumatologist at Harvard Medical School and Beth Israel Deaconess Medical Center, has dedicated his career to researching one such autoimmune disease – systemic lupus erythematosus (SLE), a form of lupus.

What is lupus?

Although the name 'lupus' is Latin for 'wolf', the disease does not have much to do with wolves. It was named this in the 13th century, by a doctor who found some patients developed a rash on their face that looked like a wolf bite.

While cutaneous lupus only affects the skin, resulting in rashes and sores, SLE, the most common form of lupus, can affect any part of the body. The immune system in a person with SLE may attack any healthy tissue, including their internal organs, causing inflammation of the tissue and its eventual death. People with lupus tend to have sore and swollen joints and feel very tired all the time, no matter

how much they rest. It is also common for them to experience chest pain, rashes, headaches, fevers, swollen legs and hair loss, though different people will be affected by lupus in different ways.

As the disease can affect so many different body parts, and there are so many different symptoms, treatments must be tailored for each individual to help them manage their unique condition. While there is no cure for lupus, modern treatments have dramatically improved the well-being and life expectancy of people with the disease. Today, 80% of patients will live for more than 10 years after diagnosis. "Infections are the main cause of death for patients with SLE as the immune system struggles to recognise and fight pathogens," explains George.

What causes lupus?

Although it is estimated that five million people worldwide live with lupus, the specific causes are still unknown. Unlike diseases such as COVID-19 and tuberculosis (TB), you cannot catch lupus from someone else, as it is not caused by viruses or bacteria. Instead, many scientists think lupus develops due to a combination of genetic and environmental factors.

"Nine out of ten lupus patients are female," says George. "This signifies the importance of hormones and sex chromosomes in the expression of the disease." Severe lupus is also more common in females of African, Hispanic and Asian descent, although it is unclear why. "We believe this is due to a combination of genetic and socioeconomic factors," he explains. "The higher mortality in these demographics may be impacted by racial disparities in certain communities."

What are T cells?

If your immune system is a team of guards, then your T cells are special agents. They are components of the immune system trained to fight pathogens, with each T cell specially equipped to recognise a particular invader of the body. T cells move around the body looking for the specific pathogen they have been trained to fight and, if they detect it, they attack any infected cells and communicate with the rest of the immune system to mount a response.

However, when someone has an autoimmune disease, such as lupus, their T cells become confused. They lose their ability to discriminate between healthy cells and infected ones, so the immune system starts to fight healthy tissue, and the body essentially attacks itself.

How does George study lupus?

George and his research team take blood and tissue samples from patients with lupus to investigate which genes and molecules they contain. Through their research, they have discovered that the T cells in people with lupus do not produce a protein called interleukin 2 (IL-2), responsible for controlling inflammation, and produce too much of a protein called interleukin 17 (IL-17), responsible for causing inflammation.

Once the team establishes which molecules need further investigation, the researchers genetically engineer mice to produce the same molecules and test whether these mice develop lupus. This confirms whether the molecules of interest play a role in the development of the disease. After this confirmation, the team returns to patients to improve treatments based on their findings.

> "NINE OUT OF TEN LUPUS PATIENTS ARE FEMALE. THIS SIGNIFIES THE IMPORTANCE OF HORMONES AND SEX CHROMOSOMES IN THE EXPRESSION OF THE DISEASE."

How is George's research benefitting patients?

"One of the major discoveries in my lab has been the identification that a gene called CREM plays a role in protein expression in lupus patients," says George. "We have shown that through distinct molecular and epigenetic processes, CREM suppresses the expression of IL-2 while it promotes the production of IL-17." When mice were made to overexpress CREM, they did not produce IL-2 and produced more IL-17, while CREM-deficient mice did not develop autoimmunity. These findings are paving the way for new treatments for lupus patients.

George's team has shown that administering low doses of IL-2 to mice with lupus reduces their level of autoimmunity and reduces their symptoms. Clinical trials are now in progress to test whether the same outcomes occur in humans. Early results appear promising, with low doses of IL-2 providing clinical benefits to patients with lupus.

The team has also shown that IL-17 contributes to organ inflammation in people and mice with lupus. "We have discovered that the T cells that produce IL-17 are present in the kidneys of people and mice with lupus," explains George. As a result of this work, clinical trials are currently ongoing to test whether it is possible to block IL-17 in people with lupus, and whether this will deliver clinical benefits to them. Other work has involved defining the molecular mechanisms that prevent lupus T cells fighting pathogens, leading to increased risk of infection in lupus patients and demonstrating that it is possible to restore the ability of these T cells to fight pathogens using precision nanotechnology approaches. By dedicating his career to studying lupus, George is improving the lives of the millions of people who live with this devastating disease.

ABOUT *LUPUS RESEARCH*

As one the world's leading experts on lupus, George has uncovered key knowledge about the disease. However, there are still many questions about lupus that remain unanswered. "We need to focus on achieving a better understanding of the great heterogeneity of the disease as every patient experiences lupus in a different way," he says. "We know that many mechanisms are involved, but we need to understand which ones are responsible for the development of the disease in each patient." If this could be determined, it would enable improved precision medicine, whereby each patient could receive personalised treatment for their specific lupus conditions and symptoms.

Other aspects of lupus also need further exploration. We do not yet know what happens inside different organs to cause inflammation, or how the body's central nervous system reacts to try and control this. Advances in technology are allowing scientists to study how remote elements in chromosomes interact to cause lupus and to investigate the molecular signatures of cells in various organs, which may shed light on some of these gaps in our understanding.

Could there be a cure for lupus one day?

The clues to how lupus manifests in patients could be hidden deep inside human DNA. Finding out exactly how certain genes lead to the disease will require many more years of careful study. Once we understand this, George thinks the knowledge could lead to a whole host of new treatments. "With the advent of gene editing tools, we may dream of offering such approaches to treat people with lupus," he says. It is too soon to say whether a complete cure for lupus will be possible, but this approach could combat the genetic causes of the disease.

Who will help improve our understanding of lupus?

Improving the lives of people with lupus requires a team effort of scientists and clinicians in a range of fields. Molecular biologists and biochemists are needed to determine the reactions that occur within cells, geneticists are needed to uncover which genes are responsible for the disease, and scientists with skills in gene editing will attempt to prevent lupus from developing in people who may be susceptible.

Epidemiologists and social scientists are required to understand how socioeconomic factors influence the impacts of lupus in different populations. George believes that artificial intelligence will play an increasingly important role in studying lupus, so computer scientists and statisticians will also contribute to future research.

The healthcare professionals who work with patients with lupus are key to this mission. From general practice doctors to rheumatologists, nurses to clinical trial researchers, these people are the ones who will diagnose the disease, care for patients and test new treatments in the years to come. How could you help improve the lives of people with lupus?

Explore careers in *lupus research*

- As with any disease, researching lupus requires working with people who have the disease, as they are the experts on how it impacts their life. The Lupus Foundation of America (LFA) has information about the range of research studies it is supporting, including current clinical trials for new lupus treatments: **www.lupus.org/advancing-research/get-involved-in-research**
- LFA also offers internships for university students: **www.lupus.org/about-us/careers-and-internships**
- Learn more about the research conducted in George's lab: **www.bidmc.org/research/research-by-department/medicine/rheumatology/tsokos-lab**

Pathway from school to *lupus research*

- Study science subjects at school and college. A strong foundation in biology and chemistry is essential for understanding lupus, and knowledge of maths and statistics is necessary for analysing data.
- As improving our understanding and treatment of lupus requires scientists from a range of fields, many university degrees could lead to a career in the field. These include biochemistry, molecular biology, bioinformatics, genetics, biotechnology, epidemiology, public health and pharmacology.
- If you are interested in working directly with patients, you could study medicine or nursing to pursue a clinical career.

Q&A

Meet George

Who inspired you to become a doctor?

There was a doctor in my family, and, growing up, I had watched him work in his clinic and operating room. I liked the aura he displayed when helping people with their problems. I entered medical school in Athens, where I studied immunology, statistics and clinical medicine. I had the good luck to be taught by professors who were not only great clinicians, but also outstanding researchers. Listening to them talk about both clinical events and the underlying mechanisms made me want to become both a doctor and researcher.

