

AN ILLUSTRATION OF INCLUSION

CHIDIEBERE IBE
THE 25-YEAR-OLD MEDICAL
STUDENT AND ASPIRING
NEUROSURGEON
ADVOCATING DIVERSITY
THROUGH ILLUSTRATION

ALSO IN THIS ISSUE

SOAPBOX SCIENCE
PROMOTING WOMEN AND
NON-BINARY SCIENTISTS
WORLDWIDE

**THE SCIENCE
BUSKERS FESTIVAL**
NURTURING STEM TALENT IN
AFRICA

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AN ILLUSTRATION OF INCLUSION

“Don’t tell me the moon is shining; show me the glint of light on broken glass.” This beautifully evocative quote, attributed to the playwright Anton Chekov, has been used by storytellers worldwide to teach budding novelists the concept of ‘show, don’t tell’. The aim of this writing technique is to immerse the reader in the story, drawing them in to the world of the fictional character rather than simply telling them what is happening in the story.

Chidierebe Ibe’s illustration of a Black fetus (p 4) is a powerful demonstration of the significance of showing, not telling. Greater attention has been paid to equality, diversity and inclusion in recent years – and rightly so – but when Chidierebe’s drawing went viral on social media in December last year, it highlighted a major issue: the lack of diversity in medical drawings.

Soapbox Science (p 36) and the Africa Science Buskers Festival (p 68) are two more striking examples of the power of ‘showing’. Set up in 2011, Soapbox Science places female and non-binary scientists on soapboxes worldwide to defy stereotypes and bring science to the streets. The Science Buskers Festival tasks primary and high school students to solve some of the world’s greatest challenges and present their innovations to captive audiences across Africa.

The researchers in this issue come from a wide variety of backgrounds and are communicating their work in a manner that shows students a pathway to rewarding and impactful careers. As Dr Nathalie Pettorelli, founder of Soapbox Science, says, “Scientists come in all shapes and sizes”. Futurum is here to show your students just that!

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“I BELIEVE THAT THE UNIVERSE HEARS US AND THAT WORDS ARE VERY POWERFUL.”

A SELF-TAUGHT MEDICAL ILLUSTRATOR, 25-YEAR-OLD CHIDIEBERE IBE BECAME A SENSATION OVERNIGHT WITH HIS DRAWING OF A BLACK FETUS. HE EXPLAINS WHY WORDS – AND ILLUSTRATIONS – HAVE THE POWER TO MAKE GOOD THINGS HAPPEN



© Kinglsey Fabian (Stile Imagery)

Chidiebere studied chemistry at the University of Uyo in Nigeria before heading to Ukraine to study medicine at the Kyiv Medical University. A self-taught graphic designer, he approached the Association of Future African Neurosurgeons (AFAN) in 2020, asking if it needed help with its designs. The AFAN did not have the resources to pay him, but a discussion with its founder, Dr Ulrick Sidney Kanmounye, about Chidiebere's interests – art and medicine – started him on his journey in medical illustration. After a year learning illustrative techniques, Chidiebere began sharing his work on social media. In early December, 2021, his illustration of a pregnant Black woman carrying a fetus went viral on Twitter, Instagram and Facebook.

WHO OR WHAT INSPIRED YOU TO STUDY CHEMISTRY?

For ten years, I kept applying to medical schools in Nigeria but couldn't get in. I was at home, watching my friends go to school, so I chose chemistry, just so I could leave the house and be able to go to university!

I have since realised that there's a whole lot of chemistry in medicine. I have read that chemistry is rated as one of the most difficult courses, so having an understanding of chemistry has helped me prepare for my studies in medicine.

WHY ARE YOU INTERESTED IN BECOMING A PAEDIATRIC NEUROSURGEON?

When I was younger, I wanted to be a doctor. I lost my mum to cancer in 2011 and it affected me a great deal. I literally watched her die, and I was helpless to do anything about it. That trauma affected me and my life.

As I grew up, I realised that I loved studying how the brain works. I read a lot of neuroscience books and about how the brain retains information. This ignited a fire in me to go into paediatric neurosurgery, not only because I'm fascinated by the brain but because I have also seen children go through things that physicians can't help with. I want to help children and provide healthcare services in the area of neurosurgery.



Chidiebere's illustration of a Black fetus.
© Chidiebere Ibe

A Black child with chicken pox. © Chidiebere Ibe

An illustration of a cold sore. © Chidiebere Ibe

WHY HAVE YOU CHOSEN TO STUDY AT KYIV MEDICAL UNIVERSITY?

I had been applying to medical schools in Nigeria, the US and the UK but wasn't accepted, so I thought I would have a better chance of applying in Ukraine. Compared to Nigeria, college education in Ukraine is good, and the school fees are inexpensive, which means I can afford to pay for my tuition fees by working part time.

Ukraine has a lot of people from different cultures. There are a lot of international students, including Nigerians.

WHAT PROMPTED YOU TO START DRAWING MEDICAL ILLUSTRATIONS IN 2020?

During lockdown, I was bored! When I saw some graphic designs created by the AFAN, I didn't think they were as good as they could be, so I reached out to them on Facebook. I received a prompt response saying that there were no resources to pay me as the association was new. Because I'm passionate about neurosurgery, I offered to do its graphic designs free of charge.

Then, my mentor, Dr Ulrich Kanmounye, saw my drawings of African children and said, "Your passions are art and medicine, so why not integrate these two together?" I had never done medical illustration before – what a thought! I did some research and found it very interesting, but I didn't know anything about anatomy. Learning about it was a gradual process. I started teaching myself until I learned how to do the illustrations.

WHAT WAS YOUR FIRST PIECE OF MEDICAL ARTWORK?

My first illustration was of the gastrointestinal tract, which I'm not proud of. Back then, I was like, wow, this is nice, but now I can see it wasn't good and I've improved over the years, thank goodness!

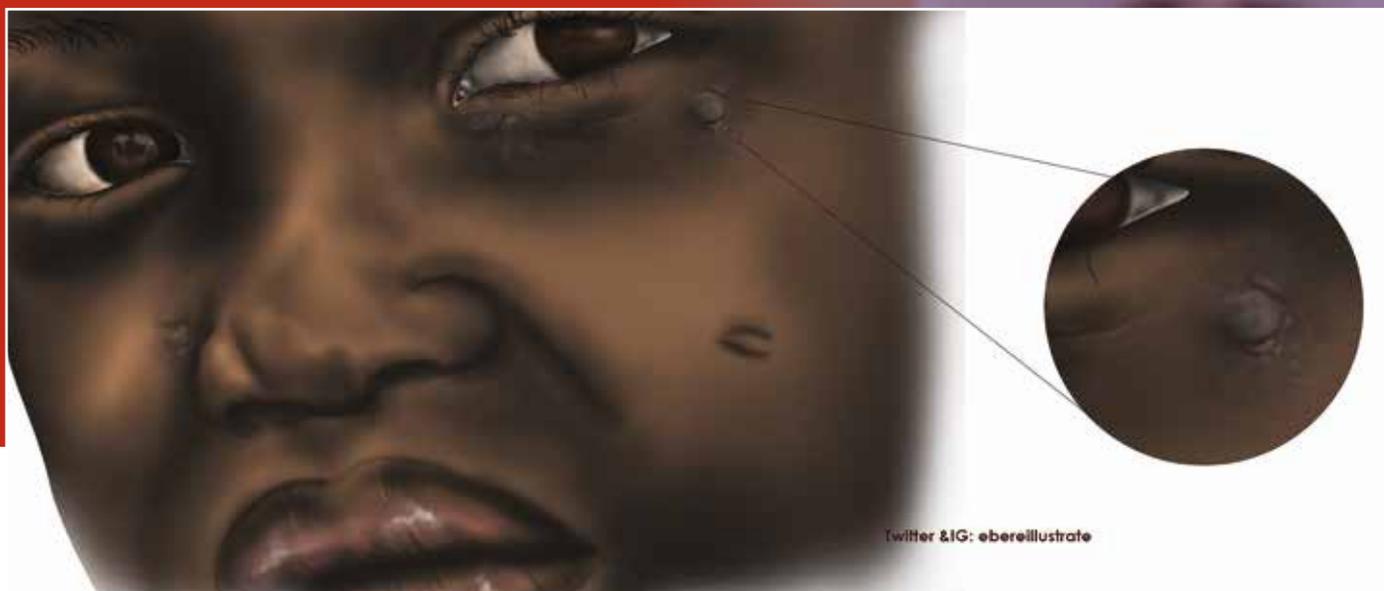
WHEN YOU PUT YOUR ILLUSTRATION OF A BLACK FETUS ON SOCIAL MEDIA, DID YOU EXPECT TO HAVE SUCH AN OVERWHELMING REACTION?

People ask me this a lot. Of course, nobody knows whether they will be famous someday, right? There wasn't any particular expectation that I was going to be famous. What's more important is that you put your hard work out there. For me, personally, I've been putting my work on social media since 2020 and I advocate for more drawings of Black people to be included in medical textbooks.

When that particular drawing hit the internet, I was literally crying because I didn't expect that to happen. At the time, I was distraught because it happened the week my visa was denied. I wasn't expecting the drawing to be so popular. When it happened, I was like, wow, I have to sit down and think about what is happening in my life right now.

I couldn't keep up with my emails; I couldn't keep up with the messages on social media. It was a moment in my life that really caught me off guard, but I'm grateful for the opportunity. My goal was never to be famous. I didn't know you can be famous for making illustrations.

I'm just doing what I'm doing with passion, really pouring out my heart and doing what I believe in.



Twitter & IG: eberillustrate

An illustration of a wart. © Chidiebere Ibe

HOW DO YOU FIND THE TIME TO STUDY, DRAW AND WORK FOR THE ORGANISATIONS YOU'RE AFFILIATED WITH?

I'm still drawing but not at the same pace as before because I have a lot of exams right now. As for the organisations I'm working with, they understand my situation.

WHAT CHALLENGES HAVE YOU HAD TO OVERCOME TO GET TO WHERE YOU ARE NOW?

In Nigeria, I lived in a remote area with no power supply. Where I lived was an hour's journey to my church, where I would travel to every day to get the power supply I needed to charge my old laptop. This was to learn about medical illustration, and I did that for about ten months. Most of the time, I used the last of my money to pay for transport to the church and I would have to work for someone in the church to pay for my way back home. I would also stay up at night reading about illustration.

Not only that but I was alone on this journey. My family is very poor. They were concerned by the length of time I would be in medical school before I could support them financially. So, I had to keep supporting myself. I had to learn a lot of skills: graphic design, photography. I had to work in fields to get money to pay my fees for medical school. But I realise that this is the story of many great people. This is what makes every young person great. This is the spirit that accompanies success.

Now, my family is proud of me because they've seen the drawings and the artwork I have on social media.

THROUGH THIS JOURNEY, WHAT HAVE YOU LEARNED ABOUT YOURSELF?

Some years ago, I was travelling to a particular area in Nigeria. Being

fascinated with medicine and doctors, I stood in front of a general hospital. I had never been in a hospital in my life, except when I was born, and I was thinking, what's happening in there right now? When would I ever go in there? I wished I could go inside and have a tour.

That same day, I ended up in that same hospital! But not as a doctor, as a patient, because on my way back I had an accident! It dawned on me that I had made a promise – to get into hospital – but I hadn't specified how or when, as a medical doctor or as a patient. Then, I had to tell myself again that I would go to hospital as a medical doctor.

It dawned on me that my words are my power, that my words are what I need to create my future. This was when I discovered that my words are my tools to help build resilience and a strong mindset. I have to use my words to create my existence. When things are difficult, I will always use my words to say this will not last forever. I will get through this and I'm really going to try to make a success of this.

WHAT WAS THE ACCIDENT?

In Nigeria, we travel by motorbike. I hailed a motorbike and the guy who was driving was drunk – I didn't know. He fell asleep and we collided into another motorbike carrying a pregnant woman. We crashed into a gutter, which was dry, thankfully, but I had wounds everywhere. No internal bleeding, though.

WHAT IS YOUR PHILOSOPHY FOR LIFE?

I believe that the universe hears us and that words are very powerful. Also, Christianity teaches me that our words are important. And, having read books on leaders, people who had made an impact on our lives, most of what they say is to use your words to create your existence. A lot of things happen in this world and those things happen when we speak about them, when we use words to create those things.



“ I’m just doing what I’m doing with passion, really pouring out my heart and doing what I believe in. ”

WHAT IS YOUR OVERRIDING PASSION?

My overriding passion is people, children in particular, and seeing the world through their eyes. Before I became a medical illustrator, one thing I could never overlook was children suffering. In Africa, you see children suffer, children without good clothes to wear or enough food to eat. You see emaciated children with a lot of health problems. So, I have a passion to help children, to give them a better life and the help they need to live a happy life.

FINALLY, WHAT IS YOUR ADVICE FOR YOUNG PEOPLE HOPING TO MAKE THE BEST OF THEIR LIVES?

The greatest gift you can give the world is the gift of self, and the way to do that is to pay attention to yourself and develop constantly. Look inwards, understand who you are and use that to create your existence.

Personally, I have never ceased to be true to myself. When opportunities come up, I always seize them, to develop myself, and that’s what has led me to this point today.

FIND OUT MORE

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HOW SMALL CHANGES IN A PROTEIN CAN HAVE LARGE IMPACTS ON HUMAN HEALTH

IN THE TAN LAB AT STONY BROOK UNIVERSITY SCHOOL OF MEDICINE, US, DR DONGYAN TAN IS LEADING A TEAM OF EARLY CAREER SCIENTISTS WHO ARE UNCOVERING THE STRUCTURES AND FUNCTIONS OF CHROMATIN. THESE DNA-PROTEIN COMPLEXES ARE ESSENTIAL FOR LIFE. SLIGHT VARIATIONS IN THEIR STRUCTURE CAN RESULT IN DISEASES, SO IT IS CRITICAL FOR SCIENTISTS TO LEARN MORE ABOUT THEM

TALK LIKE A STRUCTURAL BIOLOGIST

CHROMATIN – a DNA-protein complex found in the nucleus of a cell

CHROMATOGRAPHY – a process used to separate the components of a mixture

DNA – a molecule containing all the genetic information about an organism

ELECTRON MICROSCOPE – a microscope that produces images of very small objects by firing electrons at them

EUCHROMATIN – the transcriptionally active form of chromatin

HETEROCHROMATIN – the transcriptionally repressive form of chromatin

HISTONE – a protein around which DNA is wrapped

LESION – a damaged section of DNA

NUCLEOSOME – the subunit of chromatin, composed of DNA wrapped around a histone core

TRANSCRIPTION – the process by which genes are copied from DNA

DNA carries all the genetic information that controls how a living organism looks and functions. Given that a single strand of DNA is about 2 m long, how can it fit into the nucleus of a cell which has a diameter of only 0.01 mm? Well, we have chromatin to thank for that.

THE TWO FUNCTIONS OF CHROMATIN

In cell nuclei, DNA molecules are not 'naked' but are found tightly wrapped around a

molecule of histone protein. This subunit, comprising DNA wound around a histone core, is known as a nucleosome, and chromatin is composed of many combined nucleosomes. In this way, chromatin fulfils its function of DNA packaging, allowing 2 m of DNA to fit into a tiny cell nucleus.

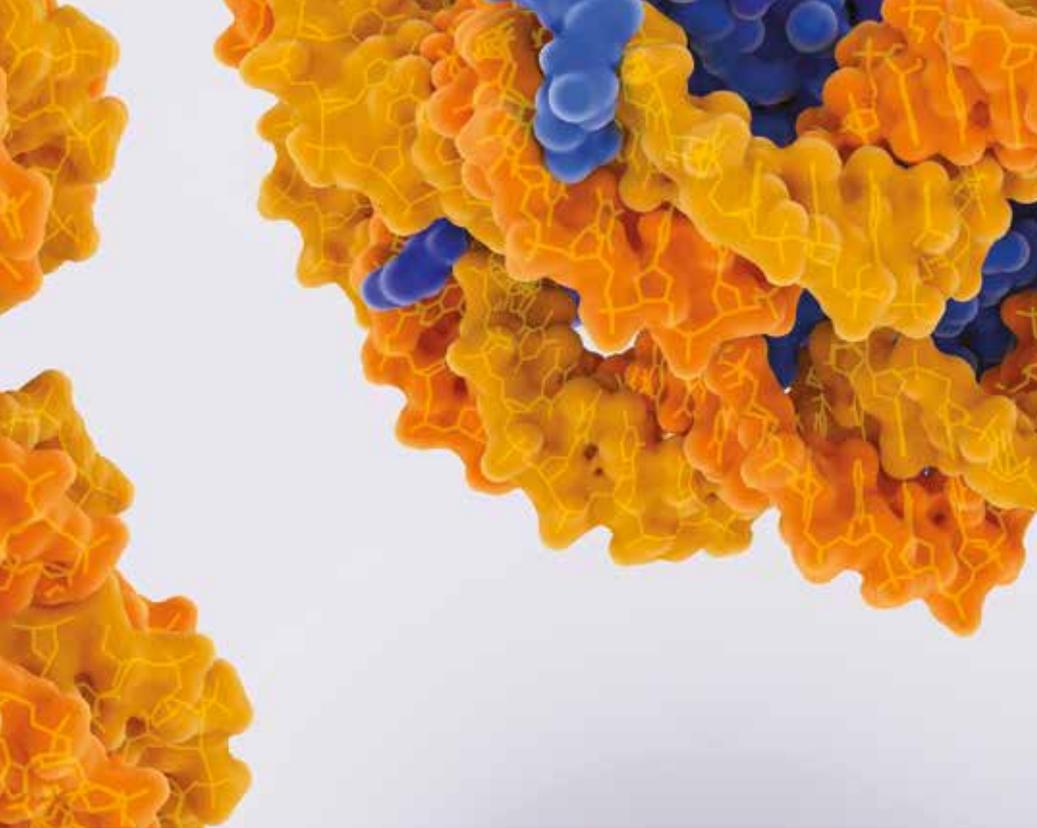
Chromatin also has the function of transcription regulation. When DNA molecules are wrapped around a histone core,

transcription proteins cannot access them to make messenger RNA (mRNA). However, the chromatin can change shape to 'open up' the structure, allowing transcription proteins to access the genetic information contained in the DNA. The open and transcriptionally active form is known as euchromatin, while the closed and transcriptionally repressive form is known as heterochromatin.

Scientists still have many questions about how the structure of chromatin influences its functions. At Stony Brook University School of Medicine, Dr Dongyan Tan is leading a group that hopes to find some answers. Her team is composed of early career scientists, from postdoctoral researchers to undergraduate students, who are investigating how chromatin structure influences the ability of DNA to repair damage to itself, and how variations in the structure of histone proteins result in different chromatin functions in the cell. These findings could uncover important information regarding human health and disease.

DETERMINING THE STRUCTURE OF CHROMATIN

The team at the Tan Lab uses a technique called single-particle cryo-electron microscopy (cryo-EM) to determine the structures of



DR DONGYAN TAN

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FIELD OF RESEARCH

Structural Biology

RESEARCH PROJECT

Investigating histone variants and
chromatin damage repair

FUNDERS

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histones and chromatin. Proteins are extracted from bacteria or insect cells through a process called 'cell lysis', whereby the cell membrane is destroyed to release the inner cellular materials such as DNA and proteins. The desired proteins are separated and purified using chromatography, then frozen in liquid ethane and imaged by an electron microscope. This method produces 2D images of the protein complex being studied. The team uses specialised computer software to process these 2D images and convert them into the 3D structure of the protein.

INVESTIGATING DNA DAMAGE REPAIR

Previous studies investigating how DNA repairs itself have tended to focus on naked strands of DNA, despite the fact that DNA in cells is wrapped around a histone core and that the structure of this chromatin will influence its function. "Chromatin structure dynamics have long been known to influence repair reactions in DNA repair pathways, and emerging evidence suggests that chromatin also plays an active role in the DNA repair process," explains Dongyan. "This means previous studies using naked DNA to model damage repair reactions present an oversimplified picture of the repair reactions inside cells."

To build a more accurate picture of how DNA repairs itself, Dongyan and the team are instead investigating DNA contained within chromatin. They use chemical methods to synthesise DNA with damaged sites, known as lesions, which are then used to create lesion-containing chromatin substrates. The team performs experiments, known as functional assays, to determine the involvement of proteins in particular cellular pathways, using

cryo-EM and other biochemical methods to establish the interactions of chromatin. "We then examine whether and how these damaged chromatin substrates change the behaviour of DNA repair enzymes previously observed on naked DNA substrates," Dongyan says.

THE IMPORTANCE OF HISTONE VARIANTS

As histone proteins provide the structural basis of chromatin, variations in the structure of the histone protein, known as histone variants, will influence the overall chromatin structure and function. To understand how, Dongyan and her team are incorporating histone variants into the two forms of chromatin, euchromatin and heterochromatin, to investigate how their structure and function are altered.

The team artificially creates nucleosomes to mimic euchromatin and chromatin fibres to mimic heterochromatin. "With these samples, we typically conduct three experiments," says Dongyan. "First, we use cryo-EM to determine the high-resolution structures of the nucleosomes and chromatin fibres. Then, we use a technique called EMSA (electromobility shift assay) to examine the DNA accessibility on the specific nucleosomes. Finally, we perform biophysical studies to investigate the dynamics of chromatin folding and condensation."

By conducting these studies on chromatin containing different histone variants, the team can determine how the structure of histone variants leads to variations in the structure of the chromatin. "These three techniques provide complimentary information that helps us understand how the incorporation of histone variants alters the structure and dynamics of

euchromatin and heterochromatin, and how changes in chromatin structure influence its functions in cells," Dongyan says.

The Tan Lab has been investigating a specific histone variant known as H2A.Z. The team has discovered that incorporating H2A.Z into chromatin results in substantial structural changes in both the nucleosome subunits and the overall chromatin fibre. "While H2A.Z increases the mobility of DNA in nucleosomes, it simultaneously enables nucleosome arrays to form a more regular and condensed chromatin fibre," explains Dongyan. "Our study provides the structural basis for H2A.Z-mediated chromatin regulation, showing that the increased flexibility of the DNA termini in H2A.Z nucleosomes is central to its dual-functions in chromatin regulation and in transcription."

If you are keen to understand how our body works at a molecular level, a career in chromatin structural biology could be for you!

ABOUT STRUCTURAL BIOLOGY

Dongyan's research focuses on improving our understanding of how chromatin regulators interact and influence the structure and functions of chromatin. There are still many things scientists do not know about these processes, and Dongyan's goal is to bridge these knowledge gaps. To achieve this, the Tan Lab applies techniques from structural biology to answer questions in the field of chromatin biology.

Improving our understanding of chromatin biology requires high-resolution structural information on how different regulators interact with chromatin in its native functional state. Cryo-EM is an ideal structural biology technique for this, as it not only allows biological specimens to be studied in their native functional state but is also uniquely suited to the study of large and flexible complexes like chromatin and chromatin-associated proteins.

HOW DOES THIS RESEARCH CONTRIBUTE TO OUR UNDERSTANDING OF HUMAN HEALTH AND DISEASE?

"Chromatin is fundamental to all DNA-based processes in cells," says Dongyan. "Under normal situations, its structure and dynamics is tightly controlled by various epigenetic regulators." These regulators include enzymes that have functions such as depositing and removing histone variants, relaxing the chromatin structure to facilitate transcription and compacting the chromatin structure to suppress transcription.

It is essential that proteins, chromatin and regulators all fulfil their proper function to ensure normal organism function and development. "Any mutations in histone proteins or deregulation of chromatin-modifying enzymes are often linked to a wide range of diseases, from neurodevelopment disorders to cancers."

WHY SHOULD YOU CONSIDER A CAREER IN STRUCTURAL BIOLOGY?

Dongyan believes structural biology is the ideal pursuit for those interested in understanding biology at the molecular level. Proteins can be seen as the 'workhorses of cells', with highly adapted structures for their specific

functions. Accessing high-resolution structural information of biomolecules provides insights into their physiological functions in cells. Importantly, this understanding serves as the basis for drug-design that targets important molecules in many diseases. "The most rewarding part of my research is the potential of discovering something novel and significant that would benefit not only the chromatin community but humanity as a whole," she says.

WHAT DOES THE FUTURE HOLD FOR CHROMATIN BIOLOGISTS?

"It is a very exciting time to be in the field of chromatin structural biology," says Dongyan. Technological advances in the field have led to much better understanding of chromatin and its role in various cellular processes, but some fundamental questions remain unsolved. "Tackling these questions will require further technology advancement, innovative ideas and collaborations across disciplines," explains Dongyan. "It is important that the next generation of scientists keeps this in mind. Renew your skills and update your knowledge to keep up with this fast-evolving field."

EXPLORE A CAREER IN STRUCTURAL BIOLOGY

- Dongyan recommends gaining hands-on experience in a lab as soon as possible. Some structural biology labs will host summer interns, while others will have research programmes designed for high school and college students.
- National laboratories, such as the Brookhaven National Laboratory (www.bnl.gov/education/programs), have opportunities that are designed for students at any stage.
- The Francis Crick Institute (www.crick.ac.uk/research/platforms-and-facilities/structural-biology) has a wealth of information about structural biology, including a dedicated careers section (www.crick.ac.uk/careers-study).
- Zippia has information about careers in structural biology, including what structural biologists do, the salary you can expect and what qualifications you will need: www.zippia.com/structural-biologist-jobs

PATHWAY FROM SCHOOL TO STRUCTURAL BIOLOGY

- At school, chemistry and biology will lay the foundations for more advanced topics in structural biology.
- At university, a degree in biology, biochemistry, molecular biology, bioengineering or biophysics could lead to a career in structural biology.
- Some universities will offer postgraduate courses in structural biology.

DONGYAN'S TOP TIPS

- 01** Embrace and celebrate every success you have in your work, even when it seems small at the time.
- 02** Be a good team player as teamwork will carry you further.
- 03** Find good mentors who will invest in your training and success. I was very lucky to have supportive mentors throughout the early stages of my career.

HOW DID DONGYAN BECOME A STRUCTURAL BIOLOGIST?

I always enjoyed math and science when I was in high school, especially physics. I like the fact that physics laws are simple yet powerful.

My curiosity and desire to understand how things work led me to establish my own research lab. I have tried to let my curiosity guide me as I search for the scientific questions that intrigue me the most. This has led me to where I am today, where I enjoy the freedom to define my own research program. I also very much enjoy the opportunity to recruit and work with talented students and

postdocs, seeing them grow, mature and become independent.

Structural biology is distinct from other sub-disciplines in biology. When we obtain the structure of a protein, this information often provides unique insights and long-awaited answers to important biological problems.

Much remains to be explored and discovered by the next generation. Now is a great time to work in the field of biomedical research and it will remain exciting for many years to come. For those of you considering this

career path, I think there are two important things to consider for your long-term health and success: find good mentors who will guide and encourage you at every stage of your career, and strike a good work-life balance. It is definitely possible to have both a successful career as a scientist and a good life.

In my spare time, I like to enjoy the outdoors with my family. I especially enjoy simple activities such as cycling in the neighbourhood with my children. We also like camping in the summer and skiing in the winter.

MEET HARRY



Harry Jung is a biomedical engineering undergraduate student working in the Tan Lab.

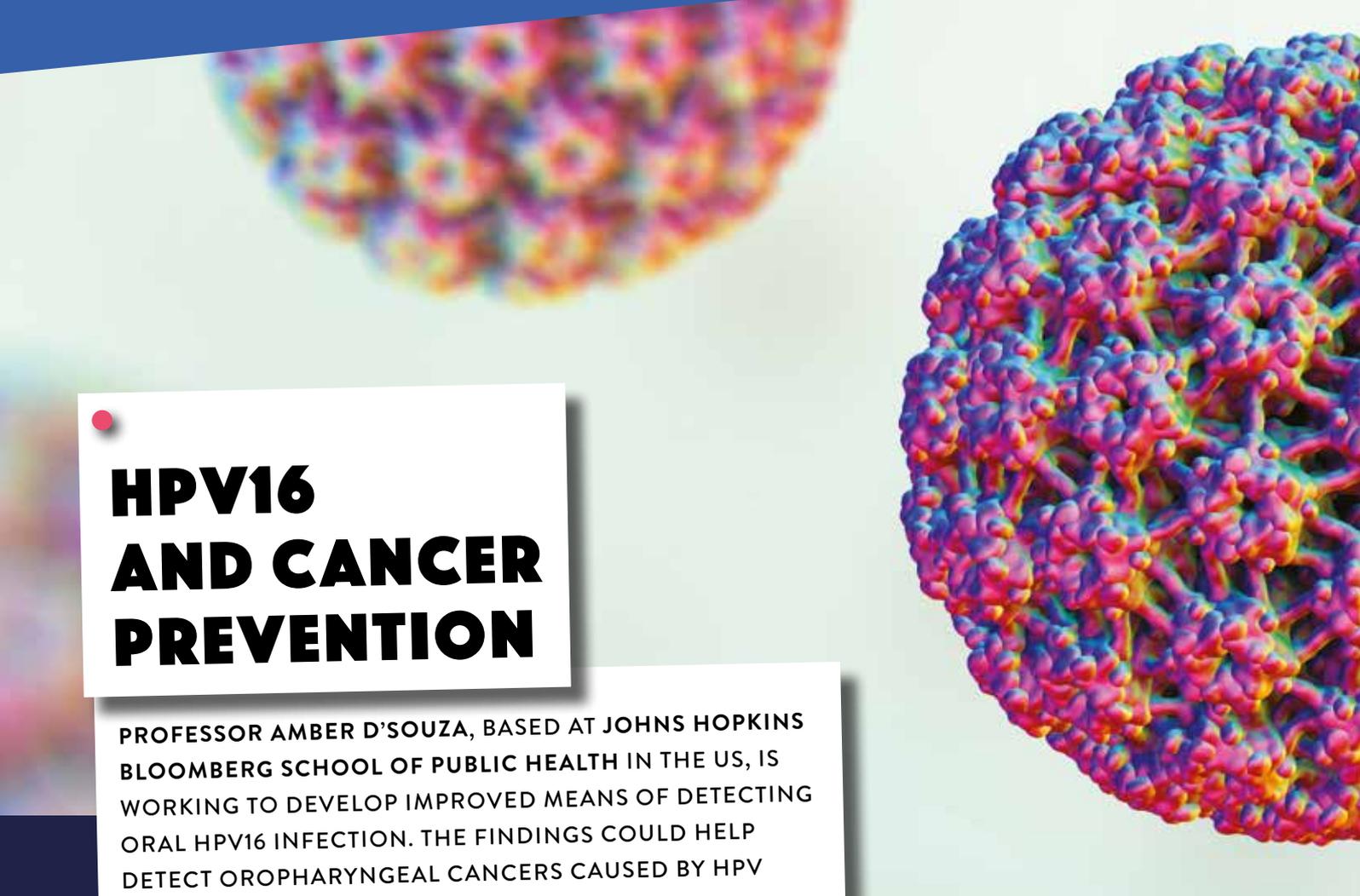
The origins of life on a primitive Earth inspired me to study biomedical engineering. I have always been fascinated by the complexity and intricacy of biomolecules such as RNA, DNA and proteins. I want to understand how tiny mutations in these molecules can lead to pathological states of healthy cells and healthy organisms. Biomedical engineering has the power to help us understand this and implement mechanisms as a force of change in patients' lives. This is what motivates me to pursue a biomedical engineering degree and further my education and training in the field.

I would definitely encourage high school students to study a degree in biomedical engineering! Biomedical engineering allows you to explore the four facets of STEM (science, technology, engineering and maths). As a biomedical engineering student, you learn the fundamentals of mechanical and electrical engineering and apply that knowledge towards human biology. Additionally, you will gain a substantial amount of knowledge in biochemistry, physics and mathematics. With all these components, biomedical

engineers aim to create novel technology to improve the lives of patients and the public.

I can easily say that my experience working in the Tan Lab has been the most fulfilling aspect of my life. The large amount of independence I have developed has allowed me to flourish as a scientist and has fostered my ability to create innovative solutions. We have a very collaborative environment in the lab. I enjoy learning and working with other lab members, as our skills and effort often synergize with one another. Learning how to work as both an independent scientist and collaboratively with other bright and more experienced minds not only furthered my work but has taught me numerous things regarding scientific research.

After I graduate with my Bachelor of Engineering, I hope to gain a PhD in biomedical science or bioengineering. I would like to investigate genetics and genetic engineering in the pursuit of combatting genetic disorders. I plan to pursue a career as a R&D scientist in the biotechnology industry to create innovative medicines and leave a lasting positive impact on the lives that could benefit from my research.



HPV16 AND CANCER PREVENTION

PROFESSOR AMBER D'SOUZA, BASED AT JOHNS HOPKINS BLOOMBERG SCHOOL OF PUBLIC HEALTH IN THE US, IS WORKING TO DEVELOP IMPROVED MEANS OF DETECTING ORAL HPV16 INFECTION. THE FINDINGS COULD HELP DETECT OROPHARYNGEAL CANCERS CAUSED BY HPV EARLIER AND REDUCE CANCER INCIDENCE

TALK LIKE AN HPV RESEARCHER

HUMAN PAPILLOMAVIRUS (HPV)

– the most common viral infection of the reproductive tract

OROPHARYNX – the middle part of the pharynx (throat and back of the mouth)

OROPHARYNGEAL CANCER – a type of head and neck cancer

SEXUALLY TRANSMITTED INFECTION – infections that usually pass from one person to another through sexual contact

HPV-OPC – a cancer of the throat caused by the human papillomavirus

HPV16 – human papillomavirus type 16

CANCER PREVENTION – action taken to lower the risk of getting cancer

The human papillomavirus (HPV) is the most common sexually transmitted infection in the world, with approximately 43 million HPV infections in 2018. In most instances, HPV is combatted by the body's immune system and does not cause any health issues or problems. However, sometimes the infection persists and leads to problems such as genital warts and cancer. In addition to causing oropharyngeal cancer, HPV can cause cervical, anal, penile and vaginal cancer. There are many different HPV strains that can cause cancer, but one type, HPV16, causes most HPV-related cancers.

Around 1% of men and 0.5% of women in the general US population have an oral HPV16 infection, with 10-20% of men and 4-10% of women having an oral HPV16 infection at some time in their life. Most people clear these infections on their own – through their immune systems – but, in some people, these infections persist and, after many years, progress to cause oropharyngeal cancer (or another form of cancer).

Indeed, HPV causes most oropharyngeal cancers in the US – this form of the cancer is called HPV-OPC. However, there are still no effective screening methods to detect these cancers. It is with this in mind that Professor Amber D'Souza, based at Johns Hopkins Bloomberg School of Public Health, and her colleagues, established

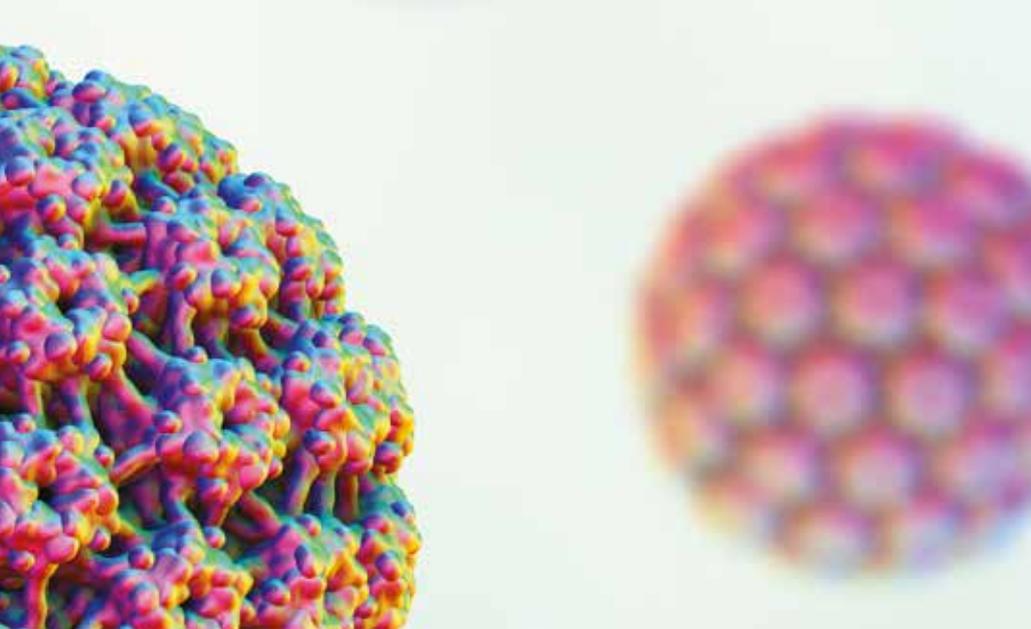
a project that seeks to improve the prevention and screening of these cancers, with a view to improving patient outcomes.

IF SOMEONE HAS HAD THE HPV VACCINE, TO WHAT EXTENT ARE THEY PROTECTED FROM HPV-OPC?

The HPV vaccine is very good at preventing new HPV infections, so among vaccinated individuals the risk of oral HPV infection is very low. "The HPV vaccine programme began in 2006 and targets young people because the HPV vaccine doesn't help clear an HPV infection a person already has when they are vaccinated and so doesn't work as well among older individuals," explains Amber. "By 2045, the rate of oropharyngeal cancer among young people (<45 years old) will have halved because of HPV vaccination that is happening now. Because most oropharyngeal cancer occurs in older people – people who have not been vaccinated –, it will take several decades before the overall rate of oropharyngeal cancer decreases."

WHAT TREATMENT IS CURRENTLY AVAILABLE FOR HPV-OPC PATIENTS?

There are several means of treating HPV-OPC patients, including surgery, radiation chemotherapy or a combination of the two. Many patients recover completely after treatment, without any serious side effects. However, for



others the oropharynx can be affected long-term, making swallowing, tasting and talking difficult. However, screening for these types of cancers is difficult and the sooner the cancer is discovered, the better.

WHY IS SCREENING FOR THESE CANCERS SO CHALLENGING?

The oropharynx is a part of the throat that is difficult to see, and it also has deep tonsillar crypts (tissue pockets) where malignant cells develop first. In addition, there are usually no physical symptoms – at least initially – so these cancers are difficult to detect at the early stages. “We know oral HPV infection persists for many years – usually more than 10 – before it leads to cancer,” says Amber. “Additionally, clinicians have never seen a pre-cancerous oropharyngeal lesion, so it is hard to screen for these cancers; by the time the infections have led to cancerous cells that cause visible lesions, it is already cancer.”

WHY ARE SOME PEOPLE MORE AT RISK OF HPV-OPC THAN OTHERS?

HPV infections are transmitted sexually; genital HPV infections are spread during sex and can spread to the mouth and cause oral HPV infection when performing oral sex. “An individual’s sexual behaviour, such as the number of partners they have, is an important risk factor, but it does not completely explain risk. Because this is a common infection, many people have a low number of partners but, by chance, get exposed and become infected,” says Amber. “Men are more likely to get infected and less likely to clear these infections. This is, in part, because of behaviour (men have more partners, on average) but also because men’s immune systems appear to be less able to control HPV infection.”

HOW IS AMBER CONDUCTING HER STUDY?

Amber and her team are studying people at increased risk of oral HPV infection, based on known risk factors. From there, they study how often oral HPV infections persist and the best

ways to screen for persistent infection. “We collect risk factor information and biological samples (like an oral rinse, saliva, blood and urine samples) and we follow those who have infection with research and clinical tests,” explains Amber. “This allows us to explore whether any of the research biomarkers and clinical tests we are considering can predict who will have persistent infection and can help us detect oropharyngeal abnormalities.”

HOW DOES AMBER DESIGN THE RIGHT STUDY TO ANSWER HER RESEARCH QUESTION?

A big part of epidemiology is study design. Amber explains, “Sometimes, we want to compare people with and without disease (called a case-control study) and, other times, we want to follow a group of people – some with the risk factors of interest and some without – to see who develops the disease (called a cohort study).” There are lots of other study designs. After picking the right design, Amber sets the criteria for who is included or excluded from the study enrolment to ensure there is no bias in the enrolment and the people in the study are representative. Amber and her team also focus on making sure they are measuring their exposure (risk factor) and outcome (disease) accurately, and collecting the information on these factors without bias.

WHAT ARE THE CHALLENGES OF RESEARCH THAT FOCUSES ON PERSONAL BEHAVIOUR?

An individual’s private behaviour is often a sensitive subject and can be challenging for participants to discuss with Amber and her team. On the other hand, it can be a positive experience when people get answers to questions they might have about their behaviours. “There is no way to cure an existing HPV infection once you already have it, so it can be difficult when our research testing identifies people who have an HPV infection,” says Amber. “Identifying an infection, without being able to offer a treatment, can cause people to worry, so we have to balance the benefits or harms of each research study.”



PROFESSOR AMBER D'SOUZA

Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Johns Hopkins University, Maryland, USA

FIELD OF RESEARCH

Epidemiology

RESEARCH PROJECT

Investigating why some people are at increased risk of oral HPV infection (based on known risk factors) to inform the best ways to screen for oropharyngeal cancer

FUNDER

National Institutes of Health (NIH)

WHAT HAVE BEEN THE KEY FINDINGS SO FAR?

When Amber first began studying HPV, it was not known that it could cause oropharyngeal cancer – she was actually part of the team that was able to show the causality. In addition, her team has learned how oral HPV infections are transmitted (sexually) and that it takes more than 10 years for these infections to lead to cancer. Finally, the team has shown that these infections do not spread through everyday behaviours, so patients do not need to worry about actions such as sharing cutlery or kissing family members. This information helps those who have oropharyngeal cancer understand how they became infected and helps those worried about whether they will develop oropharyngeal cancer understand risk levels and what affects that risk.

WHAT ARE THE NEXT STEPS FOR THE PROJECT?

It is still not known why most people are able to clear these infections while others cannot. If Amber and the team can determine the factors that influence persistence of HPV infection, they can identify who is most at risk of oropharyngeal cancer and how to best prevent these cancers.

ABOUT EPIDEMIOLOGY

Epidemiology is the study of disease or injury patterns in human populations. Initially, Amber wanted to study environmental science or wildlife biology, but came to realise that helping humans was her main interest. Amber knew she wanted to be an epidemiologist when she saw the impact it can have on public health. Epidemiologists are an important part of preventive health care systems - Amber has shown in her research how important epidemiology is in preventing and treating infections.

Amber's work has also seen her researching other infections like HIV and coronavirus, so there is a need for her to switch between research areas and compartmentalise the different projects. "I like to work on questions where there are still lots of unknowns to answer - finding those answers is an exciting feeling. I do work across different topic areas, following interesting or pressing scientific questions in whatever area they arise," explains Amber. "My training was in infectious disease, and because I studied HPV (which can cause cancer), it led me to also become an expert in cancer, and I now feel at home in both research areas."

HOW HAS AMBER DEVELOPED THE COMMUNICATION SKILLS NECESSARY TO DISSEMINATE HER RESEARCH?

Amber's work, particularly regarding COVID-19, necessitates doing interviews with the press, which has been a big learning curve for her. As the pandemic worsened, Amber conducted interviews with the press multiple times per week in 2020 and 2021, which naturally made her better - practice makes perfect! "The parts of my work I most enjoy are exploring the data to find answers in our research studies to questions we had, and then being able to communicate that information to the people who have questions about that disease or infection," she says. "I enjoy the press interviews because I know it helps communicate what we know to the public, which is important to me."

WHAT MOTIVATES AMBER TO DO THE WORK SHE DOES?

Amber went into public health to try and make a difference to people's lives. "I really believe in the power of prevention and using our health tools to decrease suffering and save lives,

such as risk-reduction through changing our behaviour to reduce infections like HPV, HIV, or coronavirus from spreading, and promoting vaccination," she explains. "I am motivated to help people who have a disease, whether that is by improving screening to detect it early or helping to understand the course of the disease."

WHAT ISSUES WILL THE NEXT GENERATION OF EPIDEMIOLOGISTS FACE?

Epidemiology is a science that is largely about how to correctly design, conduct and analyse research studies. As many of the more direct exposure-disease links have been worked out, the questions being asked are about increasing complex relationships where many factors interact. If you want to help humans and advance our understanding of diseases, then epidemiology might be the perfect career!

EXPLORE A CAREER IN EPIDEMIOLOGY

- The American Public Health Association has general information about public health, which is a good place to start. Some health departments have part-time jobs or volunteer opportunities that can be a great introduction to public health and epidemiology.
www.apha.org
- ExploreHealthCareers.org provides a lot of useful information, particularly for those based in the US who are interested in epidemiology.
- According to Salary.com, salaries for epidemiologists in the US (depending on experience and role) range between \$73,000 and \$138,000 (and more when you have a PhD):
www.salary.com/research/salary/benchmark/epidemiologist-salary

AMBER'S TOP TIP

Find something you enjoy doing! It took me a while to find epidemiology; I worked in lab science and as a teacher before working for the health department where I found out how much I enjoyed public health. For my master's, I took classes in different fields of public health. I had never heard of epidemiology, but when I took those courses, I knew I had found something I really loved and was good at!

PATHWAY FROM SCHOOL TO EPIDEMIOLOGY

Some colleges and universities have public health programmes, so Amber suggests researching particular institutions. As for subjects, she says, "Classes in science, especially biology and mathematics (in topics such as statistics), are useful. Programming skills also help as we do a lot of data management and analysis in epidemiology."

With an undergraduate bachelor's degree in public health you can work in several entry-level epidemiology positions, for example in a health department. For other epidemiology positions, you will need a postgraduate degree. People working in public health can have degrees in epidemiology, biostatistics, health policy, behavioral science, or biologic sciences.

www.prospects.ac.uk/job-profiles/epidemiologist



● HOW DID AMBER BECOME AN EPIDEMIOLOGIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I have always been interested in health and taking care of people. When I was in high school, I volunteered in a hospital and in nursing homes.

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I was always interested in science. Early on, I thought I might be involved in environmental science or wildlife biology. I majored in biology in college and thought I might study primate behaviour like Jane Goodall, but after living in a rain forest during my semester abroad in college, I realised I would miss people when

doing extended field work and was drawn to human health even more than animal and plant health.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

I am very organised and good at making and implementing plans, which has really helped with all the self-imposed steps needed to be successful in academia. The scientific process has a lot of ups and downs – experiments that don't work, hypotheses that are wrong, projects or papers you work on that are rejected or need major changes –, so resilience to try again and confidence in yourself (combined with lots of hard work and

being able to hear, incorporate and grow from feedback) are also important.

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

I love what I do but it is also very important to me to have life balance – time with my family, and some time for self-care (be that to exercise, read a book or unwind). Sometimes, it is hard to maintain the balance and I do work on many weekends, but I set aside time each day when I put away my phone, stop reading emails and switch off work. Being organised helps with this, so things aren't done last minute.

FAITH, HEALING AND MEDICINE IN THE TIME OF COVID-19

FAITH SHAPES THE WAY SOCIETIES RESPOND TO CRISES SUCH AS A GLOBAL PANDEMIC. DR EMMA WILD-WOOD, FROM THE UNIVERSITY OF EDINBURGH IN THE UK, IS STUDYING HOW FAITH INFORMS RESPONSES TO THE COVID-19 PANDEMIC IN THE DEMOCRATIC REPUBLIC OF CONGO, ONE OF AFRICA'S POOREST COUNTRIES

GLOSSARY

FAITH - a religious belief or a particular religion i.e., Christian faith

BIOMEDICAL - encompassing the sciences and modern medicine

FAITH COMMUNITIES - any group that is organised around a common faith practice, such as churches, mosques or other informal faith groups

FAITH-BASED ORGANISATIONS - structured organisations such as charities or hospitals, which are run by faith groups

INDIGENOUS THERAPEUTIC MODELS - healthcare based on beliefs and practices that originate from within a region's culture

SOCIO-CULTURAL PERSPECTIVE - awareness of the circumstances surrounding individuals and how their behaviours are affected by social and cultural factors

VENERATION - the act of honouring or respecting someone or something

For many people, the provision of healthcare has little to do with religion and faith. However, in parts of the world, faith communities are the main providers of health services. For example, during the COVID-19 pandemic, religious groups in Africa have played a significant role in providing both healthcare and communicating public health messages. While this role is clearly important, tensions can exist between the ways in which public health officials create responses to disease and the views of faith communities on disease and healing. Without cohesive public health messaging, diseases like COVID-19 are quick to spread.

Dr Emma Wild-Wood is a senior lecturer at the University of Edinburgh's Centre for the Study of World Christianity. She and a team of experts

in the Democratic Republic of Congo (DRC) are working on a project called 'Belief in the time of COVID-19'. The team is investigating how public health officials and faith leaders communicate with each other, and to the public, on health emergencies. Their aim is to help public officials understand the vital role faith communities play and find ways to improve public health messaging in the DRC.

WHY ARE FAITH COMMUNITIES PROVIDING HEALTHCARE IN DRC?

According to the Pew Research Centre, 95.8% of the population in the DRC is Christian, but a large proportion combine traditional beliefs and practices - such as spirit and ancestor veneration - with Christianity and Islam. Faith communities play a central role in Congolese society and faith

leaders hold significant public authority. It is perhaps unsurprising that Congolese people look to faith leaders for guidance on health issues.

"From the 1920s, faith-based medical services of Catholic and Protestant churches have played a large role in providing healthcare," says Emma. "They introduced biomedical ways of giving healthcare whilst never entirely effacing the indigenous therapeutic models already available to the population. From 1971, they started working on behalf of the DRC's Ministry of Health in a complex, negotiated system of co-management." Indeed, faith communities in the DRC were instrumental in leading medical responses to the outbreaks of Ebola (2,250 dead between 2018 and 2020) and measles (6,500 dead since 2019).

WHAT IS THE RESPONSE TO COVID-19 IN THE DRC?

There were 61,932 confirmed cases of COVID-19 and 1,118 deaths in the DRC between 3 January 2020 and 15 December 2021, according to the World Health Organization. As of 10 December 2021, 246,840 people were vaccinated against the disease. Compared

with other countries in Europe and North America, for example, the number of COVID-19 infections and deaths in the DRC appears to be relatively low.