And what led you to specialise in lupus?

My first patient in my first clinical rotation was a 24-year woman with lupus. The rest is history! I left Greece and continued my studies at the Arthritis Branch of the National Institutes of Health in the US. At that point, the Branch was dedicating most of its efforts to studying patients with lupus. I learnt a lot about lupus and started conducting research to understand the molecular development of the disease. My first project was to characterise the responses of T cells in patients with lupus. In the process, I had to learn more biochemistry, molecular biology, genetic engineering and bioinformatics.

What qualities do lupus researchers need?

I am driven by unsolved questions, and I strive to acquire the skills and knowledge to answer them. It is important to understand the great challenges faced by people with lupus (who are predominantly young women) and the need to regain their stolen lives. Lupus researchers can advance our knowledge of the disease through whichever field they love the most; the main requirement is a personal devotion to the care of people with chronic diseases.

What do your roles as a medical doctor and research scientist involve?

As the chief of rheumatology and clinical immunology at the Beth Israel Deaconess Medical Center, I oversee the clinical activities of the division. As a staff of 20 doctors and nurses, we see more than 25,000 patients each year. As well as treating patients in the hospital, I supervise the training of clinicians in rheumatology, help to lead the dedicated Lupus Center of Excellence, and teach students and trainees at BIDMC and Harvard Medical School.

> ***"LUPUS RESEARCHERS CAN ADVANCE OUR KNOWLEDGE OF THE DISEASE THROUGH WHICHEVER FIELD THEY LOVE THE MOST; THE MAIN REQUIREMENT IS A PERSONAL DEVOTION TO THE CARE OF PEOPLE WITH CHRONIC DISEASES."***

I also run a laboratory with 15-30 researchers where we investigate the cellular, molecular, biochemical and metabolic aspects of lupus. We start by studying tissues from patients to identify which molecules are over- or under-expressed in people with lupus. We then genetically engineer lupus-prone mice to over- or under-express these same molecules, to demonstrate that these molecular abnormalities are important in living animals, before returning to the patients to conduct treatment studies.

What do you enjoy about your multiple roles?

Well, I find pleasure with everything I am doing. Seeing patients holds me to the ground. I get to see what people with lupus need and focus my efforts on solving their problems. Teaching is always exciting, particularly in a setting where students and young physicians inspire you with novel ideas. And research presents me with challenges to advance the field by asking new questions. I am excited by the continuous need to learn new approaches to solve problems.

What are your proudest career achievements?

I am proud to have advanced, even minimally, the field of lupus research and treatment by discovering novel mechanisms of the disease. It is also rewarding to know that the medical industry has picked up many of our findings and so they are now being applied in the clinic. And I am happy to have learnt from so many bright young colleagues who have moved on to build their own careers.

George's *top tips*

1. Find a field that inspires you to dedicate significant effort.
2. Find questions that interest you, and stick with them until they are answered.

Left: George discusses the case of a lupus patient with a colleague

REDUCING THE CHALLENGES OF CHILDBIRTH IN MYANMAR

In Myanmar, one in every 500 women is likely to die during pregnancy or childbirth. The **Birth Across The Borders** project is determined to reduce this terrible statistic. Led by **Professor George Kernohan** and **Dr Lesley Dornan** at **Ulster University**, UK, and working with researchers in Myanmar and Thailand, such as **Peach**, Birth Across The Borders aims to improve maternal health for women in remote communities in Myanmar.

Dr Lesley Dornan

School of Nursing, Ulster University, UK
Southeast Asia Research Lead, Birth Across The Borders

Field of research
Maternal Health

Peach

Regional Coordinator, Birth Across The Borders

Research project
Birth Across The Borders aims to improve maternal health in Myanmar through the power of education

Funders
Economic and Social Research Council (ESRC), Global Challenges Research Fund (GCRF)

PROFILES

TALK LIKE A...

MATERNAL HEALTH RESEARCHER

Community mapping — a research method in which residents identify the resources in their community and build a picture of the challenges and opportunities

Maternal — relating to a mother

Maternal mortality rate — the number of women who die during pregnancy or childbirth, per 100,000 births

Midwife — a qualified professional who assists a woman during childbirth

Obstetric — relating to pregnancy and childbirth

Traditional birth attendant (TBA) — a person who assists a woman during childbirth who has no formal professional training

Located in Southeast Asia, Myanmar is a beautiful country of rocky mountain ranges, dense jungles and golden sandy beaches. With over 100 different ethnic groups, it has a rich cultural diversity. But Myanmar is a country facing significant difficulties. It has a long history of ethnic conflict and has been severely affected by COVID-19 and political changes in recent years. These challenges contribute to the country's very high maternal mortality rate: of every 100,000 women who give birth, over 200 of them will die. In comparison, 21 women per 100,000 will die in childbirth in neighbouring Thailand, while in the UK the maternal mortality rate is 12.

Dr Lesley Dornan, a maternal health researcher at Ulster University, is co-leading the Birth Across The Borders project, investigating the challenges facing women in Myanmar during pregnancy and childbirth. By working with local communities and healthcare practitioners, Birth Across The Borders aims to improve maternal health in Myanmar through the power of education.

The challenges of childbirth in Myanmar

It can be very difficult for people in remote communities in Myanmar to access healthcare. Many families cannot afford it, either because they cannot afford the clinic fees, or because they cannot afford to travel to reach a clinic. Most villages do not have healthcare facilities so to receive professional medical help, people must leave the safety of their community and travel long distances. During the rainy season, rivers may be flooded and jungle paths may be washed away, while in the cold season, mountain passes may become dangerous to cross. These challenges are even greater for women in labour. While most communities have a traditional birth attendant (TBA) who is responsible for delivering babies, if there is an emergency during pregnancy or childbirth, the mother will need to receive professional help.

Lesley references the 'Three Delay Model' to explain the core reasons

A mother and child in Myanmar © Martin Johnston

why women cannot or do not access medical care during pregnancy or childbirth. The first delay is in the woman's decision to seek professional help. This may be due to a poor understanding of pregnancy and childbirth and a lack of knowledge about when things are not progressing as they should, or due to the status of women preventing them from making decisions. "The traditions, behaviours and practices of the community mean it can be hard for pregnant women to decide when they should leave the community to seek professional care," explains Lesley.

Once a woman has decided to seek help, the second delay is in reaching a healthcare facility. This is due to the challenges of travelling in remote mountainous regions with little or no transport infrastructure. The third delay occurs once the woman eventually arrives at the clinic, if poor facilities or inadequate referral systems result in her having to wait to be seen by healthcare professionals.

Lack of access to education

Birth Across The Borders aims to improve the situation for pregnant women in Myanmar by harnessing the power of education. "Education is something we take for granted," says Lesley. "It is only when we don't have it that we realise how influential education is." Many families in Myanmar cannot afford to send their children to school. Peach, one of the regional coordinators for the project, explains that in many remote communities, education does not occur in schools run by trained teachers, but in temples run by monks. "This means not everyone can access education and girls are often excluded," she says. "We want to improve education so children have opportunities for a better life, but it can be hard to change the traditional views and behaviours in communities." Even in regions where girls can attend schools, ongoing conflict means it is often unsafe for them to travel outside their village.

Collecting data

To gain a better understanding of maternal health in remote communities, Lesley and Peach are conducting interviews to collect data about women's experiences of pregnancy and childbirth by asking questions such as how many pregnancies they have had, how many children they have given birth to, and how difficult it was for them to access healthcare. The team also interviews village TBAs about infant healthcare to discover what traditional practices occur after birth, and fathers, as the fathers' experiences are equally important. "The father interviews tell us how men care for their wives while they are pregnant and how this relates to the local culture," explains Peach.

Birth Across The Borders is also investigating what emergency obstetric care is available when problems occur. While most villages have a TBA, emergency care is rarely available in remote communities. As well as analysing where clinics are in relation to villages, the team is interviewing women who have had an emergency during pregnancy or childbirth, and the healthcare professional involved in emergency obstetric care, such as midwives and doctors in clinics.