While limited diagnostic and testing facilities in the country may, in part, explain these low numbers, the impact of disease outbreaks such as Ebola meant that people were more prepared. For example, in Bunia, the capital city of Ituri Province in the DRC, wash basins became common in homes, offices and commercial buildings after the Ebola epidemic. COVID-19 was first detected in the DRC in March 2020 and, in the same month, many churches closed, following COVID-19 restrictions imposed by President Félix Tshisekedi. Faith leaders also encouraged members to follow government advice on COVID-19.

HOW IS COVID-19 PERCEIVED IN THE DRC?

Emma's team found that there were three main responses to COVID-19 among Congolese people. Around two-thirds accept that COVID-19 is a disease caused by the transmission of a virus. People who hold this view recognise that public health measures are needed to control the spread of the disease. Prayer can still play an important role in the response to COVID-19 but biomedical treatment is also considered necessary.

A small number of people believe that COVID-19 is a direct intervention from God, the devil, spirits or ancestors. Not all people who hold this belief reject biomedical treatment but, for them, prayer and faith healing are essential to treating the disease. Therefore, the closure of places of worship and restrictions on gatherings was problematic. This is because some people believed that these measures were harming the response to COVID-19 rather than aiding it. Interestingly, this perspective led to the reopening of places of worship, but with precautionary measures, such as avoiding large group gatherings. This made it easier for faith leaders to engage with these communities and deliver public health messages.

A smaller group of people believe that COVID-19 is a fabricated disease, that it does not exist, or that it was created to harm others.

This is often associated with a view that the rich and powerful, particularly those in the West, are benefiting from the pandemic in some way. People's previous experience of the Ebola epidemic had a significant impact on their reactions to COVID. While measures such as the introduction of washbasins were positive, the response to Ebola was largely coordinated by international groups and some national officials. These groups did not involve local communities in the DRC, creating mistrust between health authorities and the public. This was before the health authorities realised the importance of taking differing socio-cultural perspectives into account.

WHAT IMPACT COULD 'BELIEF IN THE TIME OF COVID-19' HAVE?

The team hope that understanding the relationship between faith and healthcare in countries like the DRC will lead to more effective communication and cooperation with public health officials. Emma explains, "The language of faith is familiar to people. It is focused on well-being and can be used to communicate good health practice." Faith leaders are therefore well positioned to deliver public health messages. However, the team's research has found that faith leaders need training to understand the messages they are transmitting and why they are important, otherwise these messages can be poorly communicated.

From around 2015 onwards, global health authorities started to acknowledge the importance of faith communities. While they are working with faith-based medical services, health officials often try to use faith communities for their own public health ends. Unfortunately, this approach can backfire and create mistrust between public health authorities and faith communities, as the response to Ebola has shown. The research undertaken by Emma's team demonstrates that a different approach is needed. To cooperate with faith communities effectively, health officials need to understand how faith communities view health and well-being, and whether they see their relationship with government as positive.

Officials also need to engage those faith communities that do not have a biomedical approach to healing rather than ignore them or



DR EMMA WILD-WOOD

Senior Lecturer in African Christianity and African Indigenous Religions, Centre for the Study of World Christianity, University of Edinburgh, UK

RESEARCH PROJECT

'Belief in the time of COVID-19' – Understanding the relationships between faith, society and responses to disease during the COVID-19 pandemic in the Democratic Republic of the Congo (DRC)

TEAM

University of Edinburgh, UK: Dr Jean Benoit Falisse (African Studies and Development), Dr Liz Grant (Global Health Institute); Anglican University of Congo, DRC: Dr Amuda Baba (Public Health), Dr Yossa Way (Theology), Sadiki Kangamina (Biblical Studies and Rector); Primary Care International: Dr Nigel Pearson (Health Consultant in Fragile States and General Practitioner)

FUNDER

Arts and Humanities Research Council (AHRC)

try to impose their views upon them. With this in mind, two of Emma's Congolese collaborators are planning to write booklets in Swahili, which discuss relationships between faith and health, in order to provide education and training to local faith leaders.

"The World Health Organisation has already been calling for collaboration with faith communities," Emma explains. "For this to happen, work is still required to understand faith communities. Otherwise, health officials might try to use or manipulate faith communities, instead of recognising their inherent value and working with them in strong partnerships."

ABOUT WORLD RELIGIONS

Religion has played an integral role in shaping societies across the globe for millennia and continues to have a public and collective role today. It is therefore very important to study world religions and people's religious beliefs. As the work of Emma's team has shown, responses to events such as disease, famine and environmental crises are influenced by beliefs. Solutions to challenges that may work in one region of the world may be completely inappropriate in another.

"Aspects of society – like health – are influenced by both the distinctions between faith traditions and the way in which they sometimes overlap," says Emma. "Understanding these great human traditions tells a lot about who we are, and also it contributes to improving societal problems – like disease. Indigenous religions have traditionally been neglected in the study of

world religions. As humans recognise the need for planetary health, they are seeking the wisdom of Indigenous peoples who live close to the land."

THE IMPORTANCE OF HUMANITIES

According to Learn.com, "The humanities refer to courses in two major categories, arts and culture, that are designed to enrich a student's knowledge of the world beyond their own life." The study of humanities subjects like religion provides us with frameworks to understand how solutions to challenges such as disease, climate change and poverty can be applied in different cultural and societal settings. "Studying humanities enables us to think outside the box and engage with philosophies, beliefs, practices and behaviours that are different to our own," says Emma. "It inculcates respect and understanding for the way humans operate in the world."

A PATHWAY TO A BROAD RANGE OF CAREERS

Given the many transferable skills humanities subjects such as religious studies can offer, graduates can find themselves working in a broad range of sectors from charities to journalism, teaching, civil service, cultural heritage and retail management. "A degree in humanities gives a great foundation for someone who wants to develop skills whilst not being sure exactly what they want to do," says Emma. "I firmly recommend taking a theology and religious studies degree. It does all the things mentioned above, and it's so varied – philosophy, sociology and anthropology, literature and languages, law and history. Students get a wide disciplinary education with a focus on things that have made the world go round for millennia – religions!"

MEET EMMA



When I left school, I didn't know what I wanted to be. I had travelled as a student and learned a lot from being in different societies. I wanted to learn more and to give back, so I looked for a position that would enable me to spend more time in one place and develop a more profound understanding of the people there. I taught history and theology in the DRC and Uganda for a number of years.

I studied theology at the University of Edinburgh because I wanted to gain an academic understanding of my own Christian faith and heritage. I became increasingly interested in the way in which Christianity and Indigenous religions interacted in Africa, particularly exploring how and why people changed and adapted religious traditions. It's important to study places and people in the world that are often overlooked.

I have learned a lot from people and events that appear marginal to the dominant concerns of our own society. I have a much greater appreciation of the impact of Christianity and other religious traditions on the world – both positive and negative.

I have learned greater empathy and appreciation for people who live different lives from my own.

I enjoy teaching students – often about things they have never been able to study before. I enjoy the connection and collaboration with people across the globe, like the Congolese team on this project who brought new perspectives to our work.

EMMA'S TOP TIPS

01 Study what fascinates you.

02 Make sure you understand the methods and theories behind the academic study.

03 Go into the world, meet people and see if the theory matches the lived experience.



MEET AMUDA



Dr Amuda Baba Dieu-Merci is a lecturer in public health at the Anglican University of Congo and nursing colleges in Bunia. He is also CEO of the Pan African Institute of Community Health in the DRC and member of the 'Belief in the time of COVID-19' research project.

'Belief in the time of COVID-19' has contributed to strengthening the relationships between, and cohesion of, different faith communities, as they have realised that, together, they can be more effective in dealing with future outbreaks and disasters.

Conducting this research amidst health threats (COVID-19), conflict, and fragile social and health systems has exposed many challenges in the DRC: poverty, the proliferation of churches with diverse beliefs on social and health-related issues, and COVID-19 not being a top priority.

What I enjoy about my work is listening to and observing community members as they deal with different life issues, particularly in rural and remote areas of the DRC. I like having the opportunity to use participatory active approaches. These approaches empower community members to come up with their own solutions to challenges.

The late Dr Patricia Jane Nickson inspired me to study community health at IPASC University

College in the DRC and the Liverpool School of Tropical Medicine in the UK. Her lifestyle, community approach and integration, and capacity to listen to and observe communities was so inspiring.

It isn't usual for students in DRC to follow in my footsteps, as many choose to study law, economics, medicine, social sciences and international relations. But, as I'm a lecturer in community and public health, some of my students say they would like to benefit from the same training I received. I'm always very open to discussing these opportunities with them, even outside the lecture hall, in churches, at home and in social gatherings.

AMUDA'S TOP TIPS

- 01** Listen to your heart to understand what your passion is.
- 02** Spend time with your local community to understand people's different experiences and the challenges they face.
- 03** Find a role model whose life inspires you.
- 04** There are no drafts in life. Whatever you choose to do, do it with complete commitment and love.



THE PREMENSTRUAL DEFENCE

DR CAROLINE HENAGHAN, BASED AT THE UNIVERSITY OF MANCHESTER IN THE UK, IS TAKING A SOCIO-LEGAL AND INTERDISCIPLINARY APPROACH TO THE PROBLEMS ASSOCIATED WITH PREMENSTRUAL DYSPHORIC DISORDER. THE FINDINGS WILL HELP DEVELOP UNDERSTANDING OF – AND APPRECIATION FOR – THE RELATIONSHIP BETWEEN THE FEMALE MENSTRUAL CYCLE AND MENTAL HEALTH

TALK LIKE A LEGAL RESEARCHER

APPELLANT – a person appealing against a court's decision

AUTOMATISM – a defence which holds that a person cannot be considered as responsible for their actions

DEFENDANT – the accused person in a court of law

DEFENCE – the response given by the defendant to excuse or justify their criminal actions

DIMINISHED RESPONSIBILITY – when a defendant cannot be seen as fully responsible for their actions because of the impact a recognised medical condition has on their mental capacity

EXPERT WITNESS – a person with expert knowledge or skills in a particular field who testifies in court

INSANITY – when a defendant is considered unable to understand their actions

Premenstrual dysphoric disorder (PMDD) is a health problem that is often compared to premenstrual syndrome (PMS) but is more serious. The condition typically occurs in women in the week or two before their period starts when hormone levels start to fall after ovulation. PMDD can cause a wide range of symptoms, ranging from severe depression to irritability and anxiety.

Dr Caroline Henaghan, who is based at the University of Manchester in the UK, had PMDD for several years before she realised that her problems with anxiety and depression were connected to her menstrual cycle. After conducting her own research into PMDD and PMS, she found out about a doctor called Katherina Dalton who, alongside another clinician called Raymond Greene, had originally coined the term premenstrual syndrome (what we now know as PMS) in 1953.

However, as a lawyer, what most interested Caroline was that Katherina had appeared as an expert witness in a number of murder trials in the 1980s, where she had given evidence that allowed three different female defendants to plead a defence of diminished responsibility on account of their PMS symptoms. This is

what led to Caroline's ongoing interest in 'the premenstrual defence' which forms the basis of her current research.

PMDD – A MEDICAL DISORDER

Somewhat remarkably, it was not until 2013 that PMDD was listed as a mental health problem. On the other hand, there is a long history of society and culture attaching prejudice, stigma and shame to the female menstrual cycle. Consider the fact that it was only in 2021 that the 'tampon tax' was abolished – before then, menstrual products were considered luxury items and were taxed as such! We often consider that we live in a civilised society, but when faced with the idea that tampons are luxury items, it is easy to see how far we still have to go. However, the abolition of the tax shows that we are headed in the right direction, albeit slowly.

THE LEGAL POSITION OF THE PREMENSTRUAL DEFENDANT

The key idea behind the premenstrual defence is that a woman's behaviour, mood and actions can be driven by PMDD and, therefore, a greater degree of understanding of this should be shown when the woman is charged or sentenced. However, as it stands, there is no such thing as a premenstrual defence. "A defendant who



seeks to rely on their premenstrual symptoms to defend themselves from a criminal charge is still subject to the same laws and defence rules as any other person,” explains Caroline. “Interestingly though, in the 1982 case of *R v Smith* [1982] CLR 531, which was heard in the English Court of Appeal, the appellant Sandie Smith ‘invited the court to declare that a special defence was available to a woman suffering from pre-menstrual tension if the jury decided on the evidence that she was morally blameless’. But this argument was rejected by the court.”

This means that the present-day premenstrual defendant must rely on existing defences such as insanity, automatism or diminished responsibility. Generally speaking, there is no effective and proportionate defence for somebody in her situation – and often this is also the case for lots of other defendants who commit a crime whilst suffering from a mental health disorder. In which case, a defendant has no option but to plead guilty to a criminal offence and then rely on the judge being merciful towards her when it comes to her plea in mitigation and sentencing.

CAROLINE'S RESEARCH

Ultimately, Caroline wants to change the story that surrounds premenstrual disorders. Her background as a qualified lawyer provides the ideal springboard for her to examine PMDD through the lens of criminal responsibility. She has gone on to undertake a post-doctoral position, funded by the Economic and Social Research Council. “This has afforded me the opportunity to broaden the scope of my socio-legal research questions and look at other issues relating to the problem of premenstrual disorders, including the social role of medicine and science, and the complexities of feminist agendas in this area of study,” says Caroline. “In turn, that’s meant that, this year, I have been able to get involved in wider policy initiatives, such as the UK government’s call for evidence for its new Women’s Health Strategy.” Caroline’s hope is that her research-based

contributions toward a new set of healthcare policies for women will lead to greater awareness of PMDD and help strengthen the female patient ‘voice’ within the UK healthcare system. For Caroline, this is one of the most positive aspects of any research journey – building on what you have already learned and discovering new and exciting directions for your research.

COLLABORATIONS

One of the most important aspects of Caroline’s project is the interdisciplinary approach it takes – something that is made possible by the involvement of many experts from different fields, including doctrinal and socio-legal academics, medical specialists such as gynaecologists, scientific researchers such as clinical psychologists, medical historians and archivists, feminist activists, and creative practitioners working in the arts. “My research is really interdisciplinary, and I think that is because much of what I do focuses on the individual who is at the centre of the project – the premenstrual defendant or the person suffering from a premenstrual disorder,” explains Caroline. “I have reflected on this before and asked myself whether it is a good thing to always be drawing on a such a wide range of topic-areas. But in recent years there has been a strong shift towards interdisciplinarity within research across a number of different fields and I think that research institutions are seeing the benefits of having an interdisciplinary research team working on a particular project.”

IMPACT

There is the possibility that the research could impact on criminal law – there are already moves to bring in a defence of ‘not guilty by reason of recognised medical condition’. Caroline’s research proposes that this should be further extended to ensure that as many defendants as possible can have their mental health disorders taken into account when it comes to questions about their criminal responsibility. “Because of my lived experience of PMDD, I try to publish my research in lots of different formats so that it reaches as



DR CAROLINE HENAGHAN

School of Social Sciences (Law)
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FIELD OF RESEARCH

Law

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RESEARCH

Adopting a socio-legal and interdisciplinary approach to overcoming the challenges associated with premenstrual dysphoric disorder and conceptualising a premenstrual defendant’s criminal responsibility

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FUNDER

Economic and Social Research Council
– North West Social Science Doctoral
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wide an audience as possible – and that includes other premenstrual patients,” says Caroline. “That way, they will know that research is being undertaken to try and improve their situation and they will know that their voices are being represented when it comes to their experiences with PMDD. I think that is a really important way for me to make a meaningful impact with my research.”

This year, Caroline has done some part-time historical research at the John Rylands Research Institute and Library. It is a completely new direction for her and shows the breadth of possibility in a socio-legal career. The world is her oyster at present – so whether she becomes a lecturer and works in a law school teaching undergraduate students, or continues on her academic research path, she is bound to continue to make a positive impact on people’s lives.

ABOUT LAW

As Caroline's career has shown, a law degree does not necessarily have to lead to becoming a barrister or solicitor. Caroline's background as a qualified lawyer has stood her in good stead and informed her current research, but having an interest in the social aspects of law – and, in this case, the position of women in society – are equally important.

WHAT DOES CAROLINE FIND REWARDING ABOUT RESEARCH IN HER FIELD?

Caroline is quick to point to her love of the 'social' aspect of her socio-legal research. "The bits of what I am doing that I know have the potential to exert a powerful impact on people's lives are the best. For example, making

a contribution to re-thinking the current English criminal law defences, which have been in existence for years and years," says Caroline. "Although my research might only play a small part in any change that does come about, it is rewarding to know that I've been involved in that reform. Just as it is rewarding to have the opportunity to be involved in this project and tell everybody a bit more about my research!"

WHAT ISSUES WILL FACE THE NEXT GENERATION OF LAW ACADEMICS?

Caroline thinks that law academics will need to address very similar issues to other academics. In a post-COVID world, where technological advances and ways of working are changing all the time, a period of adjustment is going

to be necessary. "Law is still viewed as a traditional subject, so there is certainly lots of scope for advancement, change and new ways of thinking," explains Caroline. "I think that will probably come to fruition for the next generation of law academics – so the traditional law school that we have all come to know might be a very different place in years to come."

PATHWAY FROM SCHOOL TO LAW

Caroline says that there are no specific requirements to study a particular subject at school or college in order to go on and study law at university. This is good news because it means you can concentrate on studying what you love! "If you have a choice, then my advice would be to study a subject that you enjoy – that way, you are more likely to do well in it, fingers crossed!" says Caroline. "However, there are specific rules around how you then go on to qualify as a lawyer, so you do need to make sure you understand the best route for you to take at that stage."

Prospects says: "Becoming a lawyer via the university route requires you to complete a qualifying law degree (LLB) before taking the Solicitors Qualifying Examination (SQE), which is set to replace the Graduate Diploma in Law (GDL) and Legal Practice Course (LPC) for all new entrants in September 2021, although there are transitional arrangements in place for those already studying these courses."

www.prospects.ac.uk/jobs-and-work-experience/job-sectors/law-sector/how-to-become-a-lawyer

EXPLORE CAREERS IN LAW

- If you want to train as a barrister as Caroline did, you should visit the Bar Council website, particularly the 'becoming a barrister' section: www.barcouncil.org.uk/becoming-a-barrister.html
- Alternatively, if you are aiming to become a solicitor, you should take a look at the Law Society website and the 'becoming a solicitor' section: www.lawsociety.org.uk/career-advice/becoming-a-solicitor/
- Technically, there is no official minimum salary for trainee lawyers, however The Law Society recommends a minimum of £22,794 for those training in London and £20,217 for trainees elsewhere in the country. You can earn substantially more once you are qualified and more experienced.

CAROLINE'S TOP TIPS

- 01** Find out what you enjoy doing and try to build a career around the things you are really passionate about.
- 02** I know it is a cliché, but if at first you don't succeed then try and try again – so much of science is failing initially, but perseverance will get you to where you want to be.
- 03** Try and enjoy the ride. When times get tough (and they will), take a step back and think about why you began doing what you are doing. It will all be worth it in the end!



HOW DID CAROLINE BECOME A LEGAL RESEARCHER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

Reading! I am an only child and I'm afraid that I'm also a bit of cliché. My head was always in a book when I was growing up, so nothing much has changed there!

WHO OR WHAT INSPIRED YOU TO PURSUE LAW?

My dad – but he was a carpenter, not a lawyer. One day, when I was eight years old, my dad was called up to do jury service. He came back and told me all about his experience of going to court. I was hooked and I haven't looked back since. Along the way, I have met many others who have given me the inspiration to keep going. But that first spark of interest came from my dad's stint as a member of a crown court jury.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL IN YOUR CAREER?

Adaptability. Life can often be a series of lots of different challenges. But what is it they say? 'Every problem is an opportunity in disguise'. I have had a few different roles in my career and, for me, being able to adapt has been key to my success in all the different things I've done. Something that I've learned more recently – just have a go! Whatever it is, even if I don't think I stand a chance, I try to have a go. You never know your luck when you try something

new. And if you're not always successful in whatever it is you're having a go at, it will still be a good learning curve in any event.

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

Persistence is key to how I overcome any obstacles I might face. I don't always get things right first time – nobody does! But if I keep reminding myself to keep on going, I'm bound to get there in the end. That's my philosophy. And walking is the best way for me to get myself away from the screen and switch off from work. Doesn't matter where I am – the rhythm of walking along helps me to slow down and unwind.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

Finishing my PhD! That was the culmination of an awful lot of hard work (and obviously, it means that I now get to be called Dr Henaghan). But, also, because it marked the end of a long journey with my own PMDD. One year after I started the PhD, I underwent surgery for my condition. Without that operation, I am not sure that I would be in the position I am today, or that I would have been able to complete my PhD. That's my proudest achievement so far. Hopefully, there will be more to come...



The title page of Caroline's thesis and her PhD certificate

HOW CAN WE IMPROVE THE COST-EFFECTIVENESS OF MEDICAL TRIALS?

BEFORE A NEW TREATMENT CAN BE GIVEN TO PATIENTS, IT MUST FIRST UNDERGO MEDICAL TRIALS, TO ENSURE IT IS SAFE AND EFFECTIVE. DR HOWARD THOM IS A HEALTH ECONOMIST AT THE UNIVERSITY OF BRISTOL, UK, WHO HOPES TO IMPROVE THIS TIME-CONSUMING PROCESS BY ENCOURAGING THE USE OF 'ADAPTIVE TRIALS'. THESE TRIALS COULD REDUCE UNNECESSARY RESEARCH, SAVE TIME AND MONEY, LEAD TO BETTER DECISION MAKING AND, ULTIMATELY, IMPROVE PATIENT CARE

GLOSSARY

ADAPTIVE TRIAL – a medical trial whose design is adapted as it progresses

VALUE OF INFORMATION - the economic value to a funder of conducting a piece of medical research, such as an RCT

HEALTH ECONOMICS - A multidisciplinary subject drawing on economics, statistics, sociology and other fields to assist healthcare decision makers in efficient and equitable resource allocation

COST-EFFECTIVENESS MODEL - A computer program using mathematics and statistics to estimate and compare the costs and effects of healthcare policy decisions

CONTROL ARM – the group of patients in a trial who receive standard of care (the currently available drug or surgical procedure)

INTERVENTION – any medical treatment being investigated by a trial

INTERVENTION ARM – the group of patients in a trial who receive the intervention under investigation

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

When did you last take some medication? Have you ever undergone surgery? We all rely on the medical profession at some point in our lives, but have you ever considered how medics and academic researchers know how to treat us and what drugs will help us most effectively?

Before any treatment can be used on patients, it must be tested in medical trials. Randomised controlled trials (RCTs) are considered the gold standard for medical trials. If a new intervention (e.g. a drug or surgical procedure) is being tested, participating patients will be randomly assigned to either a 'control' arm, where they will receive the current standard of care or an 'intervention' arm, where they will receive the new intervention. By comparing the outcome of patients on each arm of an RCT, researchers can assess whether a new intervention is superior, or at least not inferior, to the current standard of care.

Recruiting patients for an RCT is an ongoing process as trials will require a high number of patients and it is practically impossible to recruit all of these at the beginning of the trial. Instead, recruitment and randomisation take place over several years. In conventional RCTs, all aspects of a trial (e.g. the recruitment process, the intervention) will remain the same over the period of the trial.

WHAT ARE ADAPTIVE RCTS?

Dr Howard Thom, a health economist at the University of Bristol, is investigating the advantages of adaptive RCTs over conventional RCTs. His work could help to reduce

unnecessary research, save time and money, and help the National Health Service (NHS) make better decisions about patient care.

As the name suggests, adaptive medical trials can be adapted as the trial progresses. "Early results from a trial might show an intervention is underperforming, so is not effective, or is giving patients an unexpected side effect, so is not safe," explains Howard. Adaptive trials can react accordingly to these early trial outcomes and drop arms of unsuccessful interventions. "Conversely, early results might show an intervention is outperforming all others, so the trial can be stopped early because the best intervention has been identified, or new arms can be added to test interventions that emerge during the trial." In 'adaptive enrichment trials', the criteria for recruiting patients are adapted as the trial progresses, so the trial can focus on patients who will most benefit from the treatment.

WHAT ARE THE BENEFITS OF ADAPTIVE RCTS?

"The key advantage of adaptive RCTs is that patients avoid being randomised unnecessarily," explains Howard. When a patient signs up to participate in an RCT, they may receive the latest therapeutic innovations if they are randomly assigned to an intervention arm, but there is always a risk that the new treatment does not work as well as existing treatments. Also, if they are randomly assigned to the control arm they will not personally benefit from being included in the trial.



In adaptive RCTs, fewer patients are randomised to underperforming interventions and only those patients expected to benefit the most are recruited, which saves time, money and effort, and maximises the potential benefits to patients. However, despite these advantages, adaptive medical trials are not widely adopted. Howard hopes to demonstrate the value of them to funders and patients.

THE COST-EFFECTIVENESS OF INTERVENTIONS

In the UK, the National Institute for Health and Care Excellence (NICE) evaluates the cost-effectiveness of healthcare interventions using health economic evaluation, by weighing up the costs of an intervention against its effects. “Costs can include the drug or healthcare technology itself, hospital admissions, treatments for side effects, and any visits to healthcare professionals,” says Howard. “Effects can be measured by the quantity of life years gained but also by the quality of those life years, with quality being affected by levels of pain, mobility, mental health and other factors.”