The team is also conducting community mapping to understand the context of each community. "With mapping, we look at the culture of the community," explains Peach. These maps not only highlight what resources (such as clinics, schools, roads, and water and electricity supplies) are available or absent, but how the people view the community. As well as creating maps of the present, community members are asked to create maps showing how they hope their village will look in five years' time. "Many impoverished communities live day to day and don't think much about the future," says Lesley. "Asking them about their hopes and dreams can change their perspective and gives us an understanding of how our resources can help them achieve those dreams."

Project goals and aspirations

A central goal of Birth Across The Borders is to provide education that will help pregnant women and mothers avoid dangerous situations in the future. "We want women to know when they might need to seek help during a pregnancy and we want them to know when they absolutely need to go to a clinic, to prevent the delay in them seeking care," explains Lesley. "We will also work in partnership with local organisations to train healthcare workers in basic emergency obstetric care. Across Myanmar, healthcare workers are doing amazing work to help women, and we hope to complement what is already being done."

Birth Across The Borders is very focused on designing educational resources that are practical and make sense in the communities, which means they take local cultures into account. "There are some traditional things we can't change," says Peach. "For example, men do not want to touch the blood of the women who are about to give birth and we can't do anything about that. However, we can talk to men about how they can support their wife during pregnancy, how they can transport her to hospital and how they can help during emergencies."

The project also hopes to improve the situation for communities by promoting social enterprises. For example, if women with sewing skills are encouraged to sell their products or supported to develop a small business, this will provide them with an income. This money will hopefully lessen the financial difficulties that many families in remote communities face, enabling them to access medical care and send their children to school. "The concept of social enterprise is that the extra income will not only help the individual woman, but it will feed back into the village and help the whole community," explains Peach.

Lesley and Peach hope that the efforts of Birth Across The Borders will help to reduce maternal mortality rates in remote communities in Myanmar, alongside improving the well-being of women, families and communities. As Peach says, "Even small changes can have large impacts on someone's life."

A Buddhist temple in Myanmar © Martin Johnston

ABOUT *MATERNAL HEALTH*

Maternal health refers to any aspect of a woman's physical, mental or emotional health, during or after pregnancy. As such, it is an extremely important area to work in. The World Health Organization has recognised the challenges of maternal health as a global health priority due to the unacceptably high maternal mortality rates that exist in some areas of the world.

Pursuing a career in maternal health is an incredibly rewarding way to help others. "Maternal mortality doesn't just impact the mother and baby," explains Lesley. "It impacts the whole family. When a family loses a mother, the opportunities for children to live the life they deserve as children is quite often taken away." In many countries, children are forced to leave school to care for younger siblings if their mother dies, denying them the right to their education.

The joys of working in maternal health

Knowing they are contributing to improving the lives of individuals, families and communities means Lesley and Peach both find great enjoyment and satisfaction from their involvement with Birth Across The Borders. "We're part of the tapestry of the story of Myanmar," says Lesley. "We're just one small part of this tapestry, but it it's a real privilege to be part of it."

Although the team has faced many challenges due to conflicts, COVID-19 and political changes, the project has had enormous success. "The strength of the friendships and relationships that have developed is one of the greatest rewards of Birth Across The Borders," says Lesley. "The communities have been amazing and the commitment of our in-country partners and staff has been phenomenal."

"I came to Birth Across The Borders because I now live comfortably in Thailand, but I know how tough life is where I'm from in Myanmar," says Peach. "In this project we have learnt many things about how difficult the situation is for pregnant women but we have also learnt how improvements can be made. If I can help just one woman or child in Myanmar to have a better life, then I will be happy."

Pathway from school to *maternal health*

- With so many professions dealing with maternal health, there is no one pathway leading to a career in the field. Research your options to find the route that best fits your interests.
- To work as a maternal healthcare professional, consider a degree in midwifery or medicine (specialising in obstetrics and gynaecology). You could also get a degree or do an apprenticeship in nursing.
- If you are interested in maternal health research, you could study public health at university.
- Try to find work experience in healthcare settings or with mothers. For example, Lesley recommends volunteering with mother and baby groups in your local community. "Look for opportunities where you can connect with mothers in different ways and hear some of their stories," she advises.

Explore careers in *maternal health*

- "There are many important roles in maternal health," says Lesley, who originally trained as a health visitor before becoming a maternal health researcher. "Obvious roles include working as a midwife or home health visitor, but you are also likely to encounter mothers if you work in any healthcare profession." For example, general practice doctors, specialist doctors and nurses are all likely to work with pregnant women.
- The World Health Organization (WHO) provides information about the challenges relating to maternal health around the world and how the WHO is addressing them: **www.who.int/health-topics/maternal-health**
- The NHS provides information about careers in midwifery (**www.healthcareers.nhs.uk/explore-roles/midwifery**), medicine (**www.healthcareers.nhs.uk/explore-roles/doctors**) and nursing (**www.healthcareers.nhs.uk/we-are-the-nhs/nursing-careers**).

Q&A

Meet Lesley

What motivated you to establish Birth Across The Borders?

I spent ten years living in Thailand and working as a health visitor in Southeast Asia where I had the opportunity to see families in many different settings. One day, someone told me of the difficulties women were facing during pregnancy and childbirth in remote areas of Myanmar. As I listened, I thought: Why is this not being heard? How is this still happening in today's world? Birth Across The Borders was developed out of that initial conversation and my desire to try and make a positive difference.

My grandmother died when my mum was young, so she and her sister were put into an orphanage. I saw the impact that not having a mother had on them, and I also saw the knock-on effect it has had through the generations in terms of mental health and maternal bonding. This personal experience is one of the things that drives me in this project. I want to do everything I can to prevent the same happening to other families, because I know the cost it can have.

How did your PhD research contribute to the creation of the project?

My PhD was based on how the culture within Thailand influenced women's choices, opportunities and decision-making surrounding breastfeeding. During this research, I recognised how broad culture, and its influence on our lives, is. Our cultures form who we are as people and inform the choices that women make during pregnancy and childbirth.

Why are you passionate about improving maternal health in Myanmar?

Myanmar is an incredibly beautiful country with amazing people who have had some really difficult times, and they deserve more. I believe that, despite everything, there is a resilience within these communities. I want them to have access to resources and to see their children grow up in healthier and happier environments.

What were your interests when you were younger?

I grew up with a fascination of different cultures and a desire to travel and experience them. I also enjoyed reading and loved getting lost in books. I wasn't passionate about education and I didn't do well in school, but I had a curiosity about the world that has stayed with me through my life.

What do you enjoy doing in your free time?

I still love to disappear into a book. I've had the privilege of doing a lot of travelling over the years, and I love exploring the world and meeting new people, hearing their stories and sharing their culture.

Meet Peach

What does your role as regional coordinator for Birth Across The Borders involve?

I communicate with all the other team members, including Lesley and my operational team in Myanmar, updating everyone about the progress of our work. I select the sites for the data collection and coordinate with community leaders in Myanmar, then I help collect and analyse the data we gather. I also help develop and deliver the maternal health education resources we are creating.

Who or what inspires you to do this work?

I'm from Myanmar but my mum and I moved to Thailand when I was three. My mum worked really hard to take care of me because she couldn't see any opportunity for a better life for us in Myanmar. My relatives say that my mum is a fighter – she is my idol! She taught me to be patient and to do my best.

Why are you passionate about improving maternal health in Myanmar?

Although I grew up in Thailand, I can still feel how tough life is back in Myanmar. I am very grateful for living a comfortable life in Thailand and I want to help people in my village in Myanmar have a better life. I want them to have access to healthcare and education. People should not have to worry about whether they'll have food to eat tomorrow or if it is safe for their kids to go to school or what to do if their wife gives birth. In the future, I hope that mothers and children can access healthcare and know how to take care of themselves.

What were your interests when you were younger?

I had so many interests when I was younger, but the one that never changed was my interest in travel, culture and language. I like understanding how people live differently and how they think differently. I've realised that while we can't always understand each other, we can accept each other.

What do you enjoy doing in your free time?

I live in a beautiful province in the north of Thailand where there are many mountains and a peaceful pace of life. I enjoy going into nature because it reduces my stress. It makes me feel like myself again when I can spend time outside and take a deep breath.

Peach's *top tips*

1. Everything in life is possible if you are patient.
2. Always give your best at everything you do.
3. Take all the opportunities that come your way in life.
4. When you have enough for yourself, don't forget to give to other people around you.