As the costs and effects of a new intervention are typically unknown, they must be modelled by health economics. Howard uses his skills in mathematics and computing to predict the costs and effects of healthcare interventions.

VALUE OF INFORMATION ANALYSIS

Howard conducts ‘value of information analysis’ to determine the cost-effectiveness of medical trials. He compares the conclusions of a cost-effectiveness model based on the information currently available with the information likely to be generated by a new adaptive trial. If the conclusions are predicted to change substantially, that adaptive trial has large value, and vice versa. This allows healthcare providers, such as the NHS, to determine the economic value of a new RCT. “If the value of a new trial is greater than the economic cost to run that trial, it is judged to be cost-effective.”

AN EXAMPLE OF AN ADAPTIVE TRIAL

Howard has been estimating the value of conventional and adaptive RCTs in wound

dressings for the prevention of surgical site infections. “Currently, there’s uncertainty as to whether simple dressings, tissue adhesive ‘glue’ dressings, or no dressings are the most cost-effective option for preventing infections after surgery,” he explains. “Our proposed adaptive trial would begin randomising patients to all three options but would be able to drop arms or stop altogether based on two early-stage ‘interim’ analyses.” To test this with a conventional RCT would require over 25,000 patients, but an adaptive trial would need about 17,000 patients. Additionally, value of information analysis showed the value of the adaptive trial was equal to or greater than that of the conventional trial, indicating it was more cost-effective.

WHO IS INVOLVED?

At the University of Bristol, Howard works on a day-to-day basis with senior research associate Dr Mary Ward and receives advice from Professor Nicky Welton. All three are health economic modellers and experts in value of information analysis. They work with Professor James Wason and Dr Michael Grayling at Newcastle University, who are experts in adaptive trial designs. Additional input on scientific computing is provided by Abdul-Lateef Haji-Ali at Heriot-Watt University in Scotland and, further afield, Dr Hawre Jalal, a health economist at the University of Ottawa in Canada. The application to surgical site infections was motivated by the Bluebelle study, led by Jane Blazeby, Professor of Surgery at University of Bristol. Professor Barnaby Reeves of the Bristol Trials Centre leads the RCT design for Bluebelle and advises Howard and his colleagues on practical aspects of RCTs on surgical site infections.

WHAT NEXT?

Howard and his team are now estimating the value of an RCT to assess oral anticoagulants used to prevent strokes during atrial fibrillation. There are several drugs in use for this, including coumarin, apixaban and dabigatran, but no RCT has ever directly compared them. Howard hopes an adaptive trial that drops arms early will require fewer patients, reach conclusions



DR HOWARD THOM

Bristol Medical School,
University of Bristol, UK

FIELD OF RESEARCH

Health Economics

RESEARCH PROJECT

Investigating the advantages of adaptive trials over conventional randomised controlled trials when conducting medical trials for new treatments

FUNDERS

Medical Research Council (MRC),
National Institute for Health Research (NIHR) Bristol Biomedical Research Centre (BRC)

faster and be of greater economic value to research funders, while determining which treatment is most effective.

The team is also analysing an adaptive enrichment trial in surgical site infection. This trial will recruit patients with either ‘clean’ or ‘dirty’ wounds and as the trial progresses, recruitment will focus on specific patients with the wound type for which researchers are most uncertain of the optimal treatment, thereby maximising the trial’s value.

Beyond this, the team is interested in learning how patients view inclusion in adaptive trials. “It is very important (and in fact a legal obligation) that patients understand the design of trials they are agreeing to participate in, and this presents a challenge when trying to recruit people to more complex adaptive trials,” says Howard. “We are planning to work with patient representatives to learn the best way to explain adaptive trials and to understand concerns patients are likely to have about recruitment to such designs.”

ABOUT HEALTH ECONOMICS

Health economics is a diverse field but is generally centred on helping society decide how to spend money on healthcare in cost-effective ways. Such an undertaking requires a broad range of expertise, which is demonstrated by the breadth of research among Howard's colleagues at the University of Bristol.

Dr Sabina Sanghera is studying how to measure and value quality of life in patients who have long-term conditions where their health is constantly changing, while Professor Joanna Coast has developed methods for measuring quality of life focused on the capabilities of patients rather than the severity of their symptoms. Dr Jo Thorn, Dr Sian Noble and Professor Will Hollingworth are using

randomised controlled trials to investigate the cost-effectiveness of treatments.

"There is variety even within my own speciality of health economic modelling," explains Howard. Professor Nicky Welton is using statistics to combine different types of evidence sources to decide whether new pharmaceuticals represent value for money, while Dr Elsa Marques is focused on economic modelling in orthopaedic surgery, looking at the cost-effectiveness of implants for hip and knee replacement.

"People working in health economics come from many disciplines," says Howard, "including pharmacy, medicine, finance, mathematics,

statistics, economics, computer science, anthropology and sociology." Each person will bring their own unique set of skills and expertise, and this diverse range of backgrounds ensures the field of health economics is dynamic and relevant.

If you want to make a difference in people's lives at the same time as doing something that you might not immediately associate with healthcare, then health economics might be the perfect arena for you!

EXPLORE A CAREER IN HEALTH ECONOMICS

- As a health economist, you could find yourself conducting research as part of a team like Health Economics Bristol at the University of Bristol (www.bristol.ac.uk/population-health-sciences/centres/healthecon) or for a think tank like the King's Fund (www.kingsfund.org.uk), or working for a pharmaceutical company. You could advise the government about the economics of health policies or use your skills working for a regulatory agency such as the National Institute for Health and Care Excellence (www.nice.org.uk). Or, like Howard, you could provide commercial consulting services for companies such as Clifton Insight (www.cliftoninsight.co.uk).
- The International Society for Pharmacoeconomics and Outcomes Research (www.ispor.org/home) is the professional society for health economists. Howard recommends examining the titles and abstracts of upcoming conference presentations and workshops to see what is going on in the world of health economics.
- The Faculty of Health Sciences offers numerous opportunities for school students to experience life as a student at the University of Bristol (www.bristol.ac.uk/health-sciences/outreach), including summer schools and taster days.
- According to talent.com, the average health economist salary is £50,000, depending on position and experience: uk.talent.com/salary?job=health+economist

HEAD TO HOWARD'S FUTURUM WEBPAGE FOR A POWERPOINT PRESENTATION ABOUT HIS RESEARCH:

futurumcareers.com/how-can-we-improve-the-cost-effectiveness-of-medical-trials

PATHWAY FROM SCHOOL TO HEALTH ECONOMICS

- Because it is an interdisciplinary field, you can approach health economics from many different directions.
- At school, studying economics (if available) will be valuable. Business studies, geography and history will provide a strong background in the qualitative side of health economics, while maths and physics will prepare you for the quantitative side.
- At university, a number of degrees could lead you to the field. "I often work with people who came to health economics from sociology, economics, pharmacy and medicine," says Howard. "To get into health economics modelling, good quantitative degrees, like mathematics, physics or computer science, are key."
- Postgraduate degrees specialising in health economics are available at some universities, including the University of Bristol (www.bristol.ac.uk/study/postgraduate/2022/health-sciences/msc-health-economics-and-health-policy-analysis).
- This website lists some of the different routes you can take into the field of health economics: www.masterspublichealth.net/faq/how-do-you-become-a-health-economist



HOW DID HOWARD BECOME A HEALTH ECONOMIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I was a massive nerd when I was young! I spent much of my free time programming simple computer games, studying maths and reading *The Economist*. At the time, I thought I'd become a games programmer or mathematician. I didn't realise that the design of clinical trials required people with programming or maths skills.

HOW DID YOU BECOME A HEALTH ECONOMIST?

My undergraduate degree was in pure mathematics and, like many others who enjoyed maths but didn't fancy a career as an impoverished number theorist, I was lured into doing a master's in financial mathematics. I started this in 2008, but, during the opening week of my degree, the investment bank Lehman Brothers collapsed. This kicked off the global financial crisis and led me to re-evaluate my career prospects. Luckily, I'd completed a brief summer internship at the National Centre for Pharmacoeconomics in Ireland and had hugely enjoyed working on my first cost-effectiveness model, so

I decided to complete a PhD in health economic modelling.

HOW DOES YOUR MATHEMATICAL BACKGROUND HELP YOU IN JOB?

My training in pure and financial mathematics is atypical of health economists, who usually come from an economics background, but is typical for health economic modellers. We need to be able to draw on diverse fields of mathematics, including probability theory, statistics, linear algebra and analysis, to build realistic models of healthcare interventions and patient outcomes.

WHAT ARE THE GREATEST JOYS OF BEING A HEALTH ECONOMIST?

I love solving a difficult health economic problem with some clever bit of maths or finding a new way to program a model that makes it faster or more realistic. These challenges are always new and exciting, and they're often things that nobody else has done before. I also love having an impact on the world by improving healthcare delivery and research. The mathematical and programming challenges I solve lead directly to better

evidence for decision makers, which leads to be better outcomes for patients.

WHY DID YOU ESTABLISH A HEALTH ECONOMICS CONSULTANCY COMPANY?

I founded Clifton Insight to allow me to work on further health economic problems. Pharmaceutical companies use health economics to demonstrate the value of their new interventions but have different data and challenges to governments and academics. For instance, they sponsor the RCTs themselves and they have access to individual patient data on which to base their models, which is rarely the case for academics. They also require much earlier stage modelling than in academic work, as it can begin before their interventions are licensed by regulators. These distinct types of challenges are what motivate me to do consulting work.



HOW IS BREXIT AFFECTING THE UK'S ECONOMY?

THE UK'S EXIT FROM THE EUROPEAN UNION CREATED A NEW BORDER, NOT ONLY TO PEOPLE AND GOODS, BUT TO FINANCE. PROFESSOR SARAH HALL, AN ECONOMIC GEOGRAPHER AT THE UNIVERSITY OF NOTTINGHAM IN THE UK, IS STUDYING THE EFFECTS OF BREXIT ON THE FINANCIAL SERVICES WE USE EVERY DAY

TALK LIKE AN ECONOMIC GEOGRAPHER

BREXIT – the UK's withdrawal from the European Union

ECONOMIC GROWTH – an increase in the value of the goods and services produced by the economy over time

EUROPEAN UNION (EU) – a group of 27 European countries that share political and economic laws, including the ability of member countries to freely trade with each other

FINANCIAL SERVICES – services offered by the finance industry involving the management of money and assets, including opening bank accounts, tax preparation and

management, and investment services

GROSS DOMESTIC PRODUCT (GDP) – the total value of all goods and services produced by a country

LEAVE – the campaign for the UK to leave the EU

PASSPORTING – an arrangement in which a financial services firm registered in the EU can do business in any other EU country without requiring further authorisation from that country

REMAIN – the campaign for the UK to remain in the EU

The financial sector is a pillar of the UK's economy. Brexit had the potential to unlock new financial opportunities, but also to throw up new barriers to trade and finance. With such a polarised debate, how can we keep track of the real economic effects of Brexit? Professor Sarah Hall is an economic geographer at the University of Nottingham and a member of the UK in a Changing Europe research group, an organisation providing impartial analysis about all aspects of Brexit. She is investigating the consequences of Brexit for the UK's financial sector.

WHAT ARE FINANCIAL SERVICES?

Companies in the finance industry offer a broad range of services that involve managing money and wealth. These financial services include banking, taking deposits, providing insurance, managing payments, transferring funds between accounts, issuing credit and debit cards, managing investment funds and providing currency exchange. In 2019, financial services contributed £132 billion to the UK economy, nearly 7% of the UK's total economic output. About half of this value was generated in London, with the rest spread

primarily between cities such as Edinburgh, Leeds and Manchester. In early 2020, the finance industry employed 1.1 million people, accounting for 3.2% of the UK's jobs. The UK offers many of its financial services to customers abroad, running a trade surplus in this sector of £41 billion in 2019.

PREDICTED IMPACTS OF BREXIT

Because financial services are an important part of the UK economy, and because financial trade is international, campaigners on both sides of the Brexit debate had strong opinions about the impacts of Brexit on UK finances. Leave campaigners argued the UK would have full control over its own economic policy once it left the EU, including regulation of the finance sector. Remain campaigners argued that the UK has strong trade links with the EU, its closest neighbour and largest trading partner, and that leaving the EU would endanger these links and reduce prosperity.

The heated nature of the Brexit debate makes it important for researchers like Sarah to take an impartial, evidence-based approach to understanding the consequences (both the challenges and the opportunities) of Brexit. "To make the best policy, to have the most informed public debate and to make decisions about what should happen next, we need information and analysis that tries to step back, assess what has happened and explain what the options are from an impartial viewpoint," Sarah says.



PROFESSOR SARAH HALL

Professor of Economic Geography,
University of Nottingham, UK

UK IN A CHANGING EUROPE

www.ukandeu.co.uk

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FIELD OF RESEARCH

Economic Geography

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RESEARCH PROJECT

Understanding the impact of Brexit on
the UK's financial services

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FUNDER

Economic and Social Research Council
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HOW DOES SARAH STUDY THE FINANCIAL SECTOR?

Economic geographers rely on both theory and data in their research. One theory Sarah is using to interpret the effects of Brexit is the 'gravity model of trade'. This model posits that trade will be strongest between countries that are geographically close to each other. For example, the UK's biggest trading partner is the EU, its closest geographical neighbour. Post-Brexit, the government may aim to increase trade with non-EU partners like Australia, Canada and New Zealand. However, the gravity model predicts that the distance to these countries will make it more difficult to build strong trading relationships.

The bedrock of Sarah's research is data, with important statistics sourced from the government and other financial institutions. This kind of data includes the number of offices in the UK, how many people are employed, where financial services are being exported to and similar 'big picture' information. Sarah also talks to people, interviewing financiers, policymakers and trade bodies to get a feel for what the facts and figures mean to individuals. "This is a part of the research process that I really enjoy," Sarah says. "We get to speak to people who are working in the finance sector and learn from them about the challenges and opportunities for financial services resulting from Brexit."

THE IMPACT OF BREXIT ON FINANCIAL SERVICES

Brexit has made it more difficult for the

UK to export financial services to the EU. In the past, the practice of 'passporting' allowed UK companies to easily trade with customers in any other country in the EU. After Brexit, UK companies have lost this convenience. "Market access is now allowed on a temporary basis from the EU to the UK," Sarah explains. "But UK firms are now reliant on the EU deciding which parts of financial services will have temporary access to the EU market without additional regulatory checks. This doesn't cover the same range of activities that were covered by passporting and it isn't as stable."

Since UK finance companies can no longer sell their services to customers in EU countries from their UK offices, many have opened new offices and moved operations, employees and assets to other countries in the EU. Research estimates that about 7,500 finance jobs have left London so far – a small proportion of the existing 1 million jobs, and fewer than predicted, though moves may continue. These finance jobs have been moved from London to Paris, Amsterdam, Dublin and Frankfurt, but London still remains the main hub for financial services in Europe.

The economic effects of Brexit extend beyond the finance sector. UK consumers have experienced empty shelves in shops caused by labour shortages in supply chains. Some UK citizens living in the EU have had to change banks because their UK-based banks could no longer provide them with

accounts after losing passporting rights. Overall, Sarah says, "Recent estimates from the government suggest that GDP will be 4% lower in the medium-term as a result of Brexit. This compares with a 2% decline due to COVID, suggesting that we will be seeing the economic impacts of Brexit for longer than those of COVID."

WHAT NEXT FOR THE UK ECONOMY?

Sarah sees financial services as a microcosm of the UK's economic growth strategy after Brexit and COVID. "Can the UK build back better from COVID and level-up persistent regional imbalances in productivity?" she asks. With its new freedom to craft its own financial regulations, the government is hoping to stimulate emerging areas in the financial sector, such as green finance and digital finance. However, as the country's economic geography develops, Sarah and other researchers in the field will continue to conduct the impartial analysis we need to make sound economic decisions in the future.



ABOUT ECONOMIC GEOGRAPHY

Economic geographers study how the location of an economic activity affects what that economic activity looks like – who does it, how profitable it is, how it changes over time, and how it affects social and political life. For example, economic activity in the UK is concentrated in London, which dominates the UK's economy and is an international leader in the finance industry. Economic geographers investigate why this is.

Economic geography is a branch of human geography and is closely linked to fields such as urban geography. Economic geographers have the opportunity to collaborate with researchers in different disciplines, as the issues studied in economic geography are often influenced by political, social and environmental factors. For example, topics of study in economic geography vary from country-scale issues, such as how borders affect trade and finance, to smaller-scale questions, such as how soil properties determine where productive agricultural regions develop or why gentrification occurs in particular neighbourhoods.

WHAT DOES AN ECONOMIC GEOGRAPHER'S DAY LOOK LIKE?

For economic geographers, no two days are alike! Research may involve collecting data by interviewing financiers and combing through government statistics. Academics also spend time writing academic papers and blogs to publicise their results and writing policy documents to ensure their research is implemented in government policies. Sarah also spends time teaching students, helping to run the teaching activities of her department, meeting with colleagues and networking with other academics. "As an academic researcher, you have a lot of flexibility to manage your time, which is great," says Sarah. "But you do need to be organised to work out what is a priority."

WHY SHOULD YOU BECOME AN ECONOMIC GEOGRAPHER?

Geography is a broad subject that connects to many other fields. That breadth makes it a great option for people who enjoy both humanities and mathematical subjects.

Economic geography is of increasing importance in our global economy and is coming to the attention of policymakers. "The UK's Chancellor of the Exchequer, Rushi Sunak, even mentioned economic geography in the 2021 Budget!" says Sarah. A career in economic geography offers intellectual freedom and the opportunity to contribute to understanding some of the world's most pressing problems.

PATHWAY FROM SCHOOL TO ECONOMIC GEOGRAPHY

- Most university geography courses are very flexible in terms of subjects studied at school before beginning a degree. Sarah emphasises that you should study the subjects you enjoy rather than worrying about taking the 'right' courses. As an interdisciplinary subject, breadth of knowledge and interest is important in geography. "I studied a complete mix of subjects at school – geography, maths, music and French," says Sarah.
- Most universities offer undergraduate and postgraduate degrees in geography. Some universities will allow you to specialise in economic geography or take a dual degree in geography and economics.
- An undergraduate or master's degree will be sufficient for most economic geography jobs outside academia, but a PhD is required to become a professor like Sarah.

EXPLORE A CAREER IN ECONOMIC GEOGRAPHY

- Sarah recommends exploring the resources, activities and events provided by the Royal Geographical Society (www.rgs.org) or reaching out to your local university to find events for young people interested in careers in geography.
- Specialising in economic geography will open opportunities in finance and economic analysis, or you could become an academic like Sarah and study the aspects of economic geography that most interest you.
- This article discusses some of the topics studied by economic geographers: www.marketbusinessnews.com/financial-glossary/economic-geography

SARAH'S TOP TIPS

- 01 Do what you enjoy.
- 02 Work hard.
- 03 Be inquisitive about the world around you!



HOW DID SARAH BECOME AN ECONOMIC GEOGRAPHER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

Music was a huge part of my life at school, and I nearly became a professional musician rather than going to university! I frequently travelled from my small, Teesside village to London to learn and perform, which really opened my eyes to the differences within the UK – sometimes it felt like going to a different country. I think this was really important in my decision to study geography – I was interested in why the same policies could have such different impacts in different places.

WHAT INSPIRED YOU TO BECOME AN ECONOMIC GEOGRAPHER?

I grew up in the northeast of England at a time when my local economy was rapidly deindustrialising. I became fascinated by why this was happening and why the

experience of where I lived was so different to places like London.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

One of the things I love about my job is the variety, so the things I'm most proud of are equally varied: having two books published (one finished during the COVID lockdown when I was also home-schooling my three children), providing analysis to assist with post-Brexit policymaking and supporting early career researchers.

WHY DO YOU FIND FINANCIAL SERVICES AND SYSTEMS SO INTERESTING?

They're a central part of the UK economy but are really unevenly distributed. They are important across the whole economy but are dominated in London. I really think that

understanding them can provide us with lots of insights into bigger issues like uneven regional growth in the UK and how the UK's position within the world economy will change post-Brexit.

WHAT DO YOU ENJOY DOING OUTSIDE OF WORK?

I love running, Pilates and reading, but my biggest commitments outside of my research are being a mum to my three young children – I spend a lot of time running a family taxi service! As a result, I'm determined to work to support careers for parents in research.

ANALYSING THE IMPACTS OF BREXIT

SARAH OVERTON AND JOËL RELAND FORM PART OF UK IN A CHANGING EUROPE, A RESEARCH ORGANISATION BASED AT KING'S COLLEGE LONDON, UK, WHICH PROVIDES IMPARTIAL RESEARCH AND ANALYSIS ABOUT BREXIT AND ITS EFFECTS ON THE UK AND EU

TALK LIKE A POLITICAL SCIENTIST

BREXIT – the name given to the UK withdrawal from the EU

EUROPEAN UNION (EU) – an economic and political partnership of 27 European countries that share laws in many areas. These include the ability of citizens to freely travel and work in different member countries and the ability of member countries to freely trade with each other

LEAVE – the campaign for the UK to leave the EU

REFERENDUM – a public vote on a single political question. In the Brexit referendum, voters were asked 'Should the United Kingdom remain a member of the European Union or leave the European Union?'

REMAIN – the campaign for the UK to remain in the EU

THINK TANK – a group outside the government which makes policy proposals

UNITED KINGDOM (UK) – the union of England, Scotland, Wales and Northern Ireland

In recent years, the world seems to have become increasingly divided. Brexit is a prime example of this, as the UK was split 52:48 on whether the UK should leave the European Union (EU) or remain a member.

The Brexit referendum took place on 23rd June 2016, but before people went to the polling booths, there were hard-fought campaigns on both sides from politicians, influential people and organisations who tried to persuade voters of the merits of 'Leave' or 'Remain'. Contradictory claims about the consequences of the two possible outcomes were made, which were often difficult to verify but impossible to ignore. Remain campaigners claimed 820,000 jobs would be lost if the UK left the EU, while Leave campaigners claimed leaving would allow £350 million a week to be spent on the NHS. A heavily contested campaign ended with a very close result: the UK voted to leave the EU by 51.9% to 48.1%.

After several years of negotiations, the UK formally left the EU. Exit was completed on 31st December 2020 when the 11-month transition period ended. So, what have the impacts of Brexit been? Sarah Overton and Joël Reland, from the UK in a Changing Europe think tank based at King's College London, are looking into this.

EVALUATING THE IMPACTS OF BREXIT

UK in a Changing Europe provides impartial research and analysis about Brexit and its effects on the UK and EU. Sarah, Joël and the rest of the team are working to understand more about the consequences of Brexit.

"There's no exact science for evaluating the impacts of Brexit," says Sarah, "but we commonly use methods of data analysis." For example, Sarah and Joël have compared official statistics from the UK and EU about the labour market and other aspects of the UK economy to investigate issues such as wage

growth and inflation since Brexit. They also regularly analyse polling data to understand how the public views the impacts of Brexit.

As such a vast topic, studying the impacts of Brexit is challenging. "There is an almost endless range of policy areas which could be affected by Brexit," says Joël. So, the team must go through policy documents, websites and press releases, identifying which policy changes and developments are significant. But, even this does not give a complete picture. Another challenge is that Leave voters wanted benefits such as 'control' and sovereignty, which are not measurable in a physical sense and so are hard to quantify.

It transpires that a number of the pre-Brexit claims made by the Leave and Remain campaigns were unfounded. The prediction of 820,000 jobs being lost due to Brexit has not been borne out. And the NHS is not receiving £350 million more a week now that

the UK is no longer in the EU (this particular claim was found to be a 'clear misuse of official statistics'). These examples highlight how both campaigns used (or in some cases, misused) statistics to persuade voters.

IMPACTS ON THE UNION

The UK is a union of four nations and Brexit is having consequences on this union. The referendum was decided on the basis of the total vote across the whole UK, but there were significant differences in the way different parts of the UK voted. In Scotland, 62% of those who voted in the referendum voted to remain. And polling since the referendum suggests that, on the whole, Scots think the consequences of Brexit have been negative. "The Scottish National Party is now advocating another Scottish independence referendum," explains Sarah, "arguing that Brexit has changed the terms of Scotland's place in the UK."

In Northern Ireland, the majority of voters also voted to remain. "How to keep the Irish border open was probably the most difficult question of UK-EU negotiations," says Joël. "It was agreed early on that the border had to be kept open to preserve political stability between Northern Ireland and the Republic of Ireland." This has been achieved by keeping Northern Ireland aligned with many EU laws, in an attempt to keep a free flow of trade across the Irish border. But this has practical and political consequences. Checks are now required on many goods crossing from Great Britain into Northern Ireland, resulting in some disruption to trade. "Politically, this is very difficult for the Unionist community in Northern Ireland, whose political identity is inextricably bound up in the idea that they are part of the UK, not Ireland," says Joël. "The fact that Northern Ireland now follows some different laws to the rest of the UK is challenging to this sense of connection." In contrast, this fractured connection with the rest of the UK is politically advantageous for the Nationalist community, as the issues caused by Brexit seem to be increasing support for the reunification of Northern Ireland with the Republic of Ireland.