USING BIG DATASETS TO FIND OUT WHAT AFFECTS CHILDREN'S QUALITY OF LIFE

The Understanding Society study, run by the **University of Essex** in the UK, has been interviewing residents in around 40,000 UK households annually since 2009 to find out about their lives and how they change over time. This provides a gigantic dataset for uncovering the effects of global events – not least the impacts of the COVID-19 pandemic on the experiences of children. **Professor Birgitta Rabe** is using this data to inform government support for children's well-being.

Professor Birgitta Rabe

Institute for Social and Economic Research
University of Essex, UK

Field of research
Economics

Research project
Using longitudinal data to investigate key societal questions around topics such as education, mental well-being and physical health

Funders
Nuffield Foundation, Economical and Social Research Council (ESRC)

Understanding Society is an initiative funded by the Economic and Social Research Council and various Government Departments, with scientific leadership by the Institute for Social and Economic Research, University of Essex, and survey delivery by NatCen Social Research, Kantar and Ipsos MORI. The research data are distributed by the UK Data Service.

PROFILE

TALK LIKE AN ... ECONOMIST

Economics — a branch of social science that studies the production, distribution and consumption of goods and services, as well as a huge variety of other complex issues of vital concern to society

Longitudinal study — a study where the same individuals are repeatedly examined over a long period of time to detect changes that might have occurred

Policy — a particular course of action, usually led by the government

Policymaker — a person responsible for making policies, most usually government policies

Quantifiable — data that are easily expressed and compared as quantities

Understanding Society

Longitudinal studies take place over many years, collecting regular data on the same themes to see how things change over time. "Understanding Society is the largest longitudinal study of its kind and provides crucial information for researchers and policymakers on changes and stability in people's lives in the UK," says Professor Birgitta Rabe. A professor of economics and co-investigator on the Understanding Society programme at the University of Essex, Birgitta is especially interested in investigating trends in education, family and labour economics.

Getting large sets of comparable data about arguably 'fluffy' topics – people's feelings or experiences, for instance – is a challenge across the world of science. The Understanding Society programme tackles this through undertaking structured interviews with its participants, asking them the same questions year after year and carefully recording their answers. "Our participants come from every area of the UK," says Birgitta. "The study captures important information about social and economic circumstances, attitudes, lifestyle, health, family relationships, and employment."

The importance of schools

In recent years, Birgitta has focused on children and what the data reveals about their educational experiences. "Schools are obviously places for learning, but they are also where children socialise, eat, play, exercise and interact with adults outside their own family," says Birgitta. Aside from education, there is a lot of robust evidence that schools are crucial for many aspects of childhood development, such as social skills, problem solving and exposure to diversity. "While children may grow up in less or more well-off families, schools can, to some extent, balance out the effects of these experiences by providing all children with the learning inputs and activities they need to thrive," explains Birgitta.

Understanding Society interviews parents and carers to learn about their children's experiences of school and to uncover relationships between schooling and aspects of mental health. "Parents answer questions on their children's emotional and behavioural strengths and difficulties," says Birgitta. "These questions capture areas such as behavioural problems, emotional symptoms and peer relationships." Understanding Society also asks children and teenagers directly about their experiences of life, school and relationships. Young people in the survey complete their own questionnaire, which complements the one their carers answer.


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Lockdown

The COVID-19 pandemic led to a major disruption in how schools run, as children stayed at home and learning shifted to virtual environments. Understanding Society continued to collect data, albeit via online interviews. "During the pandemic, parents were asked the same questions on their children's mental health and well-being," says Birgitta. "Having access to answers to the same questions over time allows us to directly compare changes in children's mental health." By gathering the results from all participants in the study, the researchers look for patterns that point to direct or indirect effects of the pandemic on children's mental health.

"During the summer of 2020, the government advised that some school year groups should return to school after the first lockdown," says Birgitta. "Our data found that children who were out of school for longer experienced much greater declines in mental health than those able to return to school sooner." The researchers found that these effects on well-being remained even up to when all children returned to school the following school year. This provides strong evidence of the importance of school for children's well-being.

Influencing policy

The purpose of Understanding Society is for its results to be used to make the UK a better place to live. This involves communicating the research findings to policymakers who can then make policy decisions informed by these results. "Our results on children's mental health helped influence the government's decision to vaccinate 12 to 15-year-olds against COVID-19," says Birgitta. "It was originally felt these vaccines wouldn't be worthwhile as children rarely got very sick from COVID-19, but when the mental health effects of school closures were considered, the balance shifted." Research from studies such as Understanding Society demonstrated just how detrimental school closures were to children's mental health, helping policymakers decide that vaccinations for school-age children were a good investment for the mental well-being of students, as they prevented the need for school closures.

A more easily quantifiable effect of the pandemic is the fall in children's academic performance, which has been a focus for policy, with measures laid out to try and help these children 'catch up' with their peers. Birgitta thinks these measures should also incorporate mental health considerations. "As we continue to live with the effects of the pandemic, the government will need to carefully monitor whether policies designed to reduce learning loss will help or hinder attempts to restore children's mental health and well-being," she explains. "It's important to learn whether the children who have fallen behind the most academically are also those who have suffered the greatest deteriorations in mental health." Based on Understanding Society's findings, Birgitta believes that specialist mental health support will remain necessary for these children for some time.

Free school meals

Identifying trends in mental health is just one facet of Understanding Society and Birgitta's investigations. Birgitta is also interested in the impacts of schools on children's physical health and what this means for policy. "Schools play an important role in keeping children physically active and in feeding them healthy food," she says. "Both are enormously important to help children learn, thrive and build healthy habits for a lifetime." Birgitta's research uses Understanding Society to study the impact of providing free meals to children in school on the amount of money households spend on food. Especially for poorer families, free school meals can provide a lifeline to help children get the sustenance they need. However, given the costs such an initiative involves for the taxpayer, it remains a contentious issue, so evidence to support it is invaluable.

"We conducted research into the free school meals supplied to all infant school (reception to year 2) children, as well as similar policies brought in at the local level in some areas," says Birgitta. "Our research has shown that making school meals available to all pupils can help reduce child obesity." Childhood is where we learn many of the habits, likes and dislikes that last a lifetime, so overcoming childhood obesity is extremely important as it has consequences for children's long-term health and well-being. Obesity-related health issues also have financial implications for taxpayers and the National Health Service (NHS), so addressing them earlier on could save money in the long run.

> ***"WHILE CHILDREN MAY GROW UP IN LESS OR MORE WELL-OFF FAMILIES, SCHOOLS CAN, TO SOME EXTENT, BALANCE OUT THE EFFECTS OF THESE EXPERIENCES BY PROVIDING ALL CHILDREN WITH THE LEARNING INPUTS AND ACTIVITIES THEY NEED TO THRIVE."***

These findings have been picked up by influential supporters of free school meals. "Several people, including footballer Marcus Rashford and celebrity chef Jamie Oliver, have used our research to advocate for free school meals throughout the UK," says Birgitta. The team hopes such exposure will influence long-term policy, helping to boost the health of the next generation throughout their lives.

ABOUT *ECONOMICS*

Professor Birgitta Rabe may not seem like the 'traditional' economist who you might expect to focus on supply and demand, growth and inflation, and other topics that can seem a bit distant from 'ordinary' people's lives. She explains more about her line of work and why economics is so important for the social sciences and our society at large.

"Many people think that economics is only concerned with large-scale issues such as growth, interest rates and financial markets. In fact, there are scores of economists studying the behaviour of households and individuals. I am fascinated by the factors that influence how children develop, and I hope that my findings can make a difference to children's lives – even if it is one small step at a time.

As well as those topics explored in this article, I've studied the effects of:

- breastfeeding and childcare on early child development.
- school resources on quality of education
- siblings on education and development

Research in economics will always be needed, both to study the overall economy and the behaviour of people and households within it. We have ever-better data to study important topics that affect all our lives, including through Understanding Society.

Economics is everywhere. I recommend keeping up with the news, from the cost of living crisis to how the pound is trading against the dollar, to discrimination in the labour market. So many issues come down to economics, so understanding how these factors influence the world and our society is critical to an understanding of economics itself."