IMPACTS ON EU CITIZENS LIVING IN THE UK

"Ending free movement between the UK and the EU was a priority for many Brexit

supporters," says Sarah. Yet many EU citizens live, work and study in the UK, while many UK citizens live, work and study in the EU. "The UK government had promised that EU nationals would be automatically granted indefinite leave to remain and lose none of their existing rights. However, these commitments were not delivered."

With no official database of foreign nationals living in the UK, the authorities had no way of telling who had the right to stay in the UK, and who did not. To solve this, the EU Settlement Scheme was launched, enabling EU citizens living in the UK to apply for 'settled status'. But this must be done online, meaning elderly people and those from vulnerable groups (such as those who are homeless or experiencing mental health issues) are underrepresented in applications.

IMPACTS ON OTHER SECTORS

Before Brexit, EU citizens made up the majority of temporary workers on British farms during the harvest season. Brexit has made it harder for EU seasonal agricultural workers to come to the UK, meaning that in recent years, some crops have been left to rot in their fields as there are not enough workers to harvest them. Under EU law, British farmers could receive financial support from various schemes. Without these payments, some livestock farmers may lose 60-80% of their income. Yet these EU subsidies favoured large landowners and had negative impacts on smaller farms, and so Brexit has provided opportunities for farming reform in the UK.

"UK universities and colleges have a long history of collaborating closely with those in other European states on both education and research," says Joël. However, following Brexit, the UK is no longer participating in the Erasmus programme, which enabled students to study abroad on exchange placements around the EU, and the number of EU students enrolling at UK universities has halved. It has instead set up its own replacement 'Turing Scheme', which offers more placements overall but with less generous funding.

Some have argued that, as a result of Brexit, the UK has regained a degree of sovereignty from the EU. The UK now has more freedom



SARAH OVERTON



JOËL RELAND

UK IN A CHANGING EUROPE
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FIELD OF RESEARCH

Politics and Foreign Affairs

RESEARCH PROJECT

Providing impartial research about Brexit and its impact on the UK and EU

FUNDER

Economic and Social Research Council (ESRC)

to make its own decisions and set its own regulations. We will see the country try to take advantage of this new independence as it moves forward.

The impacts of Brexit will continue to unfold with time, and there is still much we do not yet know about how this momentous political event will affect the lives and livelihoods of those living in the UK and EU. Political researchers like Sarah and Joël are therefore essential for ensuring thorough and impartial analysis is conducted into political topics such as Brexit.

ABOUT POLITICS AND FOREIGN AFFAIRS

Politics and foreign affairs encompasses a wide range of different topics relating to domestic and foreign political activities. Political scientists may work as researchers, like Sarah and Joël, investigating how national and international governments and policies influence political landscapes. Or they may work as political forecasters, trying to determine what the outcomes of political decisions or elections will be, based on past political events.

As the topic of Brexit has highlighted, politics can be very divisive. So, it is very important that researchers such as Sarah and Joël remain impartial and conduct their research objectively and without prejudice.

WHAT DO POLITICAL SCIENTISTS DO?

There is no such thing as a typical day for a political scientist! The nature of the field means that researchers are constantly updating

their topics of investigation as current affairs develop. Daily tasks include researching current political activities, writing articles about political issues, and planning and coordinating long-term projects. Sarah and Joël regularly interview politicians and government officials for the UK in a Changing Europe Brexit Witness Archive (www.ukandeu.ac.uk/brexit-witness-archive), to provide a record of the experiences of those who have shaped the Brexit process. They also monitor the impacts of Brexit in close to real time through the UK in a Changing Europe regulatory divergence tracker (www.ukandeu.ac.uk/research-papers/uk-eu-regulatory-divergence-tracker).

Political scientists study topics ranging from how parliaments and governments work, to political parties' campaigns, to public attitudes on political topics, and more. "Political scientists evaluate problems," says Sarah. "Research may involve conducting interviews

and focus groups or analysing qualitative and quantitative data."

WHAT WILL THE NEXT GENERATION OF BREXIT RESEARCHERS INVESTIGATE?

"There's still a lot of work to do monitoring, analysing and evaluating the impacts of Brexit on the UK and on its relations with other countries," explains Joël. "The UK-EU relationship will continue to develop, so we expect future researchers will be thinking about the implications of that relationship and how it might continue to change going forward."

PATHWAY FROM SCHOOL TO POLITICS AND FOREIGN AFFAIRS

- If you are interested in a career in politics and foreign affairs then history, geography, economics and foreign languages will be useful subjects to study at school. "But really, there is no set selection of subjects that you need to take in order to go into this field," says Sarah, "as any subject can be relevant to politics and foreign affairs."
- Most universities offer degrees in politics and/or international relations. But again, any degree could lead you to a career in the field. "Having people who have studied a wide range of subjects in politics and foreign affairs jobs is really valuable," explains Joël.

EXPLORE A CAREER IN POLITICS AND FOREIGN AFFAIRS

- Joining a politics or debating society at school or university is a great way to build political knowledge and meet others who share similar interests. Sarah also recommends joining campaigns on issues you are passionate about.
- For the latest analysis of current affairs, Joël suggests checking think tank websites and subscribing to current affairs newsletters. Visit the UK in a Changing Europe website to learn more about the range of research the group conducts: www.ukandeu.ac.uk
- Prospects provides information about what you can do with a degree in politics (www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/politics) or international relations (www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/international-relations).

SARAH AND JOËL'S TOP TIPS

- 01** Follow what makes you tick. You'll enjoy something more, and likely be better at what you do, if it is something you care about.
- 02** Surround yourself with people who support you and give constructive advice. Having a mentor who is a bit further along in their career can be really helpful.
- 03** Never be afraid to project personality into what you do. When you do research, it is very much your own domain and you will have a unique blend of perspectives and skills – this is what makes your research distinctive and interesting.
- 04** Take opportunities that come your way. Use them to build up a network of contacts, as well as gaining useful skills and experience.



● HOW DID SARAH BECOME A POLITICAL SCIENTIST?

I grew up in Nepal and India so from a young age developed an international perspective.

This grew over time into an interest to work in politics and international relations.

I worked in the UK Parliament at a time when there were a lot of Brexit developments happening. This work involved analysing legislation, monitoring parliamentary business, briefing MPs and

helping with policy matters. I focused specifically on UK-EU relations, foreign affairs, home affairs and justice.

Working in Parliament definitely influenced my decision to become a political researcher and to focus on UK-EU relations and the impacts of Brexit. I found it very interesting to be doing research on different topics as they were developing.

I aim to be evidence-led in my research, focusing on the findings that emerge in the data, so I don't find it too hard to remain impartial in research outputs. It's always good to be aware of your own biases during the process.

Outside of work, I enjoy spending time with family and friends, reading, watching films, running, exploring London and travelling.

● HOW DID JOËL BECOME A POLITICAL SCIENTIST?

I'd love to say I had a range of interests from a young age but really, I was just obsessed with football! However, my desire to watch any match on TV did give me an appreciation of the niche realms of the European continent. Over time, my obsessive nature translated into memorising maps, flags and capital cities, which earned me the nickname 'Atlas Boy' at school. I suppose that interest in countries and how they all stitch together has fed into my interest in international politics.

Sometimes it can be hard to remain impartial when investigating such a divisive and polarising political topic, especially when the issues at stake are ones that directly affect you or your family. But I don't think that's necessarily a problem. It's important to be aware of your own (and other people's) biases to either keep them out of the research, or to contextualise them within the research. After all, politics (and certainly Brexit) is a subject driven by emotion as much as reason and we should always be mindful of that.

When you study something that has dominated the news for years, it is important to switch off from work. I don't go on Twitter outside of work hours and always turn email notifications off on my phone. I think this should apply even if your topic is less sensationalistic than Brexit – I find it invaluable to be able to compartmentalise work time from leisure time.



“WE PLACE OUR SCIENTISTS ON SOAPBOXES IN BUSY PUBLIC SPACES SO THAT THEY CAN BE HECKLED, QUESTIONED AND PROBED BY PASSERS-BY IN A FUN, INFORMAL SETTING.”

DR NATHALIE PETTORELLI, CO-FOUNDER OF SOAPBOX SCIENCE, EXPLAINS WHY WOMEN AND NON-BINARY SCIENTISTS AROUND THE WORLD ARE TAKING TO SOAPBOXES TO TALK ABOUT THEIR WORK

Have you visited Speakers’ Corner in Hyde Park, London, UK? Since the mid-1800s, it has become a world-famous site for public speeches and debates and has hosted the likes of Karl Mark, Vladimir Lenin and George Orwell. Inspired by this iconic public speaking setting, scientists Professor Seirian Sumner and Dr Nathalie Pettoirelli decided to launch Soapbox Science – and it has become a global phenomenon.

Soapbox Science has two aims: to showcase the work of female and non-binary scientists and to bring science to the streets. Similar to speakers at Speakers’ Corner, these scientists stand on upturned crates – the soapbox – and enthrall passers-by with their science stories. However, Soapbox Science speakers are not rooted to one spot; they can be found in a number of busy public places such as parks, town centres, markets, shopping centres, seafronts and festivals all over the world.

“We place our scientists on soapboxes in busy public spaces so that they can be heckled, questioned and probed by passers-by in a fun, informal setting,” explains Nathalie, who co-founded Soapbox Science with Seirian in 2011. “This is to ensure that the events reach a diverse audience, including an ‘accidental’ audience of people who were not intending to visit a science event that day.”

ATTENTION-GRABBING SCIENCE

Explaining scientific concepts to a non-scientific audience can be challenging, but the speakers taking part in Soapbox Science events use props, audience participation and other inventive ways to share their passion for science. And, to help them to engage with as many people as possible, Soapbox Science speakers are provided with professional training.

“I can’t think of a scientist not being interesting,” says Nathalie. “They all have cool stories to share and interesting facts that will blow your mind. Our job is to help them tell these stories in the best way possible, which is why we provide training.”

SCIENTISTS COME IN ALL SHAPES AND SIZES

According to the recent UNESCO Science Report published in 2021, women still represent just 33% of researchers globally and, despite making ground-breaking discoveries across the world, their work rarely gains the recognition it deserves. Less than 4% of Nobel Prizes for science have been awarded to women and only 11% of senior research roles in Europe are held by women.



Chioma Vivian Ngonadi presenting at Soapbox Science London.
Image credit: Soapbox Science



Professor Joyce Harper presenting at Soapbox Science London.
Image credit: Soapbox Science London

Nathalie and Seirian were both ‘For Women in Science’ fellows when they decided to launch Soapbox Science. ‘For Women in Science’ is a prestigious award, which supports around 250 talented young women researchers a year and is led by The Fondation L’Oréal and UNESCO. “We decided to set up Soapbox Science following a series of personal experiences and realisations,” says Nathalie. “Firstly, there are fewer and fewer female role models available in science as you progress up the career ladder; secondly, sexism in science is alive and kicking, if you allow yourself to notice it; in addition, science stories are mostly told by males; lastly, celebrated science heroes are mostly male.”

As Seirian and Nathalie progressed in their science careers, it became increasingly apparent to them that something needed to be done, and, in 2011, L’Oréal gave them the funding they needed to get started. “When we created Soapbox Science, we wanted to demonstrate that there was a need, and a niche, for public outreach platforms that challenge stereotypes about what sort of person a scientist is and what it means to be a scientist,” says Nathalie. “At each event, we try to optimise the diversity of speakers, with respect to discipline, career stage and background. Our goal is to show that scientists come in all kinds of shapes and sizes.”

PUTTING FEMALE AND NON-BINARY SCIENTISTS IN THE LIMELIGHT

In a joint blog post written for *The Guardian* in 2014, Seirian and Nathalie

wrote, “Female scientists are less likely to be in the media; less likely to be listed as either first or last author on a scientific paper; less likely to be invited to review and comment on papers published by prestigious journals; and less likely to speak at scientific conferences.” Eight years later, much of this still holds true.

Nathalie believes that although progress has been made since the publication of this blog post, we are far from parity: “For example, a number of articles have highlighted that COVID-19 press briefings in the UK have primarily been led by men. Moreover, a recent analysis of biomedical awards over five decades, published in *Nature*, showed that men receive more cash and respect for their research than women do.”

While these statements make for sober reading, there is a lot to be optimistic about. There are hundreds of organisations all over the world, like Soapbox Science, that are making it their mission to promote and support equality and diversity in STEMM (science, technology, engineering, maths and medicine). There are scientists from all manner of backgrounds, and of various ethnicities and genders, who are paving the way for even more scientists with similar or novel backgrounds and experiences. And there are individuals, like Nathalie and Seirian, who are championing free speech so that we can all feel connected with each other and valued for who we are. What would inspire you to get on a soapbox?



MEET NATHALIE



Senior Research Fellow at the Institute of Zoology, UK
Co-Founder, Soapbox Science

WHAT WAS YOUR MOTIVATION FOR STUDYING SCIENCE WHEN YOU WERE YOUNGER?

I was interested in a huge range of things and had no idea what job I wanted to do! I decided to study science because this was, at the time, a choice that was the least likely to mean that I was committed to a specialised career path. During my first year at university, I met a PhD student; being from a working-class background and the first in my family to go to university, I had no idea about research careers and what it entailed. That chat opened my horizons and made me realise that I could develop a career in science that built on all my interests.

WHAT DO YOU LOVE MOST ABOUT THE WORK YOU DO?

There are many things I love about the work I do: I love being responsible for choosing what I do and how I do it; I love the diversity of activities: from research to communication, management and

teaching. I never get bored with my job, which is why I can't imagine doing anything else.

HAVE YOU STOOD ON A 'SOAPBOX'?

I have made a lot of women and non-binary scientists stand on a soapbox, but I have never stood there myself. I co-created Soapbox Science to promote others' work and not mine. That spot on that box isn't for me, but I'm there to make sure there is a box, every year, in as many places as possible around the world.

WHY SHOULD STUDENTS CONSIDER A CAREER IN STEMM?

I don't think the school curriculum does a great job at explaining what a career in STEMM looks like, or who it is likely to appeal to. As a kid, I wasn't obsessed with maths and science; I found STEMM fields as interesting as philosophy, arts, geography or history, yet I ended up choosing a career in STEMM, precisely because it gave me the opportunity to combine all these interests.

SOAPBOX SCIENCE EVENTS HAPPENING NEAR YOU

To find out about events, visit the Soapbox Science website: soapboxscience.org

Follow the team on social media:

-  [soapboxscience](https://www.facebook.com/soapboxscience)
-  [@SoapboxScience](https://twitter.com/SoapboxScience)
-  [@soapboxscience](https://www.instagram.com/soapboxscience)
-  www.youtube.com/channel/UCz3oBLNmVKD-pJUmr0feKA

Send an email: soapboxscience@gmail.com



Dr Imogen R. Coe presenting at Soapbox Science Toronto. Image credit: Soapbox Science Toronto

In numbers

SINCE 2011:

Soapbox Science has organised events in

59

CITIES

in

14

COUNTRIES

1,959

speakers have taken part

239,755

people have attended a Soapbox Science event (between 2011 and 2021)

The average number of visitors per event has reached around

1,500

The Utah Conservation Corps plants milkweed, grown by youth-in-custody participating in STEMCAP, along the Jordan River Parkway trail in Salt Lake City to support migrating monarch butterfly populations.

CONNECTING YOUTH-IN-CUSTODY CREATIVELY TO STEM

NALINI NADKARNI, A PROFESSOR AT THE UNIVERSITY OF UTAH IN THE US, HAS MADE AMAZING DISCOVERIES IN THE TOPS OF TREES, BUT NOW HER FOCUS IS ON SHARING SCIENCE AND NATURE WITH EVERY CORNER OF THE COMMUNITY. TEAMING UP WITH PROGRAM MANAGER LAURA GEORGE, NALINI RUNS THE STEM COMMUNITY ALLIANCE PROGRAM, WHICH CONNECTS SCIENTISTS TO YOUTH-IN-CUSTODY

It might not be your first concern if you were sent to prison, but there are no trees there. If there were, the branches would obscure the officers' view. But can you imagine living in a world of bare concrete walls, devoid of any vegetation?

Having spent more time than most climbing trees as a canopy researcher, Professor Nalini Nadkarni saw this as a problem. How were incarcerated individuals supposed to become well-adjusted members of society without having a connection with nature? So, she started working to bring the plants to the incarcerated, involving them in conservation projects and delivering a series of science lectures. Then, in 2017, the Utah State Board of Education asked Nalini if she could start something similar for youth-in-custody.

WHO ARE YOUTH-IN-CUSTODY?

In Utah, youth-in-custody (YIC) means anybody under the age of 21 who is looked

after by the state or a Native American tribe, or is being held in a detention facility. Young people can end up in custody for a variety of reasons, including crime, addiction to drugs and mental health problems.

While it is the law that all YIC have access to education, there was no doubt in Nalini's mind that more needed to be done to give these young people better opportunities. To her, a creative connection to science, technology, engineering and maths (STEM) could be the key to a brighter future.

WHY IS ACCESS TO STEM IMPORTANT FOR YIC?

The goal of the juvenile detention centres and residential treatment centres in Utah is to help YIC become independent and re-integrate into society. Because STEM is important in society, it is a crucial part of their education. "Access to quality STEM education is essential to equip all people – especially young people – with the tools and

experiences to effect change in an evolving society, promote innovation, prepare for employment opportunities and stimulate lifelong learning," says Nalini.

Nalini's response to the Board of Education's request was to create the STEM Community Alliance Program, or STEMCAP. Through this programme, academic scientists present their work to YIC and become directly involved with science lessons. Bringing these professional scientists into the classroom not only enriches the content of the curriculum, but also gives the YIC a chance to learn about careers they may not have heard about before.

WHY DOES STEMCAP FOCUS ON ENVIRONMENTAL ISSUES?

Although STEMCAP covers a broad range of STEM disciplines, and also incorporates the arts, humanities and social sciences, the environment is a central theme. The



**PROFESSOR
NALINI NADKARNI**

STEMCAP Program Director and
Professor of Biology,
University of Utah, USA

EXPERTISE

Canopy Ecology, Forest Conservation
and Science Communication

Known as the “Queen of the Canopy”,
Nalini has spent much of her career
climbing into the upper reaches of trees
to study the plant life there. It was also
her idea to create the STEM Community
Alliance Programme (STEMCAP), which
gives incarcerated youths access to art
and science.

FUNDERS

National Science Foundation (NSF),
Utah State Board of Education



LAURA GEORGE

STEMCAP Program Manager,
University of Utah, USA

EXPERTISE

Environmental Humanities

For her master’s degree, Laura researched
how to make environmental education
more inclusive. She now manages the
Initiative to Bring Science Programs to
the Incarcerated (INSPIRE) as well as
STEMCAP.

For questions about STEMCAP, or to get
involved as a presenter, visit
STEMCAP.org or contact Laura at
laura.george@utah.edu.

reasoning behind this is that environmental issues involve us all. Whether you are talking about climate change, biodiversity loss or pollution, the solutions are never down to one person: they require collective action. By feeling involved in these collective efforts, YIC can start to feel more confident about their role in society.

Laura George is Program Manager for STEMCAP. “Environmental issues transcend science and threaten our well-being,” she says. “We want YIC to know they deserve a voice, to feel they can be a part of working toward something positive.” STEMCAP even gives YIC students the opportunity to work on conservation projects alongside other community members and scientists. Laura explains, “The results of the work students put in are tangible, so they get a sense of success from these projects. It is not so much about the environmental content, as it is about how these issues can bring people together.”

WHAT IS IT LIKE TEACHING AT A YOUTH-IN-CUSTODY CENTRE?
Teachers can find it challenging to work in YIC centres because of strict safety requirements. While their top priority is delivering a good lesson, the staff at the centre are focused on keeping everybody safe. This means that the classroom cannot contain materials that could hurt people, which can include anything made of metal or glass. In some places, even everyday objects such as permanent markers and paintbrushes are banned.

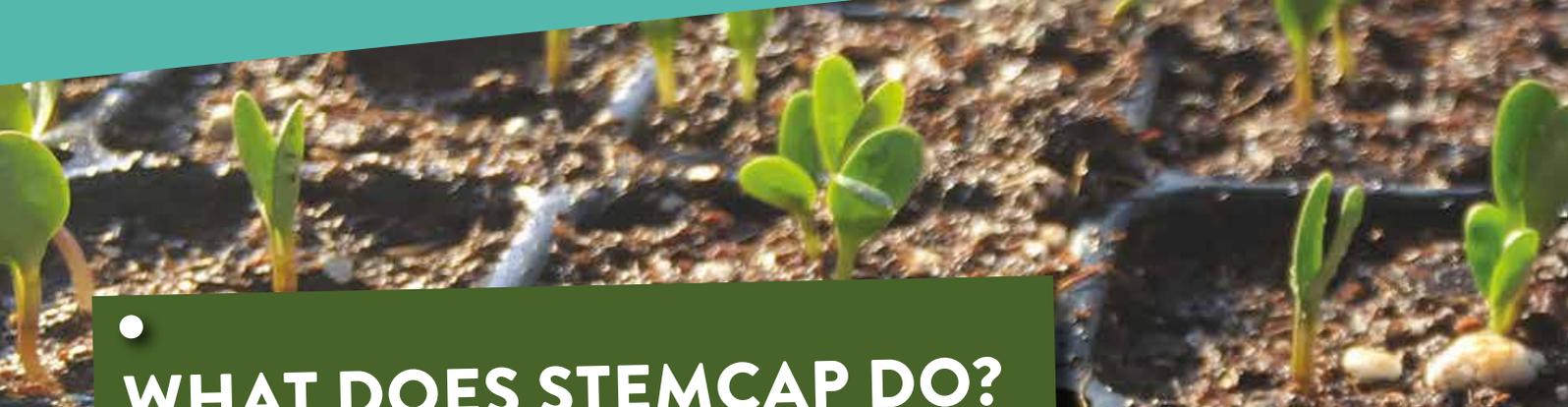
As well as having to be creative when it comes to materials, teachers need to be flexible. “Security lockdowns and other last-minute schedule changes can make it impossible to predict when students will be in the classroom,” says Laura.

Despite these challenges – or perhaps because of them – the presenters involved in STEMCAP have said their

experiences working at YIC centres have been rewarding, both personally and professionally. The presenters also realised that their assumptions about YIC were wrong when they saw how engaged the students were in their lessons.

WHAT NEXT FOR STEMCAP?
The evidence so far shows that STEMCAP is a success. When the Utah Education Policy Center reviewed the programme, they found that the YIC showed high levels of interest and curiosity during lessons. Perhaps even more importantly, they saw students getting a better sense of who they were and how they could contribute to society.

Laura hopes that STEMCAP can inspire similar programmes across the US. They have already written a handbook that describes how STEMCAP works, which can be sent to other institutions around the country as inspiration.



WHAT DOES STEMCAP DO?

TOPICAL PRESENTATIONS

Topical presentations introduce YIC to the STEM community. Each presentation teaches students about some cutting-edge science, but the most important thing is not the science itself. Instead, the aim is really to showcase the diversity of people involved in science, and demonstrate the fact that it is current and dynamic. “We hope students take away that there are people in their community engaging

in science in a variety of ways, and that those people do not all look the same or come from the same backgrounds,” says Laura.

As well as talking about their research, presenters are encouraged to discuss struggles they had in school and the unique paths that led them into science. This shows students that not all scientists were perfect school

students who always knew what they wanted to do.

Interestingly, not all of the presenters are scientists. Artists, writers and community members who engage with STEM in non-professional ways also contribute, showing the students that there are many different ways to be involved in STEM.

MISSION STEMCAP

Students involved in Mission STEMCAP address one of five “Grand Challenges”. The Grand Challenges were selected by a group of scientists at Stanford University in the US, who believe they are the biggest threats that humans face right now: extinction, biodiversity loss, climate change, pollution and overconsumption.

Over the course of two weeks, students learn about one of the Grand Challenges with STEMCAP staff and guest presenters from a wide variety of backgrounds. They are then asked to respond to the challenge and talk about it with each other and members of the community. The aim is to show the importance

of collaboration: all of the challenges can only be overcome if people work together. Furthermore, Laura says, “Mission STEMCAP empowers youth by giving them a voice, and showing them ways to use that voice for a cause they care about”.

CONSERVATION PROJECTS

STEMCAP runs three conservation projects. In one, YIC grow milkweed in a greenhouse, a plant that is crucial to the survival of monarch butterflies. In another, they work with the Salt Lake City Seed Library to help preserve heirloom varieties of plants. The

third project introduces students to citizen science – research projects that rely on online participation from members of the public.

“These long-term projects build student confidence as they begin to see positive results

of the work they put in,” says Laura. “They also show members of the local community that YIC are capable of and interested in conservation work.”



STEMCAP BY THE NUMBERS

7,000

The number of youth-in-custody in the state of Utah, 2019

3X

Black youths were three times more likely to be put into custody in 2017 than other racial groups

197

Workshops completed by STEMCAP to date

188

Guest presenters for STEMCAP, including artists, scientists, conservationists, writers and engineers

8

YIC centres reached

MEET NALINI



When I was a kid – who frequently climbed trees in my backyard – I wanted to be a grown-up who helped nature, especially trees. I thought I might become a forest fire-fighter or a park ranger, but when I learned about the field of ecology in college, I decided to become a forest ecologist and help trees by better understanding their biology and ecology.