"SO MANY ISSUES COME DOWN TO ECONOMICS, SO UNDERSTANDING HOW THESE FACTORS INFLUENCE THE WORLD AND OUR SOCIETY IS CRITICAL TO AN UNDERSTANDING OF ECONOMICS ITSELF."

Pathway from school to *economics*

- Birgitta says that an A-level in mathematics will likely be important to study economics post-18. A range of other subjects can be useful, including statistics, economics and geography. Find out more about university entry requirements here: **www.ucas.com/explore/subjects/economics**
- While an undergraduate degree in economics is likely the most straightforward path to a career in economics, Birgitta notes other pathways are also possible. Find out more about economist careers here: **www.nationalcareers.service.gov.uk/job-profiles/economist**

Explore careers in *economics*

- The University of Essex, where Birgitta and the Understanding Society programme are based, offers a range of free activities and events for school students of all ages: **www.essex.ac.uk/schools-and-colleges**
- The Royal Economic Society has a number of initiatives for school students, including a programme to increase diversity in economics students, an essay competition for sixth-form (year 12 and 13) students and an open-access annual lecture: **www.res.org.uk/education.html**
- According to Prospects, typical starting salaries for economists in the UK range from £25,000 to £35,000, with the potential to increase to £40,000 or more after a few years: **www.prospects.ac.uk/job-profiles/economist**

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How did Birgitta *become an economist?*

I saw that unequal opportunities in society had a lot to do with economics. This inspired me to learn more and, ultimately, hopefully contribute to changing things for the better.

I like to think my career has been helped by my analytical mind, my drive to see things through to the end and my ability to communicate my findings clearly. Collaborating with great colleagues and working to your own strengths and the strengths of others is also important.

To overcome challenges, sometimes you have to be persistent and just try and try again. Nobody is perfect, and mistakes or setbacks happen to everyone; resilience is what's important.

A proud career moment for me was winning a prestigious prize for my PhD thesis. I bought a sparkling new bicycle with the prize money! Additionally, seeing my research used for policy is always fantastic.

> ***"TO OVERCOME CHALLENGES, SOMETIMES YOU HAVE TO BE PERSISTENT AND JUST TRY AND TRY AGAIN. NOBODY IS PERFECT, AND MISTAKES OR SETBACKS HAPPEN TO EVERYONE; RESILIENCE IS WHAT'S IMPORTANT."***

Birgitta's *top tip*

Learn as much as you can, but stay firmly grounded. It's important to remain able to speak with non-experts and to never lose sight of the bigger picture of what you're trying to achieve.

WHAT CAN THE HISTORY OF WOMEN'S SUFFRAGE TEACH US ABOUT WOMEN IN POLITICS TODAY?

Although women's suffrage has come a long way since 1893, when women in New Zealand were the first in the world to gain the right to vote in parliamentary elections, progress has not been easy, and we have still not achieved gender equality in politics. **Dr Mona Morgan-Collins**, a political scientist at **King's College London**, UK, is exploring how women were represented in politics after suffrage, with the lessons she is learning having implications for politics today.

Dr Mona Morgan-Collins

Department of Political Economy, School of Politics and Economics, King's College London, UK

PROFILE

Fields of research
Political Science, Political Economy

Research project
Exploring women's voting behaviour and substantive representation in politics by examining women's suffrage

Funder
Economic and Social Research Council (ESRC)
This work was supported by the ESRC, grant number ES/T01394X/1, 'From Suffrage to Representation'

TALK LIKE A ...

POLITICAL SCIENTIST

Electoral system — the rules used to determine the results of an election

Legislature — an assembly of people who have been elected to make laws for a state or a country

Polling station — a building where voters cast their vote during an election

Proportional representation (PR) — an electoral system in which parties gain seats in proportion to the number of votes cast for them

Single member plurality (SMP) — an electoral system in which the winning candidate is the one who gets the most votes. SMP is also known as 'first past the post'

Substantive representation of women — representation of women's interests in policies and legislatures

Suffrage — the right to vote in elections

Suffragist — a person who advocates for suffrage

Despite women's right to vote now being a near-universal legal standard around the world, women are still under-represented in politics. "It remains common across countries and types of elections that women are less likely to vote, less likely to participate in other political activities and less likely to run for political office," explains Dr Mona Morgan-Collins, a political scientist at King's College London. This gender gap is largest in the top level of politics, where women continue to be less likely to be prime ministers or presidents, and less likely to rule in government offices. So, why have we still not achieved gender equality in politics?

When did women get the right to vote?

It is often thought that women's suffrage came about in the early 20th century and that, before this, women had no access to politics. "However, history is rarely linear," says Mona, who points out that several countries, including the UK, allowed rich widows to vote before this. Also, as countries began to give women the same voting rights as men, this right was often not extended to all women. In the US, for example, although some women could vote from 1920, full suffrage did not occur until 1965 when Black women were given the right to vote. "It has only been in the last few decades or so that suffrage for *all* women has become a standard across the globe," explains Mona.

What challenges did women face when voting, even after suffrage?

"Women faced so many barriers!" says Mona. "It was really hard for women to vote back then." Even after achieving suffrage, women faced cultural, structural and institutional barriers that prevented them from engaging in politics to the same extent as men. Society at the time viewed women as incapable of operating independently in politics and thought that women would, and should, vote in the same way as their husbands. These cultural beliefs did not change overnight once women had the legal right to vote.


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Women were often expected to give up work when they married, meaning they did not have the same informal opportunities as men, for example through chatting with colleagues, to learn about and share opinions of politics. Women were less likely to have access to transport and more likely to have caring duties for children, so physically getting to the polling station was a greater challenge than for men.

Cultural and structural barriers to voting can undermine politicians' incentives to mobilise voters. And, if politicians do not engage women voters in electoral campaigns, they hardly have an incentive to advocate for them once elected. Despite suffrage, politicians may be reluctant to represent women's interests in their policies. The fact that, even today, women's interests remain under-represented by politicians in most contexts is proof of this. After suffrage, as politicians believed that few women would vote and that those who did vote would do so in the same way as their husbands, and as politicians did not understand what women wanted from politics, women continued lacking substantive representation of their interests. Suffrage is a necessary condition for better representation, but not a sufficient condition.

The suffragists

The suffragists were those who campaigned, firstly for women's right to vote, and then for women's representation in politics. "The suffragists did so much more than just fight for suffrage," says Mona, who has discovered that they were also crucial in the process of securing women's representation after suffrage. They encouraged women to decide what issues mattered to them, educated women about politics and educated politicians about women. Politicians were more likely to represent women's issues when women were viewed as capable individuals with defined interests. In Norway, for example, Mona's research has shown that politicians from districts with strong suffragist movements advocated for financial support through pregnancy and easier access to divorce in the legislature, thanks to the influence of the suffragists' voices.

However, the suffragists' campaigns were defined by the women in the suffragist movement, who were predominantly white and middle class. This meant that the 'women's interests' were only the interests of active, privileged women. As a result, the interests of all women were not represented. "But," says Mona, "the concept of women's interests had been born and could grow from there."

How does Mona analyse voting behaviour?

Mona is interested in the voting behaviour of early women voters in different countries, and she is analysing a previously untapped wealth of data to explore this. In the past, women cast their votes in separate ballot boxes to men, allowing politicians of the time to know their voter demographics and allowing Mona to determine how many women compared with men voted at any given polling station. She also collects data from electoral registers, the lists of eligible voters that contain information such as age, sex, occupation and whether that individual voted, and she examines records of suffragists' activities and politicians' votes on policies in legislatures. By quantitatively analysing all these data, Mona is gaining insights into the voting behaviour of the first women able to vote, the responses of politicians to women's suffrage and the importance of suffragists for both women's voting and politicians' responses to women in legislatures.

What else has Mona discovered?

While previous studies had shown that the type of electoral system used in a country influenced women's voting turnout, with women being more likely to vote in proportional representation (PR) systems than in single member plurality (SMP) systems, the reasons behind this were never fully understood. Mona investigated this and found that electoral competition had a more powerful effect on women's turnout.

She discovered some SMP countries had higher turnouts of women than PR countries if the electoral districts were competitive, while some PR countries had low turnouts of women if political parties did not have a stable geographically-bounded support base. "This is because high district competition in SMP and high geographical concentration of electoral support in PR increase the overall incentive of all voters, regardless of gender, to vote," says Mona.