My love of being in nature inspired me to study biology, and wanting to somehow ‘payback’ nature – especially trees – because they provided me with such joy and beauty.

I believe everyone can benefit from involvement in science and nature, particularly those who are denied access to them because of physical, financial or cultural barriers. And I believe that academics can benefit from exposure to people outside of science, by

becoming more aware of different viewpoints and ways of knowing. So, while I love carrying out research about forests, I get an equal sense of fulfilment communicating science to people who do not have access to traditional education venues like schools and museums.

In 2003, I began the Sustainability in Prisons Program in Washington State, to bring science lectures and conservation projects to incarcerated adults in state prisons. After I moved to Utah in 2011, I started a project called Initiative to Bring Science Programs to the Incarcerated (INSPIRE), and then eventually STEMCAP in 2017.

The achievements that I value the most are those that create something new, something different. Something potentially transformative. These include being the parent

of two children, and starting programmes that have brought scientists into meaningful contact with the incarcerated, faith groups, urban youth and policy-makers.

TOP TIP FOR BECOMING INVOLVED IN YIC PROGRAMMES

Try to identify your pre-conceptions of YIC so you can approach them with an open mind. Even though we tend to think of incarceration as a bad thing that must be eliminated, youth-in-custody really benefit from being in facilities with dedicated teachers and resources that they would otherwise not have access to. I also recommend that you should be as truthful as you can when you interact with YIC, because that is what so many of them have not had in their lives.

MEET LAURA



Growing up I wanted to be a vet because I loved animals. I eventually discovered that being a vet can be hard because you often see pets you cannot help and have to put them to sleep. When I was in high school I wanted to be an author or an English teacher.

For my undergrad, I majored in English and minored in ecology at the University of Georgia in the US. I chose these areas of study because I love fiction and poetry, but I am also very passionate about the outdoors, environmentalism and plants.

I then decided the environmental humanities master’s programme at the University of Utah was a great way to combine my love of writing with my interest in the natural world. At Utah, I created an environmental education curriculum that centred on plants and connected to urban ecosystems. The idea was to make it accessible to students in Salt Lake

Valley, who have fewer opportunities to explore more remote environments. I then worked to present my curriculum to underserved youth around the valley.

I believe that connection to nature is healing, and that familiarity with your environment is empowering. But environmental education is not generally a priority in schools, which means only kids whose parents have the interest and money to send them to summer or after school programmes have access to it.

I also feel strongly that environmental education is needed to address climate change, pollution and biodiversity loss. The Earth is our home, and we all rely on it, so I believe that it is only fair to ensure everybody gets a good environmental education and has the power to protect their planet.

I plan to continue managing STEMCAP for

a few more years. In that time, I want to bring STEMCAP to other states, publish more research on our work, and create a programme to help students continue engaging with STEM once they are released from custody or have graduated from high school and no longer attend class at YIC centres.

TOP TIP

Don’t be afraid to combine your interests and forge your own path. I was often told that English and ecology were too different, and that I should pick one or the other. Also, be aware that contributing to STEM and protecting the environment can take many different forms. Don’t shy away from STEM just because you don’t see yourself as a scientist. Science is everywhere, and we are all scientists in our own way.



HOW CAN WE ENSURE THAT CHILDREN IN OUR CARE SYSTEM GET THE BEST POSSIBLE START TO LIFE?

DR DOMINIC MCSHERRY, A DEVELOPMENTAL PSYCHOLOGIST AT ULSTER UNIVERSITY, IS WORKING ON A GROUND-BREAKING, LONGITUDINAL STUDY ACROSS NORTHERN IRELAND, THE AIM OF WHICH IS TO UNDERSTAND HOW DIFFERENT CARE PATHWAYS IMPACT THE LIVES OF YOUNG PEOPLE IN CARE

TALK LIKE A DEVELOPMENTAL PSYCHOLOGIST

SELF-ESTEEM – confidence in your own value and abilities

ATTACHMENT THEORY – a psychological theory that young children need to develop a deep emotional relationship with at least one carer for normal social development

PEER PRESSURE – the influence a social group has on its members to fit in with its expectations

BIRTH PARENT – the biological parent of a child, who may be different to the parent who raises the child

LONGITUDINAL STUDY – making continuous or repeated observations of the same participants (a group of individuals, for example) over prolonged periods of time, often years or decades

Every child needs someone to look after them. Sometimes, for many different reasons, a child's birth parents are unable to do so. When that happens, the local authority helps to find them someone else to live with. This is the care system. Going into the care system is probably more common than you think: in the UK in 2020, over 100,000 children were in care.

Through no fault of their own, being in the care system can be disruptive to a child's upbringing, so researchers are working to understand how it can be improved. One of these researchers is Dr Dominic Sherry, a developmental psychologist at Ulster University, who has been studying the lives of hundreds of children in care. His project, the 'Care Pathways and Outcomes Study', has discovered that one of the keys to support children's health and wellbeing is ensuring that children stay with the same carers over a long period of time.

WHAT HAPPENS WHEN A CHILD GOES INTO CARE?

In Northern Ireland, where Dom works, and similar to the rest of the UK, a child will generally be in one of five types of placement: adoption, foster care, Residence Order, kinship foster care, or living with birth parents.

In both adoption and foster care, the child lives with a different family to the one they were born into. The difference is to do with who is legally and financially responsible for the child. In adoption, responsibility for the child is given completely to the new carers, who are known as adoptive parents. However, in a foster placement, the birth parents and the local authority share a legal responsibility for the child, and the foster parents receive money to help look after them. If everything is going well for the child, then a decision can be taken for the local authority not to be involved anymore, turning the arrangement into a Residence Order.

Adoptive or foster parents can be complete strangers to the birth family, but those working in the care system usually first try to find someone who is a friend or relative to look after the child. This arrangement is kinship foster care. Finally, some children will return to live with their birth parents if they become able to care for them again.

WHY IS IT IMPORTANT TO STUDY THE CARE SYSTEM?

Every child's experience of care is unique, and many children in care build strong, loving



relationships with their new families, helping them to lead happy and successful lives. Compared to children who are not in care, however, they are more likely to encounter difficulties. People who were in care tend to do less well at school, and have a higher chance of becoming unemployed or sent to prison than people who are or have been raised by their birth parents. They are also more likely to have health problems and low self-esteem.

SETTING UP THE CARE PATHWAYS AND OUTCOMES STUDY

The Care Pathways and Outcomes Study includes every one of the 374 children in Northern Ireland who were in care and under the age of five in March 2000. Dom says, “It is the only study in the world that has been able to follow a population of young children through the care system and see how they get on across the different types of experiences that they have. The study is important because it will help us to understand how children form new parental relationships, what difficulties they might experience in this regard, and how such difficulties might be overcome. I’ve also been very fortunate to be supported in this work by excellent colleagues over the years, such as Dr Montse Fargas Malet, Ms Kerrylee Weatherall, Mr Clive Robinson, Dr Greg Kelly, Dr Emma Larkin and currently Dr Grainne McAnee.”

This knowledge will help the professionals who operate the care system in Northern Ireland to see what works well, what does not work so well, and to make better informed choices in the future. Furthermore, the findings from the study could be applicable to other care systems across the UK and around the world.

HOW CAN WE COMPARE INDIVIDUAL EXPERIENCES OF THE CARE SYSTEM?

To draw conclusions about the care system, psychologists like Dom need a way to compare

how different young people are getting on. This can be done using questionnaires that have already been tried and tested on a range of people in the community. These ‘standardised measures’ allow researchers to see the differences in the answers given by people in care. The questionnaires used in the Care Pathways and Outcomes Study asked the young people about their relationships with their parents/carers and friends and how they felt about themselves.

The young people in the study were also interviewed to gain a fuller understanding of their experiences. This was done carefully so as to make sure they understood what the study was about and that they definitely wanted to be involved. Dom explains, “We were very conscious that we would be speaking about quite sensitive issues with these young people”. To help the young people engage in a fun way, the interviewers developed board games and storybook activities. They also gave them the opportunity to move on from any question or topic that they did not want to talk about using ‘stop’ and ‘move on’ signs.

The purpose of asking the children in the study to complete questionnaires and interviews was to try and see the care system from their perspective. Dom and his team analysed their answers and found some surprising results.

WHAT MAKES FOR A SUCCESSFUL PLACEMENT, ACCORDING TO THE CHILDREN?

Adoption is often seen as the ‘gold standard’ placement for children in care, but the findings of Dom’s study challenge this view. He and his colleagues found that children in other types of placement were just as happy and had equally strong attachments to their carers. The important thing did not appear to be the type of placement, but whether they had been in



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FIELD OF RESEARCH

Developmental Psychology

RESEARCH PROJECT

The Care Pathways and Outcomes Study – a project following the lives of hundreds of children in care in Northern Ireland

FUNDER

Economic and Social Research Council (ESRC)

the same placement for a long period of time. The study also found that the perspectives of parents and carers sometimes differed from those of the young people. This shows how important it is to ensure that young people’s voices are included in research about them.

WHAT WILL THE CARE PATHWAYS AND OUTCOMES STUDY LOOK AT NEXT?

The study is now in its fourth phase, following the young people through their late teens and into early adulthood. This can be a tricky time for young people’s relationships with their parents/carers, as they start to seek independence and peer pressure plays a strong role in their behaviour. The hormonal changes during adolescence can also impact a young person’s mood, and parents/carers can get frustrated when they do not understand what is going on.

Although these tensions occur in all families, when they happen for young people in care it can be more serious, as either side can request a placement move if there is an argument, and social care professionals are also likely to be involved. This intense pressure means that the risk of placement breakdown increases during the teenage years. By studying this phase, Dom and his colleagues hope to understand how and why this happens in more detail.

ABOUT DEVELOPMENTAL PSYCHOLOGY

Think about what you were like two years ago. Do you feel like you are still the same person today? How have your thoughts, feelings and behaviour changed? Developmental psychology tries to understand these changes over our whole lives, but with a special focus on childhood and adolescence as these are when the most dramatic changes occur.

Good developmental psychologists are inquisitive, open-minded and sensitive to the challenges that research participants might face. They are prepared to engage at all levels of society, and always conscious of the historical context of developmental psychological theory.

IS DEVELOPMENTAL RESEARCH STILL BIASED TOWARDS WESTERN CULTURES?

"I do agree that this is the case," says Dom. "The original theories of developmental psychology emerged in the 1900s in developed Western countries, and were written particularly by white, middle-class males. That lack of diversity is an issue, as it means those theories were heavily influenced by a particular culture, in which women, poorer people and non-white people were considered inferior. However, today we can look critically at those theories from other perspectives, and progress has been made in boosting diversity in the field." For example, when Dom became the editor of an academic

journal, one of the first things he did was to make sure that the scope of the journal included consideration of race and ethnicity.

WHERE CAN DEVELOPMENTAL PSYCHOLOGY TAKE YOU?

After a degree in developmental psychology, you can move into a wide range of areas, such as social work, youth work, the police, media, advertising and recruitment. The great thing about developmental psychology is that it focuses on why we behave the way we do, and how our understanding of the world changes from the moment we are born. So, any profession that requires an understanding of human behaviour will benefit from your perspective.

EXPLORE A CAREER IN DEVELOPMENTAL PSYCHOLOGY

- Meet some more developmental psychologists and learn about what they do on the American Psychological Association's website: www.apa.org/education-career/guide/subfields/developmental-education-training
- Explore the eight stages of human psychological development at www.simplypsychology.org/Erik-Erikson.html
- Some psychologists also work in healthcare. Explore career options in the NHS at www.healthcareers.nhs.uk/explore-roles/psychological-therapies/roles-psychological-therapies
- Dom says, "At Ulster University, students completing the BSc in psychology will get the opportunity to do a year-long placement with an organisation in some area related to psychology. This allows them to develop skills and gain experience that will support their future career aspirations."
- Ulster University also hosts regular seminar series that postgraduate students and lecturers can attend and contribute to. "Very often, a leading psychologist, or a key external partner organisation, will be invited to talk about their work or provide training to both staff and students," says Dom. "The university's student union offers a wide range of courses and activities that students can engage in, both educational and fun. There is lots of support for any student who may be struggling with their own personal issues, for example, our 'Mind Your Mood' campaign. It is one big community at Ulster University, and we all support each other."
www.ulster.ac.uk/faculties/life-and-health-sciences/psychology
- It is worth looking at other universities, too, to see if they offer similar experiences.

PATHWAY FROM SCHOOL TO DEVELOPMENTAL PSYCHOLOGY

- You don't need to take all three sciences for a psychology degree, but most universities look for at least one out of chemistry, physics, biology or maths.
- Some schools offer psychology at A-level, and other useful subjects could include sociology, geography, anthropology, economics, politics, philosophy and history.
- To remain in psychology after your first degree you would normally complete a master's and sometimes a doctorate degree, to become qualified as a clinical, educational, occupational or research psychologist.



● HOW DID DOM BECOME A DEVELOPMENTAL PSYCHOLOGIST?

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

I was very fortunate that GCSE (O) level psychology was introduced to my school curriculum when I was 15. I was selecting my choices at the time and thought it sounded interesting. The first lesson I took was focused on 'attachment theory', that innate process where children form a relationship with their parents or carers from birth. I'm still doing attachment research today! Suffice to say, I was immediately hooked and knew that this was what I wanted to do for the rest of my life.

WHAT OTHER SUBJECTS DID YOU STUDY AT SCHOOL?

I also studied history, French, Italian, chemistry, physics, mathematics and English literature at school. I particularly enjoyed history and would probably have pursued that avenue if psychology hadn't come along. It's very focused on key historical figures and their impact on the world, and I was always interested in why these people did what they did, and how other people responded to them.

YOU HAVE SPENT YOUR CAREER RESEARCHING THE IMPACT OF ADVERSITY AND TRAUMA IN CHILDHOOD. ARE THERE ANY POSITIVES?

It needs to be acknowledged that some aspect of stress in life can be a good thing, as it can keep you focused on what matters

to you at that time, and motivate you to do your best. However, it is difficult to imagine how the experience of trauma can ever be considered a positive. Trauma emerges when the system is overloaded by stress, when our natural resources for managing stress have been spent, and can lead to significant mental health illness.

HAVE YOUR STUDIES CHANGED YOU IN ANY WAY?

I think my work has made me more aware of the challenges that other people in society have to face. I have found that many problems such as homelessness, addiction and crime have their roots in early traumatic experiences. That perspective allows you to be very humble and empathetic. Two great scholars writing in this area at the moment are Bruce Perry and Gabor Mate. They ask not 'what is wrong with you?', but 'what happened to you?'. This approach takes the blame away from people who are struggling, and focuses on their experiences, which they will have had little control over in their early lives. This is a very positive ethos, and it really grounds my work.

WHAT DO YOU ENJOY MOST ABOUT YOUR WORK?

I get to work with some amazingly talented people in universities and across our communities in social work departments, schools, hospitals and voluntary organisations. I enjoy organising and conducting research,

setting research questions and gathering the data to be able to answer these questions. It can be quite exciting at times! I also find it rewarding to work with people who have experience of care or adversity in their lives. This is expertise by experience and is such a vital companion to academic knowledge.

DOM'S TOP TIPS

- 01** Work hard but keep an interest in other things too, such as sport and music. You'll be able to fall back on these for relief and distraction when you need them.
- 02** Remain inquisitive at all times, and never accept anything as definitive, at an individual and group level. People change and evolve throughout their lives, and as such our understanding of individual and societal development needs to change and evolve too.
- 03** Keep the link between understanding human development and improving health and wellbeing at the centre of your thoughts.
- 04** Enjoy the fact that you get to study and discover new things about human beings. How exciting is that!



WHAT DOES THE PAST MEAN TO PEOPLE TODAY?

OUR BELIEFS ABOUT THE PAST HELP DEFINE WHO WE ARE AND HOW WE LIVE IN THE PRESENT. DR SARAH KURNICK, ASSISTANT PROFESSOR OF ANTHROPOLOGY AT THE UNIVERSITY OF COLORADO BOULDER, IN THE US, STUDIES HOW ANCIENT MAYA PEOPLES AT PUNTA LAGUNA, MEXICO, PERCEIVED THEIR OWN HISTORY. THE MAYA WHO LIVE IN PUNTA LAGUNA TODAY PLAY A KEY ROLE IN THIS RESEARCH, DISCOVERING, INTERPRETING AND COMMUNICATING THEIR OWN HERITAGE

TALK LIKE AN ARCHAEOLOGIST

ANCIENT MAYA – The ancient Maya flourished in Mesoamerica (contemporary Belize, Guatemala, and parts of Mexico, Honduras and El Salvador) between about 1800 BCE and 1500 CE. The descendants of the ancient Maya continue to live in this region and to speak Mayan languages

CLASSIC PERIOD – The period from about 250 to 925 CE when divine kingship was at its height. This is when we most commonly see the erection of stelae (stone slabs) with detailed hieroglyphic inscriptions, and when we see the peak of famous sites like Tikal

POSTCLASSIC PERIOD – The period from about 925 to 1500 CE when many of the Classic period dynasties ended, leading to more decentralised political structures and less inequality

CIST – a burial chamber

POLITY – a political entity

Archaeology is the study of the human past through material remains. Digging for ancient artefacts may seem innocuous, but archaeology has been political from its beginnings. In some instances, nations have claimed roots in early complex polities like Rome to legitimise

contemporary political goals, especially imperialist expansion. In other instances, archaeologists have excavated the graves of indigenous peoples without consideration for the wishes of their descendants or have taken home their finds without obtaining permission from, or compensating, local people. Too often, archaeologists have used data collected about past peoples to benefit themselves and archaeology, and not descendent communities.

To combat this history of injustice, many modern archaeologists, like Dr Sarah Kurnick at the University of Colorado Boulder, practise community archaeology, where archaeological research is done with, by and for local people.

THE IMPORTANCE OF COMMUNITY ARCHAEOLOGY

Located in the jungle of the Yucatán Peninsula in Mexico, Punta Laguna is a small Maya village and spider monkey reserve. The Maya who live there today are descendants of the ancient Maya who lived in the same region over a thousand years ago.

Sarah and her colleague, David Rogoff of the University of Pennsylvania, are co-directors of the Punta Laguna Archaeology Project, a community-led excavation that aims to learn more about the people who once lived in Punta Laguna. This project is an example of community archaeology, where the members of the modern Maya community of Punta Laguna make decisions about research questions, excavations,

interpretation of evidence and presentation of findings. The goal is for Maya peoples to take charge of their own history and lead the research into their own ancestors.

Today, Punta Laguna is a tourist attraction, where visitors can explore the archaeological site to learn about the ancient Maya, go on a tour of the spider monkey reserve, canoe across the lagoon and experience contemporary Maya culture. These activities are all run by and benefit members of the local community. One of Sarah's goals is to help tour guides give visitors comprehensive information about the site's archaeology. In this way, community archaeology helps participants control narratives about their past while also providing economic benefits for the village.

Not only is community archaeology a moral and ethical imperative but incorporating different viewpoints into the research agenda also makes for better science. Local people will have practical and cultural knowledge of archaeological sites that help them frame important research questions and propose new interpretations. "This project could not exist without the expertise of local community members," Sarah explains. "They advise us on everything from the nature of political authority among contemporary Maya peoples, to which snakes are poisonous."

THE ANCIENT MAYA OF PUNTA LAGUNA

Like nearby Cobá, one of the largest ancient Maya cities ever built, Punta Laguna was



DR SARAH KURNICK

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FIELD OF RESEARCH

Anthropological Archaeology

RESEARCH PROJECT

How did Postclassic Maya communities at
Punta Laguna interact with their Classic
Maya past?

FUNDER

National Science Foundation (NSF)

occupied continuously during the Late Classic and Postclassic periods. Nevertheless, both sites experienced a profound reduction in size and population during the Classic to Postclassic transition. Sarah is studying how the Postclassic Maya perceived their own past. Did they look back on the Classic period as a golden era, or did they distance themselves from their history? Did Postclassic inhabitants at Punta Laguna venerate, destroy or ignore the buildings, monuments and objects constructed by their Classic period ancestors?

So far, members of the Punta Laguna Archaeology Project have documented over 200 structures at the site. “Some of these are just above ground level, while the tallest reach over 6m in height,” says Sarah. Many of the structures are solid platforms built of stone that would have supported buildings made from perishable materials, like wood. They may have been houses, religious buildings or administrative centres. Miniature masonry shrines are also common. These one-room stone buildings are too small to enter and may have been the locations of deity or ancestor veneration. Similar shrines have been found at Cobá and at several Maya sites on the east coast of the Yucatán Peninsula.

The team’s excavations have also uncovered numerous artefacts, the most common being pieces of ceramic vessels. Obsidian blades, most likely imported from present-day Guatemala, and marine shells, imported from the coast, indicate ancient trade links with Punta Laguna.

“Most surprisingly,” Sarah says, “we have excavated an empty cist with two complete vessels, pieces of pyrite and greenstone, and a burial with the remains of two individuals.”

The team’s research so far suggests that the Postclassic occupants of Punta Laguna revered their Classic past. “In one instance, Postclassic people seem to have built a small mound to ceremonially bury two ceramic vessels made during the Classic period,” says Sarah. “We are still working to understand what the site of Punta Laguna reveals more broadly about Postclassic Maya political authority, following the major social transformations that accompany the transition to the Postclassic period.” Sarah and the team will need at least one more field season before they can make more interpretations.

MANIPULATING THE PAST TO CONTROL THE PRESENT

Controlling the image of the past has been a political tool in ancient cultures and is still witnessed today. Consequently, defacing monuments of past public figures is a tradition stretching back thousands of years.

The ancient Akkadians of Mesopotamia defaced a bronze likeness of the historical King Sargon of Akkad. The Mesoamerican Olmec disfigured colossal basalt portrait heads of past rulers. The ancient Romans even had a formal process called *damnatio memoriae*, where all images of a condemned individual were destroyed. And today, activists in the US pull down and deface monuments of Confederate leaders and

other controversial figures such as Christopher Columbus, to protest continuing systemic racism. People of all cultures are concerned with how to present the past, what should be remembered, and how.

The presentation of the past is sensitive because beliefs about a community’s origins and history justify political choices made today. A ruler may use images of successful conquerors of the past to legitimise their own military campaigns. Claims that indigenous peoples lack a sense of national identity or are simply extinct rationalise denial of their sovereignty and their exclusion from political power.

Sarah’s project explores the manipulation of the past at Punta Laguna, for both its Postclassic and contemporary residents. What was the relationship between the Postclassic people of Punta Laguna and their Classic heritage? How did they perceive the decline of the nearby city of Cobá? How will giving control of today’s archaeological research to the modern inhabitants of Punta Laguna help them shape their present? Like their Postclassic ancestors, the modern people of Punta Laguna must have the freedom and power to investigate, interpret and communicate their history to others. Archaeology can aid them in doing so.

ABOUT ARCHAEOLOGY

Archaeology, which in the US is a subfield of anthropology, is the study of the human past through material remains. While historians read ancient texts to understand the past, archaeologists examine the structures and objects our ancestors left behind.

‘Material culture’ refers to human-made artefacts (e.g., pottery and clothing), art and even the rubbish dumped by ancient societies, as well as human-driven environmental changes such as irrigation and domestication of animals. It also includes the social behaviours associated with these objects and practices. Archaeologists find, catalogue and interpret material culture with the aim of understanding what life was like for past societies.

A DAY ON A DIG

Excavations, or ‘digs’, are a key part of archaeological research, allowing archaeologists to uncover the remains of past societies. Sarah

describes a day of work at Punta Laguna: “We wake up early and start working as soon as it is light enough to see. It is hot, and there are a lot of bugs and snakes. Sometimes there are also spider monkeys watching us. To excavate, we start by clearing vegetation from an area with machetes. We then lay out excavation units with string and wooden stakes, usually in 2 m by 2 m squares. We use trowels to remove the dirt within each square in 10 cm layers. We excavate very slowly and keep detailed records including notes, drawings, photographs and GPS points. All dirt removed from the units is screened through mesh and all artefacts are taken back to a lab house. There, we wash them, dry them, label them, count them, weigh them, describe them, and photograph them.”

THE POWER OF THE PAST

Community archaeology harnesses the power of storytelling about the past to create a more just present. Powerful groups in society can use

claims about the past to legitimise social and economic inequalities. And marginalised groups can reclaim power and upend social hierarchies by building their own narratives. Archaeologists have a moral imperative to work with, not around, local communities when interpreting their history.

Far from being merely a study of dusty artefacts without impact on the present day, archaeology is a tool for social change. “We need to consider who communicates the past – who decides what is included in history books and who is memorialised in monuments,” Sarah says. “Just imagine how our understanding of history might change if it was told by the marginalised rather than the powerful.”

EXPLORE A CAREER IN ARCHAEOLOGY

- Sarah recommends visiting the website of the Archaeological Institute of America (www.archaeological.org) if you want to learn more about the field. It contains articles about careers in archaeology, information about what to do if you think you have discovered an archaeological artefact, and archaeology lesson plans for schools. It also features interactive digs, where you can follow excavations taking place around the world.
- The Society for American Archaeology (www.saa.org) also has a wealth of information about archaeology, including resources for schools and information about careers.
- Archaeologists do not spend all their time excavating ancient sites in exotic locations! They also work in laboratories, analysing the artefacts they uncover to understand what they represent about past societies and cultures. Archaeologists who work in universities also teach students, ensuring the next generation of archaeologists are equipped to conduct high-quality, ethical research.
- Many archaeologists work in ‘cultural resource management’. This subfield includes managing museum collections, developing educational resources about the human past, evaluating construction sites for potential archaeological finds before work begins, and working for government agencies and non-profit organisations that preserve heritage sites.