For example, when women gained suffrage in New Zealand, with an SMP system, they were almost as likely to vote as men due to the competitive nature of politics in the country at the time. Politicians were therefore incentivised to mobilise women to vote, and women were more likely to do so. In contrast, women's turnout in Chile, with a PR system, was very low after suffrage as political parties at the time could not rely on stable support from local strongholds. Electoral competition, rather than the electoral system, contributed to the extent women voted in equal numbers to men, and therefore the likelihood of politicians representing women's interests.

What next for women in politics?

"We know that women's suffrage is necessary for women's participation and representation in politics," says Mona, but she argues that suffrage alone is not sufficient. "Something more needs to happen to ensure women's right to vote leads to politicians developing policies that improve women's substantive representation." Mona's research uncovers how things used to be done in the past, which is essential if we want to know how to improve politics and policies in the present. "If we want to improve representation of women's interests today, we have to bring more women into politics and have collective discussions of what women's interests are," says Mona. "Women's organisations can achieve both. The suffragists did. It is only when women's movements are strong and electoral competition is favourable that politicians will adopt policies that represent women's interests."

ABOUT *POLITICAL SCIENCE*

Political science is the study of governments and political systems at local, national and international levels. If you study political science, you will learn about democracy, investigate political systems in different countries, analyse past and current political behaviour, and examine political theories. This is different from the study of politics, which examines the state of affairs in a country, and it is important to note that you do not need to enjoy politics to enjoy political science: "Those interested in political science may not even be interested in politics, like me!" says Mona.

Political science research often draws on many different disciplines, such as economics, sociology and history. Mona is a lecturer of political economy, a field that combines politics and economics. "Most social science research is interdisciplinary," she explains. "I study a core political science topic – voting behaviour and representation. To understand this, I use methods and theories from economics, gender studies and history."

Communicating political science research to politicians, policymakers and the public is just as important as the research itself, as it allows people outside academia to learn from and act on the research findings. "Some people might ask whether research on suffragists in Norway and Chile 100 years ago has any relevance to today's practitioners," says Mona. "But it does." For example, as women were absent from government politics at the time of suffrage, politics happened within women's organisations such as the suffragists. "This offers a window of opportunity to understand the impact of women's groups, something that is hard to isolate from the impact of women politicians in recent times." As we continue to work towards achieving better representation of women's interests in politics, we have a lot to learn from the politics of the past that successfully improved women's representation.

Pathway from school to *political science*

- As well as studying humanities and social science subjects at school, such as history, economics and sociology, Mona highlights that maths and statistics are key for political science research. Her research involves quantitative data analysis, but even if you are interested in qualitative research or want to become a politician, you will still need to understand quantitative political science research.
- If you're interested in political science, Mona suggests looking online to find political science reading lists compiled by academics. These will direct you to relevant articles that will introduce you to current theories and ideas in the field.
- Many universities offer degrees in political science, politics, international relations or politics, philosophy and economics, all of which could lead to a career in political science. To become a researcher, you will then usually have to complete a PhD.
- Visit the School of Politics and Economics at King's College London to learn more about the different degree programmes you could study: **www.kcl.ac.uk/politics-economics**

Explore careers in *political science*

- As a political science researcher, you can focus on whichever aspect of politics most interests you. While Mona studies political history in the context of women's suffrage, you could investigate the influence of modern political practices on policies or examine how politics in different countries contribute to international relationships.
- A degree in political science will provide you with the skills and knowledge needed to work in policymaking, government departments, non-governmental organisations and political parties. "There is not one way to use a political science degree," says Mona. "That's the most exciting part. You can define your specific interests, pursue them, and see where they lead."

Q&A

Meet Mona

When did your interest in political science begin?

Growing up, I hated politics! I enjoyed reading anything I came across, but always avoided following politics. As a teenager, I entertained different ideas of who I wanted to become – a lawyer, a psychologist, a biologist, an actress... I'm grateful for the chance to have explored different interests and considered different careers.

Then one day, I learned about the power of electoral systems and how they can determine who wins elections. These are simple rules that we put in place and then they shape who governs. Sometimes different people can get elected under different systems, even if the preferences of voters don't change. That fascinated me. I learnt everything I could about electoral systems and decided to pursue this fascination for a career.

What inspired you to become a political scientist?

When I was growing up, women were rarely visible in politics and political science was dominated by men, so I did not have any role models. None of the books I was reading about electoral systems at that time were written by women. I realised that if there were no women writing books about this topic, it was time for me to write one. Somebody should, so why not me?

What personal qualities have helped you become a successful researcher?

Resilience and persistence. As a researcher, you are bound to encounter setbacks – models not working, data collection falling apart or finding the opposite of what you thought you would find. You will sometimes find people who put down your capabilities or who won't believe your work is worthwhile. A researcher needs a tough skin to work through these difficulties. The one thing that always helped me was the belief that even if things were hard, I would eventually find my way through. And so far, I always have done, even if this meant following a different path to the one I imagined.

What have been the highlights of your career?

I loved having the opportunity to spend time conducting research at the University of Oxford, UK, and Harvard University, USA. Being exposed to different academic environments and scholars is not only professionally stimulating but also very personally rewarding. The real highlights are the outputs of my work, which have been published in top political science journals. Knowing that my work is inspiring students and scholars to pursue their own research ideas is a sign of professional success and is very satisfying.

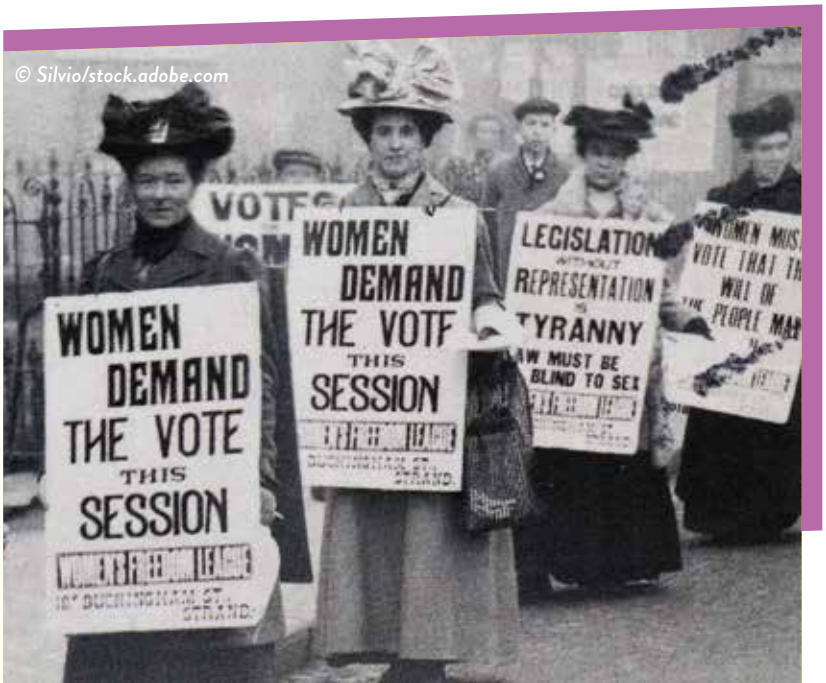
> **THERE IS STILL SO MUCH I WANT TO LEARN ABOUT EARLY WOMEN VOTERS AND WOMEN'S POLITICAL REPRESENTATION!**

What are your ambitions for the future?

I want to keep doing good research that will shape our knowledge in the field of political economy. There is still so much I want to learn about early women voters and women's political representation!

What do you enjoy doing in your free time?

I used to spend my free time with books and yoga. Now, I spend it with my 2-year-old daughter and my small fluffy dog, Artichoke. There is very little that is more relaxing than a walk in the park with the two of them.



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Mona's *top tips*

1. Read, read and read! Then discuss what you have read with others.
2. Figure out what your interests are and follow your curiosity. Opportunities will come!
3. Do not be afraid to change paths. Learning that something is not the right path for you is just as important as figuring out that something is.

HOW AND WHY DO GOVERNMENTS FORGET?