SARAH'S TOP TIPS

01 Develop relationships with archaeologists (in universities, museums, government agencies, etc.) who can mentor and encourage you. I could not have succeeded without the support of several people who believed in and helped me.

02 Look for internships and field opportunities that you can participate in.

PATHWAY FROM SCHOOL TO ARCHAEOLOGY

- Sarah recommends taking anthropology courses as soon as you can. If these aren't available, history courses will be useful, especially those that focus on regions outside Europe.
- In the US, many universities offer degrees in anthropology which will allow you to major in archaeology. In other countries, specialised archaeology degrees may be available. Most practising archaeologists will have a master's degree or PhD in archaeology or anthropology.
- Archaeology apprenticeships are available in some countries, providing a practical, hands-on route into the profession. For example, Historic England provides a range of heritage-related apprenticeships (www.historicengland.org.uk/services-skills/training-skills/work-based-training/heritage-apprenticeships).
- Having relevant work experience will be a benefit when applying for university or an archaeology job. Look for opportunities to participate in digs as soon as possible and reach out to local archaeological societies and museums to enquire about excavations and internships.

● HOW DID SARAH BECOME AN ARCHAEOLOGIST?

HAVE YOU ALWAYS WANTED TO BE AN ARCHAEOLOGIST?

I've always been interested in the past. When I went to college, I thought I was going to study history. Then I started taking classes in anthropology and archaeology and realised that archaeology was a better fit for me. I like working with objects instead of texts and appreciate being able to do research outside.

WHY DO YOU FIND THE ANCIENT MAYA SO FASCINATING?

The Maya area was one of a handful of regions in the world where individuals independently developed agriculture as a means of subsistence, established large, sedentary centers, and developed socially complex, hierarchical societies. This makes the ancient Maya a fantastic example of arguably

the most important change in all of human history: the transformation of small, nomadic, largely egalitarian groups into large, settled, hierarchical societies.

WHAT IS YOUR FAVOURITE FIELDWORK MEMORY?

I always love interacting with children at Punta Laguna, especially the young girls, and giving them tours of our lab house and showing them the artefacts we have excavated.

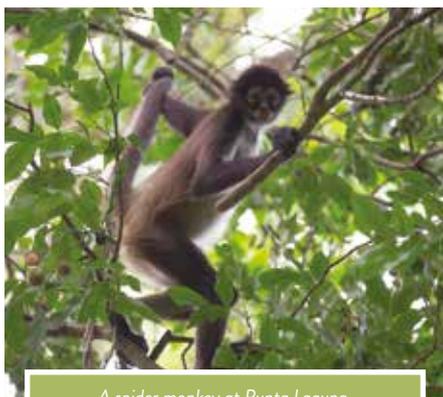
WHAT DO YOU MOST ENJOY ABOUT YOUR WORK AS AN ARCHAEOLOGIST? AND WHAT DO YOU FIND MOST CHALLENGING?

I enjoy fieldwork the most. There is something incredibly compelling about seeing an object no one else has seen for hundreds, if not

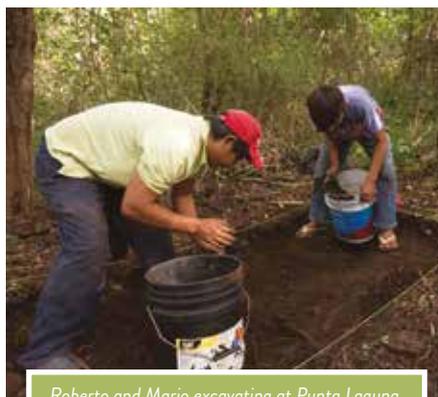
thousands, of years. Fieldwork is also the most challenging part of the job. The logistics, such as getting permission from foreign governments and securing grant money, are often very difficult and time-consuming. But the effort is worth it!

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

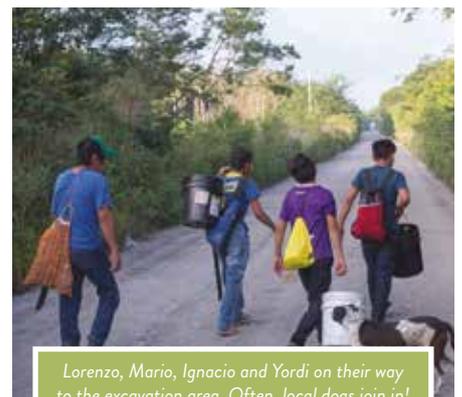
Being hired as an assistant professor of anthropology at the University of Colorado Boulder has definitely been a highlight! In the future, I hope to get tenure [a permanent position] and to continue the Punta Laguna Archaeological Project over the long term.



A spider monkey at Punta Laguna.
Photo credit: Conrad Erb



Roberto and Mario excavating at Punta Laguna.
Photo credit: Conrad Erb



Lorenzo, Mario, Ignacio and Yordi on their way to the excavation area. Often, local dogs join in!
Photo credit: Conrad Erb



WHY DO PEOPLE STAY?

THOUGH MIGRATION IS IN THE NEWS ALMOST DAILY, MOST PEOPLE DO NOT MIGRATE, EVEN IF THEY HAVE THE OPPORTUNITY AND MEANS TO DO SO. WHY NOT? AT THE UNIVERSITY OF CAMBRIDGE IN THE UK, DR DANIEL ROBINS HAS BEEN RESEARCHING IMMOBILITY, AND HAS DISCOVERED THAT IT IS OFTEN LINKED TO FEELINGS OF DUTY AND BELONGING

TALK LIKE A HUMAN GEOGRAPHER

IMMOBILITY – people staying in their country of birth, either by choice (voluntarily) or because they cannot leave (involuntarily)

GLOBAL CITIZEN – somebody who feels they are part of a worldwide human community

MIGRATION – the movement of people from one place to another in order to live there

PATRIOTISM – the feeling of love, devotion and attachment to one's country

RESCALE – change the size or scale at which you are looking or thinking about something

In the year 2020, over 280 million people were living in a different country to the one they were born in. That is more than three international immigrants for every 100 people in the world. You, someone in your family, or one of your friends may well be one of them, and you may have already thought about why people choose to move to a different country. But, have you ever considered why people choose to stay?

Immobility is the other side of the migration coin. That is, the 7.5 billion people who have stayed in their country of birth, despite the fact that many of them could choose to move if they wanted to. Dr Daniel Robins is a postdoctoral researcher in human geography at the University of Cambridge, and he has been asking what causes the majority of people not to migrate. Focusing his research on London, in the UK, and São Paulo, in Brazil, he hopes that investigating the reasons for immobility will eventually give us a deeper understanding of why other people leave.

HOW CAN WE INVESTIGATE IMMOBILITY?

Daniel's work happens in four main stages: literature review, data collection, analysis and

writing. During the first stage, he reads and makes notes on other people's research to see what studies have been done before, and what conclusions they came to. By the time he has written up his notes into a literature review, he is fully up to date on the latest theories and concepts and knows what questions remain unanswered.

Following this, he spends his time talking to people about their lives and experiences. He collects information by recording his interviews and noting down his observations. The analysis stage involves transcribing the recordings to written text and searching the data for patterns. To make conclusions about immobility, he must find similarities in what lots of people say. Finally, Daniel writes about what he has learned from the interviews, linking it to the previous work he read about in the literature review stage. Daniel's work is rigorous and meticulous – and reaps revealing results.

WHAT IS SNOWBALL SAMPLING?

Imagine a snowball rolling down a hill. As it rolls, it picks up more snow, and the bigger it gets, the faster it grows. In a similar fashion, Daniel finds people to interview by starting



DR DANIEL ROBINS

Postdoctoral Researcher
University of Cambridge, UK



FIELD OF RESEARCH

Human Geography



RESEARCH PROJECT

Understanding immobility and migration
in Brazil and the UK



FUNDER

Economic and Social Research Council
(ESRC)

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Postdoctoral Fellowship scheme. Grant
number: ES/V011863/1*

with a small group, then asking them for the names of other people he could contact. Because each person leads to several more, he can quickly accumulate a large enough sample of interviews.

Using the snowball sampling approach, Daniel conducted interviews in 2018 with Brazilian people who had chosen not to migrate. He chose to use a technique called semi-structured interviews. This means he had a number of set questions that he asked every participant, but also allowed room for follow up questions and time for the person to talk freely.

WHY DO PEOPLE CHOOSE TO STAY IN THEIR OWN COUNTRY?

Some people stay because of involuntary immobility. This means that they do not have the resources to migrate, even if they wanted to. Often, this applies to the poorest people in a society, who have no choice but to stay where they are. On the other hand, rich people are able to leave and enter the country whenever they like. They also have the resources to shield themselves from economic and social problems. This means that they have no reason to migrate permanently, unless there is a very serious reason such as war or natural disaster. These people are an example of voluntary immobility, where people have the capacity to leave but choose to stay.

Daniel is especially interested in two other reasons for voluntary immobility. The first of these is our sense of belonging. Where do you

feel comfortable, safe and accepted? If the answer is where you live currently, you are unlikely to want to move. The second reason is that many of us feel a sense of duty to stay. Typically, our sense of duty is directed towards our family. If we feel that our family needs us, we will likely stay for their sake, even if we want to leave.

People can also feel a sense of duty towards larger things such as their country or wider community. Interestingly, this can happen even if they do not agree with political or traditional ideas of patriotism. Showing loyalty to your country can mean very different things to different people.

THE SCALE OF BELONGING

Where do you feel you belong? You might be thinking of your household, school, town, country, or a mixture of these things. From a single family to a country of millions, our sense of belonging exists at many different scales.

When something happens at a national level that people do not like, their sense of belonging can be rescaled. This might mean looking to smaller scales; instead of feeling attached to their country, people might feel they belong to their city or neighbourhood. However, people can also rescale their belonging to something bigger; they might feel that they are global citizens more than they are citizens of a particular country. By rescaling, people can still feel they belong, even when they do not feel comfortable with political,

economic or social changes at the local, national or international level.

HOW CAN MIGRATION RESEARCH INFLUENCE POLICY?

As well as investigating immobility, Daniel has been studying people who have migrated from Brazil to London. While writing his PhD, he found that many Brazilian migrants to the UK could live here by claiming ancestral European Union passports from countries like Italy and Portugal. However, there are also many who arrive on tourist visas and must work without the proper work visa. Due to Brexit, both groups are now facing similar problems.

Daniel hopes that his research will persuade the UK government to add Brazil to the Youth Mobility Scheme. This scheme works similarly to an exchange programme, with young people from either country having the opportunity to go and work for a couple of years in the other country. Daniel explains, "After Brexit, the UK government suggested that it might include more countries in the Youth Mobility Scheme to replace the freedom of movement lost due to Brexit. I think Brazil would be a good candidate, so I am using my research to try to convince the government of this."

Daniel's research reminds us that the world around us – and how and where people choose to live their lives – is changing all the time. Studies into human geography will always result in fascinating insights and can even shape how some of those changes come about.

ABOUT HUMAN GEOGRAPHY

Where do people live, how do they organise themselves, and how do they interact with their environment? Human geographers tackle these questions by examining how culture, communities, economics, history and politics interact. Where physical geography focuses on environmental processes and the natural world, human geography looks at how human lives, activities, values and social behaviour are shaped by the world around them.

WHAT ARE THE REWARDS AND CHALLENGES OF BEING A HUMAN GEOGRAPHER?

Daniel highlights that if you work as a researcher, one reward is that you get the chance to learn and write about topics that you find interesting. This freedom is rare in other types of jobs. On the other hand, you have to obtain your own funding, and this can be a

challenging part of the job, sometimes harder than the research itself! This is because there is a lot of competition for a limited amount of research funding. Daniel points out that you need to show to the institutions that award funding that your research is going to be important and impactful.

WHAT ISSUES COULD THE NEXT GENERATION OF HUMAN GEOGRAPHERS EXPLORE?

Human geography is all about scale and places, and technology is rapidly changing how we see these things. Future human geographers will explore how faster communications and online services are allowing people to change the way they live and work. Traditionally, most people travel (often long distances) into city centres for work because jobs are centralised there in a physical space. Now, the internet

makes it possible for many people to work from home, cutting out commuting time, and the COVID-19 pandemic has increased our awareness of that.

Daniel believes that the ability to decentralise workplaces will have big implications for how cities are structured and where people choose to live. Right now, many people want to live as close to the city centre as possible: throughout Europe, the countryside is being abandoned by young people who move to work in the cities. However, if a lot of jobs are moved online, will more people choose to live in smaller towns and villages? What impact will this have on how we build and develop cities? As a human geographer, these are just some of the questions you could be exploring.

EXPLORE A CAREER IN GEOGRAPHY

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

PATHWAY FROM SCHOOL TO GEOGRAPHY

- Geography is very diverse and people in this field come from a wide variety of backgrounds. For example, Daniel has worked with people with degrees in biology, computer science, philosophy, history, geology and anthropology, as well as geography.
- If you decide to study human geography at university, you may need to study English and at least one humanities subject in preparation – geography, politics, history, philosophy and economics are all good options.
 - Daniel adds, "There are also aspects of human geography that are more scientific. For example, demography, which is the study and measurement of human populations. In cases like this, subjects like maths and IT would be useful."
- Many geography courses allow you to study both human and physical geography. If you are interested in the physical side, mathematics, biology and physics will provide you with a good foundation. Check the requirements of university courses you might be interested in when you choose your subjects.

● HOW DID DANIEL BECOME A HUMAN GEOGRAPHER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

I was actually more interested in music when I was growing up. But I was always interested in the reasons why people act the way they do, and how ideas and beliefs about the world affect human behaviour.

WHO OR WHAT INSPIRED YOU TO STUDY PHILOSOPHY?

I wanted to study philosophy because I was interested in the nature of reality, people's beliefs about reality, and how these beliefs affect our experience of the world. These are some of the fascinating questions that philosophy explores.

HOW DID YOUR DEGREE IN PHILOSOPHY LEAD YOU TO GEOGRAPHY?

Social sciences, including geography, are actually very influenced by philosophy. Philosophers will create theories to explain

human behaviour, while social scientists will then often try to apply these theories in the way they conduct their research and interpret what they find. So, the two subjects are quite connected, even if it might not seem like it.

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

I was delighted to get the current position I have which has funded my research at Cambridge. My ambition is to get my next project about Venezuela funded so I can continue with my research. I am hoping to do a project which will be about migration in a very different context. At the moment, there is a very serious economic crisis in Venezuela, resulting in five million people leaving the country. These five million people play a very important role for those who stay, because they send money home to support their families. The problem is,

for various reasons, this can be hard to do. I want to study the different ways these migrants manage to send money home.



Daniel's expertise as a human geographer has led him to research focusing on migration in Brazil and Venezuela.

DANIEL'S TOP TIPS

- 01** Because geography is such a diverse subject, don't feel you should be limited to certain A-levels if you want to do a geography degree at university.
- 02** It is never too late to start a career in geography. I spent many years working in other sectors before deciding to pursue a university career.
- 03** It is important to be flexible in your interests and try to approach issues from different perspectives.



HOW CAN URBAN PLANNERS AND ARCHITECTS REDUCE INEQUALITY IN CITIES?

AS CITIES GROW, WHAT HAPPENS TO INDIVIDUAL NEIGHBOURHOODS WITHIN THEM? THIS IS WHAT THE CENTRE FOR SUSTAINABLE, HEALTHY AND LEARNING CITIES AND NEIGHBOURHOODS HOPES TO FIND OUT. LED BY PROFESSOR YA PING WANG AT THE UNIVERSITY OF GLASGOW, UK, THIS COLLABORATION BRINGS TOGETHER ARCHITECTS SUCH AS DR JOSEPHINE MALONZA AT THE UNIVERSITY OF RWANDA AND URBAN PLANNERS SUCH AS DR SHILPI ROY AT KHULNA UNIVERSITY, BANGLADESH, TO EXPLORE HOW TO IMPROVE URBAN ENVIRONMENTS

TALK LIKE AN URBAN STUDIES RESEARCHER

AKARUBANDA – the traditional Rwandan concept of public open space

PULL FACTOR – something that encourages someone to move towards an area

PUSH FACTOR – something that encourages someone to move away from an area

URBAN SPRAWL – the rapid spatial expansion of a city due to unplanned, uncontrolled and scattered growth

URBANISATION – the proportional increase of population living in urban areas compared to rural areas

By 2030, the United Nations predicts that 60% of the world's population will live in cities. While cities can provide residents with services and employment opportunities, rapid unplanned urban growth means these advantages are not available to everyone.

“Cities are very complex,” explains Professor Ya Ping Wang of the University of Glasgow. He is the director of the Centre for Sustainable, Healthy and Learning Cities and Neighbourhoods (SHLC), an international research collaboration that

hopes to better understand this complexity. The SHLC team is studying urban neighbourhoods in 14 cities in Africa and Asia, including Kigali and Huye in Rwanda, and Dhaka and Khulna in Bangladesh. Team members have a wide range of urban studies-related backgrounds, from urban planning, such as Dr Shilpi Roy at Khulna University, to architecture, such as Dr Josephine Malonza at the University of Rwanda, and from health to education. Their research will unpack the challenges of urbanisation and support the United Nations' Sustainable Development Goals, not only to ensure cities and communities are sustainable, but also to ensure those living in urban environments have good health and well-being, and access to quality education.

WHY ARE CITIES GROWING?

Cities offer opportunities for employment and social interaction, enticing migrants to urban centres, while poverty commonly drives migrants from rural regions. “In Bangladesh, unequal land distribution, inadequate education and healthcare, unemployment and displacement by natural disasters all act as push factors, forcing rural residents to leave,” explains Shilpi. “Urban industries, income opportunities, better social amenities and improved livelihoods in cities all act as pull factors to draw rural people to urban areas.”

Cities also expand in response to growing national populations. “The rapid urbanisation we are currently seeing in Rwanda is

primarily fuelled by the high birth rate and resulting phenomenal increase of the country's population,” says Josephine.

WHAT PROBLEMS ARE CAUSED BY URBANISATION?

Overcrowding, pollution, congestion, urban sprawl, overuse of resources and lack of access to amenities are just some of the problems caused by urbanisation. In Bangladesh, the number of slums has increased almost five-fold since 1997 as more people move to the cities, and over one in five urban residents live in poverty, highlighting how rapid urbanisation commonly leads to increased social inequality.

At the same time, cities generate large amounts of waste, which can end up in waterways or in the air that people breathe. Over half of all solid waste produced in Khulna is dumped on the roadside. “Unplanned urbanisation in the cities of Bangladesh has led to crowded and polluted living conditions, with urban services insufficient to serve the communities that live there,” says Shilpi. Air pollution can have serious consequences not just for human health but for education. In 2021, schools were closed in the Indian capital of Delhi due to record levels of air pollution.

WHAT METHODS ARE THE SHLC TEAM USING?

Although urban sustainability is often discussed at city-level, the diversity within a single city means broad generalisations



SHLC
Centre for Sustainable,
Healthy and Learning Cities
and Neighbourhoods

**THE CENTRE FOR SUSTAINABLE,
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PARTNER INSTITUTIONS

University of Glasgow, UK; Khulna University, Bangladesh; University of Rwanda, Rwanda; Human Sciences Research Council, South Africa; University of the Witwatersrand, South Africa; Ifakara Health Institute, Tanzania; National Institute of Urban Affairs, India; University of the Philippines, Philippines; Nankai University, China



FIELD OF RESEARCH

Urban Studies



RESEARCH PROJECT

Investigating the sustainability of cities and urban neighbourhoods by assessing residents' access to healthcare, education and opportunities



FUNDERS

UK Research and Innovation (UKRI),
Global Challenges Research Fund
(GCRF)

lose the intricacies of city life. The SHLC is investigating cities at a neighbourhood-scale to address this issue. “We carry out large-scale household surveys and focus group interviews in different types of neighbourhoods,” says Professor Michele Schweisfurth, from the University of Glasgow. She is a professor of comparative and international education and a co-investigator in the SHLC team. “This helps us to understand neighbourhood characteristics, including the demographic, social and economic composition of different districts within a single city.”

Team members also statistically analyse official datasets to quantify urban growth and urban inequality. They use satellite imagery and visual observations to map out urban expansion and land-use change. And they review urban policy documents to explore how development is viewed and managed in the case-study cities.

WHAT DO NEIGHBOURHOODS NEED?

For a neighbourhood to be considered a ‘sustainable, healthy and learning environment’, all residents within it should have access to educational, employment and healthcare opportunities. “The presence of affordable, quality and adequate facilities for all increases the living conditions of a neighbourhood’s residents,” explains Shilpi.

“If development opportunities are integrated in a neighbourhood, people commute lesser distances to access work, healthcare and education,” says Josephine. “If a neighbourhood is vibrant, this will encourage healthy lifestyles, employment opportunities and economic growth.”

Sustainable neighbourhoods should also reduce their impact on the natural environment. This requires efficient public transport services to reduce dependence on private cars and waste management services to prevent rubbish being dumped on streets and in waterways.

It is also incredibly important for urban

neighbourhoods to contain open, unbuilt areas, such as parks. “Public open spaces are lifelines for communities,” explains Josephine. “They help to improve our social, physical and mental health – all of the things which give life meaning.” In Rwanda, there is a traditional concept of public space known as *akarubanda*. Shared social spaces in rural settlements provide opportunities for community members to gather and socialise, dance, share food and exchange words of wisdom. Through her research and engagement with policy makers, Josephine hopes to bring *akarubanda* back into contemporary Rwandan cities.

HOW COULD URBAN DEVELOPMENT POLICIES IMPROVE CITIES?

“More attention needs to be paid to improving city planning and regulation, especially prioritising neighbourhood-based development,” Shilpi says. “This is necessary to deal with inequalities and the lack of services in growing urban areas.” She and Josephine both advocate for improved urban development policies in their countries. These policies need a bottom-up approach, driven by community members and the needs of individual neighbourhoods, to ensure new urban development serves the people of the city.

Urban sprawl is a significant challenge in Rwanda and Bangladesh as informal settlements grow around cities. Josephine suggests a solution could be to create urban qualities (such as services and employment opportunities) in rural settlements, thereby minimising rural to urban migration and so reducing the pressure on cities. Shilpi hopes to see unified urban governance in Bangladesh, in which all the different agencies involved in city management work together to regulate development. She also highlights that all development policies should consider the environmental impact of urbanisation and industrialisation.

The research findings from the SHLC are already being communicated with stakeholders. Shilpi and the Bangladesh

team have shared their results with the mayors of Dhaka and Khulna and are now preparing policy briefs based on SHLC findings to ensure national urban policies promote sustainable, healthy and learning neighbourhoods. Josephine and the Rwandan team have met with stakeholders to plan how new policies can be implemented, and Josephine has been appointed to a joint sector review board at the Ministry of Infrastructure and a technical advisory group for the city of Kigali, where she can apply her research findings at government level.

The members of the SHLC are not only helping us understand cities in greater detail but are using their expertise to improve our urban environments. As Shilpi comments, “With a career in urban studies, you can really make a difference in the world!”

ABOUT URBAN STUDIES

The world is rapidly urbanising. As people flock to cities in search of employment opportunities, urban populations are increasing faster than ever. As cities expand to accommodate this influx of migrants, urban planning has never been more important.

WHY DO CITIES NEED TO BE PLANNED?

Cities cannot be left to grow spontaneously as they expand, as this results in neighbourhoods that do not have access to adequate infrastructure and services. In many cities around the world, unplanned, uncontrolled and scattered growth has resulted in informal settlements, or 'slums'. "In Bangladesh, wealthy neighbourhoods are almost all planned and

offer quality services and facilities," says Shilpi. "In contrast, most poorer neighbourhoods are unplanned, with deficient urban amenities as a result." This unplanned development therefore deepens social inequalities.

"Planning is important as it helps cities to develop strategically, based on existing resources and a well envisioned future," Josephine explains. "Without this balance, cities would outrun their resources and end up in a complete mess."

WHAT ARE THE HIGHLIGHTS OF WORKING IN URBAN STUDIES?

"I am passionate about the quality of life in urban areas, and hence unpacking the

multifaceted layers that urban societies have to navigate to enjoy life in cities," says Josephine. Working in urban design as well as architecture provides her with a wider perspective, giving her a deeper understanding of social life in the unbuilt parts of cities that architects do not necessarily engage with.

Shilpi is motivated by knowing her expertise in urban planning can promote equality in urban areas. "Rapid urbanisation leads to pollution, environmental degradation and inequality," she says. "Urban planning has immense scope for tackling these urban challenges and securing a sustainable future for urban residents."