We all tell stories about past events, and people working in government departments are no exception. These stories cause knowledge to be passed on between different generations of employees, allowing departments to learn from the successes and failures of the past. However, what happens when these stories are lost from memory? **Associate Professor Alastair Stark, Professor Heather Lovell** and **Professor Rodney Scott** are working on an international collaboration to unpick how an organisation's memories of the past can influence the policies made in the present.

Associate Professor Alastair Stark

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Professor Heather Lovell

Professor of Energy and Society, School of Social Sciences, School of Geography, Planning, and Spatial Sciences, University of Tasmania, Australia

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Field of research
Public Policy

Research project
Investigating the effects of institutional memory on policymaking decisions

Funder
Australian Research Council (ARC), Project number DP210100149

PROFILES

TALK LIKE A...

PUBLIC POLICY RESEARCHER

Institutional amnesia — when an organisation forgets knowledge it used to possess

Institutional churn — the turnover of staff in an organisation as existing employees leave and new ones are hired

Institutional memory — the collective knowledge of past events held by an organisation

Policy — a course of action adopted by an organisation. Public policy refers to policies created by governments

Policymaker — a person responsible for developing policies

Public servant — a non-elected person who works for the government, i.e., not a politician

Public service — the sector of government containing departments that serve the needs of the public, known as the 'civil service' in some countries

The most important role of any government is to create and uphold public policy. These policies form the backbone of a nation, by setting the rules to support and protect the country and its citizens. However, what factors influence the policymaking process? How do changes within government departments impact the policies these departments create? An international team of academics, including Associate Professor Alastair Stark at the University of Queensland, Australia, Professor Heather Lovell at the University of Tasmania, Australia, and Professor Rodney Scott at the Te Kawa Mataaho Public Service Commission of New Zealand, is hoping to answer these questions by investigating how changes in institutional memory affect public policy processes.

What is institutional memory?

"Institutional memory is the knowledge of the past that is held by organisations," says Heather. "This includes both formal knowledge, archived in documents and files, and informal knowledge that is held in people's heads." This informal knowledge commonly involves stories of the organisation, perhaps discussed in meetings or shared as gossip over lunch. It is much harder to pin down this informal knowledge to study it, as it does not exist in any physical form and its dynamic nature means these stories are constantly changing

> ***"STORYTELLING IS A REPRESENTATION OF THE PAST, BUT STORIES DON'T NECESSARILY TELL YOU EXACTLY WHAT HAPPENED, OR ALL OF WHAT HAPPENED."***

as they get passed from person to person. In contrast, reports of an organisation's past actions are recorded and filed away, so formal institutional memory tends to remain static.

The team believes that dynamic, informal institutional memory is just as important in the decision-making process within organisations as official records of the past. "The theory is that these two different types of institutional memory – formal, static memory and informal, dynamic memory – have different effects on policymaking processes," says Al.

How does storytelling influence memory?

"Storytelling uses narratives to represent the past in a particular way," explains Heather. "Within governments, storytelling might involve passing on information about the nation's cultural traditions or using metaphors that simplify complex processes for newer members of staff."

However, this informal method of transferring information is not always reliable. "Storytelling is a representation of the past, but stories don't necessarily tell you exactly what happened, or all of what happened," explains Rodney. While stories can provide a wealth of information, key details of true events are likely to be misremembered or changed through time. "When studying storytelling, it's important to understand what happened, how this was interpreted and remembered by the people there, and how these memories are passed on through stories."

What role does institutional churn play?

One key factor affecting institutional memory is the turnover of staff, known as 'institutional churn'. When staff members leave, they take their memories of the organisation with them. Once all the employees who remember 'how things used to be done' have left, these stories will no longer be told in the lunchroom and that knowledge will have faded from institutional memory. When institutional memory is lost, it can result in 'institutional amnesia', causing organisations to forget knowledge of policymaking and policy processes.

How does churn vary between governments and departments?

To date, most academic research has been focused on institutional churn in corporations, but the team wants to understand more about churn in governments. "We have analysed data on churn in government departments in Australia, New Zealand and the UK, going back to the year 2000," says Heather. The initial results have shown some interesting similarities and differences between nations and departments.

For example, churn is lower in the Australian Public Service than in the New Zealand Public Service and the UK Civil Service. Transfers between departments are particularly high in the UK Civil Service, as employees are routinely moved between different government departments. In all three countries, the Prime Minister's cabinet is associated with the highest rates of staff turnover while the department responsible for foreign affairs has the lowest rates of turnover.

How is the team investigating the impact of churn?

After analysing data on the extent of churn in the Australian, New Zealand and UK governments, the team is now digging deeper to understand government employees' attitudes towards this churn. "We have developed a survey to find out what respondents think about how turnover has affected the ability of their organisation to remember the past in relation to current policy," explains Heather. Following the survey, the team will carry out interviews with government employees to gather further information that cannot be captured with a written questionnaire and conduct case studies with public service agencies in these three countries to uncover what influences memory in each institution.

What does the team expect to discover?

Although Al, Heather and Rodney are still in the early stages of their work, other researchers have speculated that institutional churn may have both good and bad effects on policymaking. "Churn can cause a loss of institutional memory, but can also bring new ideas to an organisation," says Rodney. "In the case of people moving between government departments, key insights can be transferred and spread across the civil service." In this project, the team hopes to test these ideas to establish exactly how institutional churn influences institutional memory and therefore policymaking processes.

"At a simple level, it is likely that some churn is good, but too much is bad," says Rodney. "However, it may be more complicated than that, and churn may have different effects in different situations."

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For instance, churn among senior members of staff may have different effects to churn among non-managers, as employees at different levels may hold different types of institutional memory. If turnover is gradual, with staff replacement only happening every now and then, stories can be passed on to new employees as they arrive, and so institutional memory will linger. However, if everyone in a team leaves at once, there will be no one left to teach the new team about the department. "Providing evidence for these sorts of insights will help us make recommendations to public servants about how to manage churn more effectively," says Al.

How is the team investigating the impact of storytelling?

The team will use a method called 'thick descriptions' to unpick the influence of storytelling on institutional memory. "Thick descriptions combine empirical descriptions (objective descriptions of what happened), with the remembered experiences of public servants, and their personal interpretations of what happened and why," says Rodney. This will provide rich data for the team to analyse and make conclusions about the reliability of informal memory and what this means for policymaking.

"We expect to find that stories from the past have a strong impact on behaviour and decisions in the present," says Al. "It is likely that these stories sometimes have positive effects, sometimes have negative effects, and sometimes have both at once." Storytelling is an effective way of passing on what has been learnt in the past so this knowledge can be applied to inform current decisions. However, if the context in which these lessons were learnt is different from the context in which they are being applied today, it may not be appropriate to use this knowledge as it could result in unintended outcomes. "We want to find out how, why and when stories have these different impacts," says Rodney. "This will help us advise policymakers on how to use these stories effectively, allowing them to keep the good effects while minimising the bad."

> **"WE EXPECT TO FIND THAT STORIES FROM THE PAST HAVE A STRONG IMPACT ON BEHAVIOUR AND DECISIONS IN THE PRESENT."**

Influencing policy

The team's research will only be useful if it is effectively communicated back to policymakers, so working closely with public service agencies is a key aspect of the project. The team will share their discoveries with the departments involved in the study, providing them with specific advice and helping them to learn from the results of the project.

"Beyond that, we will also engage with the central agencies of each nation to provide more general advice on how best to manage churn and institutional memory," says Al. "Central agencies exist at the centre of governments and are responsible for creating the policies that define how all the other agencies work, so this will help our project make a difference far beyond the agencies involved in our case studies." The team's research will therefore be useful for governments around the world, ensuring they do not forget crucial knowledge as staff members change and allowing them to learn from the successes and failures of past policies. •

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ABOUT *PUBLIC POLICY*

"Public policy is fundamental to everyday life," says Heather. "How a government decides to act affects everyone, directly or indirectly." Public policy is everywhere, affecting how nations approach issues as diverse as energy usage, healthcare and business. While policies are implemented by policymakers working in government departments, they are studied by researchers in academic institutions to investigate whether they are effective at addressing the issues they are aiming to solve. All research findings must be communicated back to the policymakers, to ensure policies will benefit society.

"Public policies are, broadly speaking, the sum total of government action," says Rodney. "They address a vast range of topics, covering anything that the government works on, from housing to tax to the environment." Policies are made by both national and local governments, and international policies are drawn up and enacted as a result of countries working together.

The policy cycle

The process of policy development is known as the 'policy cycle', which describes the different stages of defining the issues to address, drafting and reviewing the policy, implementing the policy in society and evaluating its performance. "The process of developing policies is continuous and, in most cases, pretty slow," says Al.

Researchers study the policy cycle to help policymakers understand which parts of the process work well and which parts do not lead to effective public policies. By combining the knowledge of academics and policymakers, the process of developing and implementing public policies can be improved.

Crossing disciplinary boundaries

Public policy research can be interdisciplinary. In this research project, although most team members are political scientists, the team combines theories and methods from many different disciplines, including human geography, anthropology, sociology and psychology, to address the questions surrounding institutional memory. Each team member contributes their own set of skills and expertise to the project. For example, as a human geographer, Heather brings concepts of how policy ideas move from place to place, which can be applied to consider how stories about the past move within and between different government departments. As a policy practitioner, Rodney brings a wealth of 'hands-on' experience to the team.

Pathway from school to *public policy*

- At school, Heather recommends studying a mix of science and social science subjects. "Sciences will enable you to understand and translate technical knowledge, while social sciences will allow you to appreciate different viewpoints, synthesise diverse knowledge and write clearly," she says.
- At university, degrees in public policy, political science, sociology or human geography could all lead to a career in policy research or implementation.

Explore careers in *public policy*

- If you are interested in analysing public policies you could become a researcher, while if you are interested in implementing them you could become a policymaker. Or, if both analysis and implementation appeal to you, you could do both, like Rodney.
- Find out more about careers as a policy analyst, including the skills you need and the work you can expect to do, from the Australian Government (**www.yourcareer.gov.au/careers/224412/policy-analyst**), the New Zealand Government (**www.careers.govt.nz/jobs-database/government-law-and-safety/government/policy-analyst**) and the UK Civil Service (**www.civil-service-careers.gov.uk/professions/working-in-policy**).
- *The Mandarin*, an Australian news organisation, has a section dedicated to careers in the public sector: **www.themandarin.com.au/career-advice**

Meet *the team*

Associate Professor Alastair Stark

Field of research: Public Policy

I grew up in a context of social exclusion, in a challenging environment with a variety of problematic behaviours. When it comes to learning, everyone is different. I hated the rigid nature of school and being told what to learn and how to learn it. I therefore failed as a school student.

I left school as soon possible, with no qualifications. I got a job via a government programme (a public policy) designed to give young people with no qualifications the chance to gain work experience and a college certificate. This public policy changed my life.

I worked in local government and went to college one day a week, where I learnt how governments continually try (and fail) to address social problems. This enabled me to go to university to study politics and public administration, which was revelatory. I came alive as a learner because I was given the independence to learn in ways that worked for me.

Learning about policy was like opening a door – I could now explain all the things that surrounded me: the problems I personally faced, the larger societal issues that created my environment, and how government policies tried to fix them. I learnt why my everyday experiences looked and felt the way they did and so understood my personal world much more effectively.

After this, I never looked back. I had a career in government then a career in researching government. The goal of public policy research is to improve how governments respond to the problems all around us. My primary interest is in crisis management policies, and I've had the satisfaction of working with the Australian government to ensure we learn (and don't forget) lessons from crises.

Teaching students about public policy is undoubtably the most rewarding part of my job. I enjoy showing students how their surroundings have been shaped by government policies and how they can influence policies for the collective good. Many of my students go on to work in government, and, years later, many tell me they still use the lessons I taught them in their careers.

In my free time, enjoy collecting sci-fi novels and, although no one ever gets to read them, writing sci-fi short stories. I have an unhealthy obsession with dystopian futures, zombies and steam punk!

I have never forgotten it was a public policy that gave me the opportunity to escape my context, and that studying policy opened the world up to me. That is why I study public policy – because policies can change lives. They changed mine.

Alastair's top tips

1. Don't be afraid to fail. And never let your failures convince you that you are a failure.

2. Try many things, fail many times, and, when you find your passion, work hard at it and seize any opportunities that come your way.

Professor Heather Lovell

Fields of research: Human Geography, Sociology, Public Policy

In this project, I am leading one of the detailed case studies looking at energy policies in Australia. I studied human geography at university, and this has allowed me to work a lot with policy processes. I'm most interested in how policies travel from place to place.

Most of my research investigates energy and climate policies. Over the past decade, I have been studying smart grids – electrical networks that intelligently balance supply and demand to maximise efficiency. I'm interested in how policymakers create policies for totally new and complex concepts such as smart grids.

I enjoy how varied my work is. On any given day I could be working on many different things – contributing to research projects, teaching students or participating in committees. No two days are the same! I really enjoy seeing patterns in research across different disciplines. For example, I realised that political scientists are studying very similar processes to some human geographers, just using different terminology. Making these connections can help draw together insights from different disciplines and progress our cumulative knowledge.

I've had many excellent mentors throughout my career, especially during my PhD and first postdoctoral research jobs. They all happen to have been women, and I think that was important for me to learn how to navigate academia as a woman.

In 2014, I was fortunate to be awarded a grant from the Australian Research Council to research smart grids in Australia. I'm originally from the UK, so this opportunity to move across the world and experience a different way of life has been a real highlight.

As a young child, I loved finding out about plants and animals. My brother and I would spend time collecting snails and ladybirds. I loved spending time outdoors and seeing the seasons change, as well as reading stories. These days, I still enjoy being outdoors in my free time. I like walking our dog and running on the many mountain paths that are right on our doorstep in Hobart, Tasmania.

Heather's *top tips*

1. An academic career is very rewarding, but hard work. Try not to compare yourself with other people.

2. The culture of long working hours in academia can be tricky to navigate if you have caring responsibilities, such as children. But remember that good ideas do not necessarily take a lot of time to generate.

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Professor Rodney Scott

Field of research: Public Policy

I work in the New Zealand Public Service as the Chief Policy Advisor. In this role, I support the Public Service Commissioner (the head of the New Zealand Public Service) by providing advice on the design and direction of public services. This involves traditional policy analysis and engaging with research communities and international practices.

I have worked for many years on how public institutions can make better use of institutional memory and learn lessons from past experiences. My work in the New Zealand Public Service means I bring insights as a public servant to this research project. These insights help the team think about how to make our findings useful and practical.

I'm fortunate to be involved in both policy research and implementation. I enjoy the intellectual stimulation of academia and seeing how these findings are applied to make a difference to New Zealanders.

I never thought I would end up in public service or academia. I started out working as an osteopathic doctor, then moved into managing the operations of several health charities. Every step of my career has felt like moving further from the people I'm trying to help, but at the same time helping a greater number of people. I wanted to explore topics in greater depth, which led me to work more closely with academics to support better policy advice.

I am fascinated by aspects of public administration, such as public ethics, political neutrality, stewardship and public participation. While both public and private sector administration involve managing resources to deliver goods and services, the factors I am interested in are not fundamental in the private sector. I am also very interested in public service motivation, what we call 'te hāpai hapori' in New Zealand, or 'a spirit of service to the community'. Why do some people feel a calling to serve their community? How can we protect and nurture this spirit?

Passing the Public Service Act 2020 was a career highlight for me. This was a once-in-a-generation change to protect the integrity of the public service and to make it more effective for years to come. Another highlight was establishing the Public Service Fale, for which I got to work with inspiring leaders from across the Pacific. The Fale is a new function to help 16 Pacific Island Nations strengthen their own public services.

Growing up in Australia, I loved sports and music. I played Australian-rules football, cricket and basketball. I also played the piano in a few terrible cover bands. These days, I still enjoy sports and music in my free time and I also enjoy travelling. My work has taken me to dozens of countries, and I love learning about different cultures and ways of life.

Rodney's *top tips*

1. Never stop learning. Every step of my career has involved learning new skills.
2. Keep an open mind about what you like and what you feel you are good at. This will change over time.
3. Focus on making a difference. It is the impactful moments that I look back on and that keep me motivated.

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