EXPLORE A CAREER IN URBAN STUDIES

- Visit the Centre for Sustainable, Healthy and Learning Cities and Neighbourhoods to learn how experts in urban studies and related fields are applying their skills to improve urban environments around the world: www.centreforsustainablecities.ac.uk
- Josephine says that urban studies will enable you to explore the past, present and future of cities with humans at their centre. "A range of career pathways will allow you to impact sustainable cities by engaging with their economical, environmental and cultural trends."
- As an urban planner, you could design new neighbourhoods or redevelop existing ones. As an architect, you could design the buildings and infrastructure needed in these new developments.
- Prospects provides information about what you could do with a degree in urban planning (www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/urban-planning) or architecture (www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/architecture).
- The International Society of City and Regional Planners works in over 90 countries to help make cities safe, resilient and sustainable: www.isocarp.org
- The International Union of Architects provides information about the collaborative role that architects can play in addressing the UN Sustainable Development Goals: www.uia-architectes.org/webApi/en

PATHWAY FROM SCHOOL TO URBAN STUDIES

- Shilpi highlights that it is useful to study both science and arts subjects at school if you are interested in pursuing a career in urban studies. She notes that students with a strong mathematics background will have more opportunities in the field, and Josephine also recommends studying geography and physics.
- University degrees in urban studies, urban planning, architecture and human geography will all allow you to explore the role of architecture and society in urban environments.
- At university, Josephine recommends taking modules in urban design, environmental design, urban geography and urban anthropology, while Shilpi recommends modules in Geographical Information Systems (GIS), remote sensing and transportation planning.

JOSEPHINE AND SHILPI'S TOP TIPS

- 01** Work hard: dreams don't work unless we work.
- 02** Focus on positive inspiration, the world is full of possibilities and surprises.
- 03** Read widely; for instance, you can learn about urban planning by reading books on everything from classic civilisation to the urban reform movement of the 20th century.

HOW DID JOSEPHINE BECOME AN ARCHITECT?



DR JOSEPHINE MALONZA IS A LECTURER IN THE SCHOOL OF ARCHITECTURE AND THE BUILT ENVIRONMENT AT THE UNIVERSITY OF RWANDA.

FIELDS OF RESEARCH:
ARCHITECTURE,
URBAN DESIGN

As a young child, I hated seeing girls playing 'cooking' and boys playing with toy cars. I wanted to see girls playing with more technical things, like the boys did. When I was 15, I decided I wanted to be an architect. I studied hard in STEM subjects at school and had the opportunity to study architecture at university.

I was one of only two female students in my architecture class at university. I was a curious student but did not have any female role models in the School of Architecture. This inspired me to become a lecturer so that I could be a role model for girls in the future. My seriousness of purpose in teaching and mentoring students saw me appointed as the dean of the school when I was only 31 years of age.

Architecture and society have a complex relationship. For architecture to be understood by society, society has to form a central part of it. For this reason, I

have changed the way I teach architecture and urban design. My modules are now more participatory and my students interact with communities and live sites. Last year, my class conducted a successful community workshop towards finding an innovative solution to informal housing in Kigali.

My research has initiated several stakeholder engagement activities where national policy has been discussed and plans for implementation have been mapped out. I have also been appointed to several boards in the city of Kigali and at Rwanda's Ministry of Infrastructure, where pressing urban development dynamics are tackled.

Seeing how proper architectural education can transform societies keeps me engaged and motivated in my job. The kind words of appreciation that I receive each week – especially from my students and school alumni – keep me fuelled to do more.

HOW DID SHILPI BECOME AN URBAN PLANNER?



DR SHILPI ROY IS AN ASSOCIATE PROFESSOR OF URBAN AND RURAL PLANNING AT KHULNA UNIVERSITY IN BANGLADESH.

FIELDS OF RESEARCH:
PLANNING POLICY,
URBAN GROWTH,
NEIGHBOURHOOD
PLANNING

At an early age, I was interested in drawing, designing, and building models of houses. During secondary school, I found three mentors through family networks who were studying architecture and urban planning. I had the option to study either subject at university but chose to pursue urban planning based on the better job prospects in this field in Bangladesh.

Many of my family members work in academia, so an academic career in urban planning appealed to me. After graduation, I decided to prepare myself for this career. I studied a master's in Spatial Planning at Oxford Brookes University in the UK, then I attended the University of Manchester for my PhD in Planning and Landscape.

I feel privileged to have had this opportunity to access higher education. Public funds covered all my education-related expenses in Bangladesh. I

therefore have a sense of social responsibility to pay this back to my country through my work.

I have worked for city development authorities and NGOs such as Action Aid to address the challenges facing urban neighbourhoods in Bangladesh. I would not have had the opportunity to do so without a planning background and specialised degree in planning and regeneration.

As the leader of the SHLC in Bangladesh, I am responsible for coordinating the research, capacity building activities, management and impact activities in the country. The scope of the SHLC project is immense and has given me the chance to work with partners across Asia and Africa. By the end of the project, we will have a good understanding of what makes a neighbourhood sustainable and thus be able to guide policymakers in this direction.

WHAT IF WE UNDERSTOOD THE ROLE UNDERWATER PLANTS PLAY IN THE FLOW OF WATER?

DR XIAO YU, BASED AT THE UNIVERSITY OF FLORIDA IN THE US, IS THE PRINCIPAL INVESTIGATOR OF A PROJECT THAT SEEKS TO MODEL THE FLOW OF WATER OVER SUBMERGED AQUATIC VEGETATION. THE FINDINGS WILL HELP SCIENTISTS STUDY A VARIETY OF KEY ECOSYSTEM PROCESSES IN RIVERS AND ESTUARIES

TALK LIKE A COASTAL AND OCEANOGRAPHIC ENGINEER

SUBMERGED AQUATIC VEGETATION –

a rooted aquatic plant that grows completely under water

VEGETATION BLADE – the expanded part of a leaf or petal

BLADE-TO-BLADE INTERACTIONS – when multiple vegetation blades come into contact and interact with each other

DEFLECTED HEIGHT – the height of the vegetation blade when submerged under water. The deflected height is different from the length of the vegetation blade because the vegetation blade bends under the flow of water

HYDRODYNAMICS – a branch of physics that deals with the motion of fluids and the forces

acting on solid bodies immersed in fluids (and hence the resistance forces acting on the fluid by solid bodies)

FLOW ATTENUATION – the action of slowing down the flow of water

TURBULENCE - fluid motion characterised by chaotic changes in pressure and flow velocity. Turbulence can be seen in everyday phenomena such as surf and fast flowing rivers

FLOW VELOCITY - the distance travelled by a fluid per time i.e., metre/second or feet/minute

MODELLING – the generation of a physical, conceptual or mathematical representation of a real phenomenon that is difficult to observe directly

NATURAL RESOURCES MANAGEMENT – using natural resources (land, water, soil, etc.) in a way and at a rate that maintains and enhances the resilience of ecosystems and the benefits they provide

TRANSPORT – a term used to describe the way in which rivers pick up and carry materials as they flow downstream

MONAMI – a coherent waving motion in flexible blades

CAUCHY NUMBER – the ratio of hydrodynamic drag force to the elastic restoration force. Visit this website for a revision of forces and elasticity: www.bbc.co.uk/bitesize/guides/zt9smsg/revision/2

Submerged aquatic vegetation (SAV) is a term that refers to aquatic plants that grow completely under water. These plants reside in both freshwater and saltwater, but in estuaries – where both fresh and saltwater are often mixed together – they can be particularly important for aquatic organisms, which rely on SAV for food and shelter.

Indeed, SAV is a critical part of the ecosystems that exist in bodies of water and plays an important role in rivers and estuaries. If we picture the gentle movement of blades of grass

and other vegetation below the surface of rivers and estuaries, we can see that the flow of water runs over and through this vegetation, which affects the flow.

Most of us would take this for granted and think no more of it – but for Dr Xiao Yu, who is a coastal and oceanographic engineer based within the Department of Civil and Coastal Engineering at the University of Florida, the flow of water that runs over and through submerged aquatic vegetation forms the basis of his latest project. His study aims to

develop a framework for modelling flow over flexible SAV and quantify the influence of vegetation structural properties and blade-to-blade interactions on hydrodynamics, in particular flow attenuation and turbulent mixing processes.

By understanding the physical-biological-ecological links between the structure of SAV and the ways in which water flows in relation to it, Xiao hopes to uncover findings that will be of critical importance to natural resources management.



DR XIAO YU

Assistant Professor, Department of Civil and Coastal Engineering, University of Florida, USA

FIELD OF RESEARCH

Coastal and Oceanographic Engineering

RESEARCH PROJECT

Understanding the influence of underwater plants (submerged aquatic vegetation) on hydrodynamics and their collective behaviour under different flow conditions

FUNDER

National Science Foundation (NSF)

WHAT ARE BLADE-TO-BLADE INTERACTIONS?

A vegetation blade is the expanded part of a leaf (or similar) and a single, flexible blade reconfigures its posture with flow velocity. Naturally, as the flow velocity increases, the blade bends and the drag force is reduced. Thus, the extent of the bend greatly affects hydrodynamics (i.e. the flow of water). So good, so far. However, when we consider areas where there is dense vegetation, there is the possibility for a vast number of interactions. Think about the influence the flow of water has on multiple blades of vegetation – the bending and shaping of these blades will likely lead to many blades coming into contact and interacting with many others.

This is known as blade-to-blade interaction and although it is extremely complicated to study, it is vitally important, not least because the collective behaviour of vegetation blades could be significantly different from the total sum of each individual blade. It is here where Xiao’s modelling comes into play, as he attempts to use computational techniques to describe the interactions and the affect they have on the flow of water.

WHY IS IT IMPORTANT TO MODEL FLOW?

“When vegetation blades come into contact with each other, blade-to-blade interactions may alter the deflected height, so attributing the observed deflection height solely to the bending stiffness of a single blade is often insufficient,” says Xiao. This is what makes his project novel – he is investigating the influence of interactions among multiple blades, including both their hydrodynamic interaction and direct contacts. It is Xiao’s belief that these investigations will

prove critical to describe the hydrodynamics at play, which are primarily driven by the whole canopy of vegetation.

IS CONTINUOUS SAV CANOPY MOTION A CONCERN FOR XIAO?

Yes! “Canopy-scale vortices can induce a waving motion in flexible blades, namely ‘monami’ when the vortex is strong enough to depress individual blades and the instantaneous drag force exerted by the vortices is greater than SAV buoyancy and rigidity,” explains Xiao. “The flexibility of the canopy and presence of ‘monami’ affect momentum transfer and mass exchange between the canopy layer and the overlying flow at large scales. This has ramifications for mass transport, sediment transport, residence times, biogeochemical processes and ecological interactions.”

HOW WILL XIAO’S STUDIES HELP ENGINEERS AND NATURAL RESOURCE MANAGERS?

SAV provides important ecological services in the rivers and estuaries of Florida (where Xiao’s studies are focused) and other parts of the world. Indeed, aquatic plants are an important habitat for a wide range of invertebrates, fish and other animals. They are also an important food source for various species, including those of conservation concern, such as the West Indian manatee. It is, therefore, concerning to learn that algae have been increasing in many Florida springs, which represents a threat to these ecosystems and could have devastating effects on the life situated within them.

“Recent studies suggest that reductions in flow velocity can prevent ‘monami’ generation and blade-to-blade interactions that inhibit undesired algae growth,” says

Xiao. “Understanding the physical-biological-ecological coupling in rivers and estuaries with flexible SAV can provide support for natural resources management and guidance for the protection and restoration of aquatic ecosystems, such as the minimum flow requirement.”

WHAT HAVE BEEN THE KEY FINDINGS OF XIAO’S PROJECT?

One of the main findings of the project so far concerns the inclusion of blade-to-blade interactions. By including them, the deflection height of SAV is reduced, meaning larger drag. “The dynamics primarily depends on the Cauchy number, vegetation density and the ratio of the characteristic length scales of ‘monami’ to the spacing of adjacent blades,” says Xiao.

Ultimately, by developing a model that can investigate the deformation of vegetation blades and interactions between multiple blades, Xiao and the team hope to better understand the effects of SAV on key ecosystem processes, such as sediment transport and algae growth. Science is often for its own end – and Xiao’s work certainly attests to this –, but the life that relies on ecosystems and SAV could benefit from the findings.

ABOUT COASTAL AND OCEANOGRAPHIC ENGINEERING

Given the current and future impacts of climate change, now is arguably the most important time for coastal and oceanographic engineering. As the polar icecaps melt, water levels will rise around the world and this will have significant impacts on coastal communities and areas.

Coastal and oceanographic engineering is one notable field that will help to drive research and innovation in areas that will help humanity overcome some of the challenges associated

with climate change – not just for human populations, but for the animals and other organisms that rely on ecosystems in and around bodies of water. As Xiao's research shows, it is possible to combine several seemingly independent research interests in order to solve various challenges.

WOULD XIAO RECOMMEND A CAREER IN COASTAL AND OCEANOGRAPHIC ENGINEERING?

In a word, yes. Xiao is unequivocal in his passion

for the field. "I would definitely recommend a career in the field," explains Xiao. "There are a lot of exciting opportunities in coastal and oceanographic engineering for next-generation scientists and engineers: the sustainable delivery of economic, social and environmental benefits associated with coastal infrastructure; underwater exploration using remotely operated underwater vehicles (ROVs); the floating city by Oceanix that can withstand a Category 5 hurricane."

EXPLORE A CAREER IN COASTAL AND OCEANOGRAPHIC ENGINEERING

- Marine Careers is an essential resource for those looking to develop a career in ocean engineering and related fields. This site really should be able to answer any questions you might have:
www.marinecareers.net/ocean-engineering
- The University of Florida's College of Engineering provides a wealth of information relating to coastal and oceanographic engineering, including some of the exciting research that is taking place and useful resources: www.eng.ufl.edu
- "We also offer scholarships to high school students and teachers who want to work with our faculty, and graduate students and undergraduate students who want to explore university-level research," explains Xiao. "The students are given opportunities to present their research at STEM research competitions or during non-competitive poster sessions."
- In the US, ocean engineers make an average of \$73,000 per annum, but this is largely dependent on the particular job role being performed. You could be a marine biologist, marine engineer or coastal engineer, to name a few, and all have different average salaries.

PATHWAY FROM SCHOOL TO COASTAL AND OCEANOGRAPHIC ENGINEERING

Xiao began by studying hydraulics before moving on to ocean engineering. As such, there is no pre-defined pathway and it really rather depends on exactly what you want to do. However, as with any form of engineering, a solid basis in mathematics and science while at school and college – particularly physics – will be important. Given some of the work that Xiao is engaged in, biology and computing could be useful.

XIAO'S TOP TIPS

- 01** Be an active learner. Curiosity has always been the driving force behind research; asking 'why?' and 'how?' will keep science moving forward.
- 02** Actively seek out research opportunities from an early stage. It will stand you in good stead and give you an idea of what to expect if you pursue a career in academia.
- 03** Staying motivated is so important for a successful career – if you can find a research topic you are passionate about, half the battle is already won.

MEET XIAO



The Three Gorges Dam project inspired me to study hydraulic engineering. It was one of the largest engineering projects in China and the largest dam structure in the world. When I studied within the Department of Hydraulic Engineering at Tsinghua University, I learned the environmental impacts of water infrastructure and decided to focus on environmental fluid mechanics and sediment transport for my PhD.

I always wanted to be a scientist when I was younger. My mother was a middle school chemistry teacher and she inspired me to pursue a STEM career.

We constantly face challenging research problems and by working with researchers from other disciplines, I am exposed to new ideas and perspectives, which enables me to see things from

different angles. I also enjoy learning about new technologies (such as machine learning) and applying them in my own research.

My long-term goal as an educator is to engage students in interdisciplinary STEM careers and prepare them by imbuing them with the skills they need to solve challenging, practical engineering problems. One of the greatest challenges the US is facing now in graduate-level engineering programmes is the decreasing number of undergraduate students who pursue their studies for career development in the highly challenging technology area – particularly underrepresented and women students. It is, therefore, very important to develop effective ways to engage students to pursue STEM careers by offering them first-hand research experience opportunities so they can realise the benefits.

MEET ROB



Rob Taylor is an undergraduate student in environmental engineering at the University of Florida, working with Xiao on the NSF-funded project: A framework for modelling flow over flexible submerged aquatic vegetation.

My role in the project is primarily validating model results with field observations. The work is varied, ranging from building mounts for the cameras and velocity instruments, to scuba diving and running the experiment in the field, and analysing the images to extract the data we are looking for.

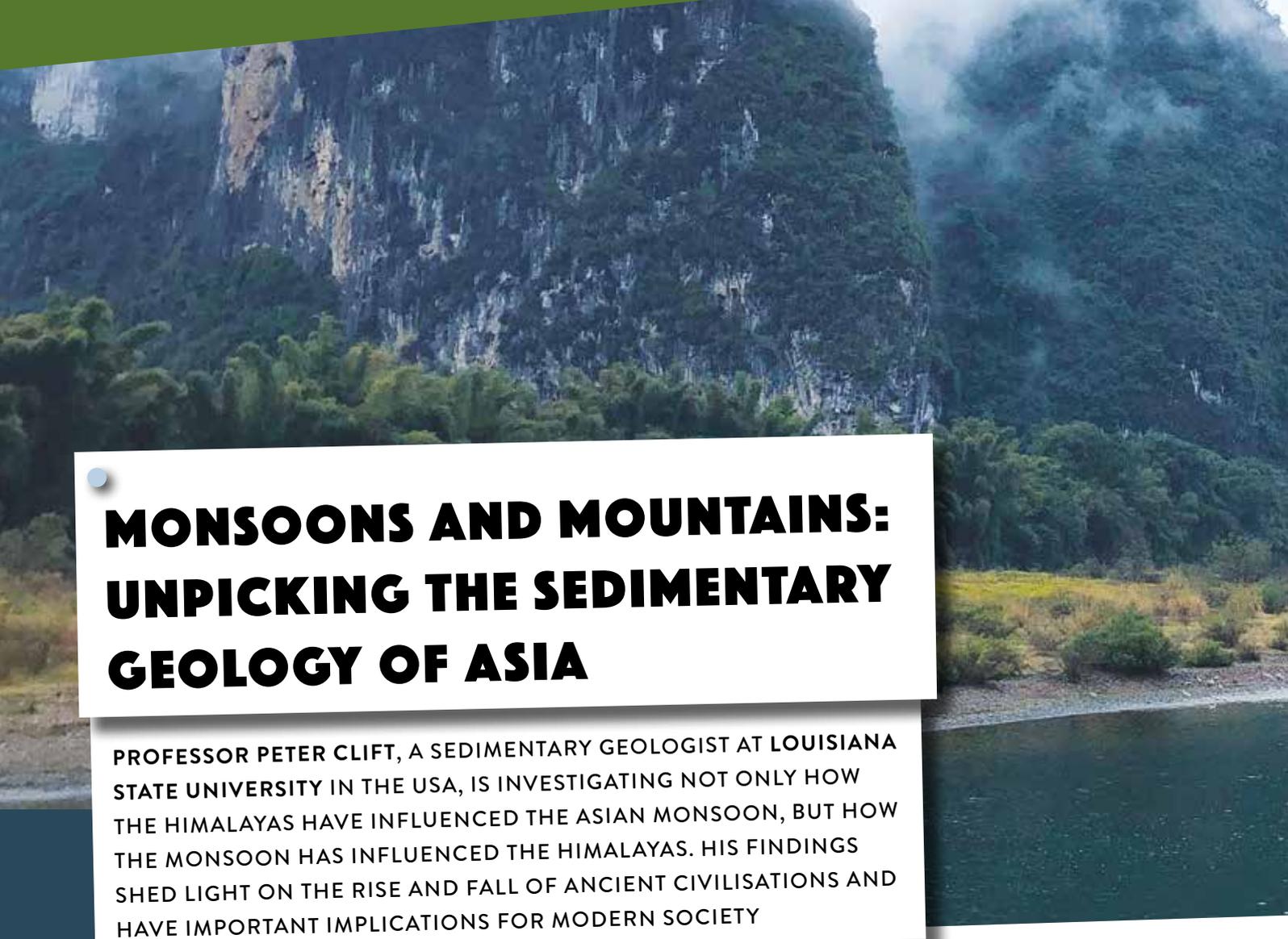
I was never the child who knew exactly what I wanted to do with my life. In fact, I didn't even want to attend college after high school. The pragmatic and hardworking side of me thought I would be a charter fisherman, and the creative in me wanted to pursue music or filmmaking. However, after encouragement from many family members and friends, and without feeling forced into it, I decided to attend community college. I eventually landed on environmental engineering for my bachelor's degree because of my long history with Florida's ecosystems.

Solving math and physics problems really stimulates

my mind in a unique and pleasurable way. As I have moved along in my studies, and systems have gotten more complex, I've started to realise that so many of the engineering problems that we solve just boil down to a collection of physics problems like those learned in the early years of my studies. I also love how so many of the topics we study can be directly applied in industry and help the environment.

Immediately after graduation, I plan on working in environmental consulting for some time. The position I'm in now keeps me in the field for 20-25 hours a month doing mostly flow monitoring on Florida rivers for public projects. I will likely stay with the company after graduation and fill the rest of my hours with engineering work such as hydrologic modelling, coastal design, geographic information systems (GIS) work and data analysis.

In the end, I want to be able to make a direct impact in areas like environmental protection and ecological restoration, educate the public about climate systems and how humans impact them, and help solve the technical, social, economic and political issues that will undoubtedly come along with climate change.



MONSOONS AND MOUNTAINS: UNPICKING THE SEDIMENTARY GEOLOGY OF ASIA

PROFESSOR PETER CLIFT, A SEDIMENTARY GEOLOGIST AT LOUISIANA STATE UNIVERSITY IN THE USA, IS INVESTIGATING NOT ONLY HOW THE HIMALAYAS HAVE INFLUENCED THE ASIAN MONSOON, BUT HOW THE MONSOON HAS INFLUENCED THE HIMALAYAS. HIS FINDINGS SHED LIGHT ON THE RISE AND FALL OF ANCIENT CIVILISATIONS AND HAVE IMPORTANT IMPLICATIONS FOR MODERN SOCIETY

TALK LIKE A SEDIMENTARY GEOLOGIST

CHEMICAL WEATHERING – the process of rainwater chemically reacting with minerals in a rock, converting them to new (and often weaker) minerals, such as clays

MONSOON – a system of winds that reverse direction seasonally, bringing strong rains over continental areas during the summer

PLATEAU – an area of relatively level high ground. The Tibetan Plateau is the highest and largest in the world

SEDIMENT – loose mineral material composed of eroded rocks

SEDIMENT CORE – a sample collected by drilling vertically into sediment. Materials deeper in the sediment core were deposited longer ago in geological time

SEDIMENTARY ROCK – rock composed of solidified sediment

Professor Peter Clift, at Louisiana State University, uses geological methods to delve deep into the Earth's past. He is interested in understanding the relationships between the Asian monsoon and the mountains and plateaus of the region. As well as understanding past climates, this information has also helped him uncover knowledge of why past civilisations rose and fell.

“Monsoons are climatic systems that occur on all the major continents,” says Peter. “They reflect seasonal changes in wind patterns, driven by temperature differences between the ocean and land, which bring rain deep into the continental interior.” The Asian monsoon is the largest in the world, due to the unique geography of the region. “The shape and scale of the Himalayas and the Tibetan Plateau make the monsoon stronger,” Peter explains. “In fact, the rain of the Asian monsoon is responsible for sustaining the agricultural systems that feed the majority of the world's population.”

While mountains can affect monsoons, monsoons can also affect mountains. Rain causes chemical weathering of rocks,

and over long timescales, monsoons will erode mountains.

OCEAN DRILLING

Peter's work takes him to some far-flung corners of the world, both on land and at sea. “In the South China Sea, we used a modified oil drilling ship to penetrate hundreds of metres into the seafloor, to extract long sediment cores that provide a vertical record of the Earth's geological history,” he explains.

These marine expeditions can be long and intense. “We spend eight weeks at sea, working 12-hour shifts with no days off,” says Peter. Each expedition will contain a variety of different scientists on board, and teamwork is key to ensuring all the scientific research objectives are achieved. Some scientists will describe the sediment cores as they are brought onto the ship, some will measure the chemical or magnetic properties of the cores, and some will identify fossils in the sediment.

ANALYSING SEDIMENT

Peter and the team analyse the sediment extracted in these cores to reconstruct how

Monsoon clouds gather near Guilin, southern China



PROFESSOR PETER CLIFT

Charles T McCord Chair in Petroleum Geology, Louisiana State University, USA

FIELD OF RESEARCH

Sedimentary Geology

RESEARCH PROJECT

Using sedimentary cores to understand the relationships between the Asian monsoon and the Himalayan mountains

FUNDERS

International Ocean Discovery Program, National Science Foundation, US Navy, ExxonMobil

the environment and climate have changed in the past. The cores provide clues about the rate of continent erosion and the chemical breakdown of sediments, which indicate the strength of monsoons in the geological past.

Geologists use many innovative methods to analyse sediment cores, including:

- **Chemical analysis:** Sediment is dried, crushed and melted, then its exact chemical composition is analysed, revealing the extent of chemical weathering.
- **Zircon dating:** Zircon crystals contain uranium, which decays into lead at a known rate. By comparing the amount of uranium and lead in zircon, the source and, sometimes, the age of the sediment can be determined.
- **Fossil dating:** Because species have evolved over time, the type of fossils found in sediment can be used to estimate the time when the sample was deposited.
- **Radiocarbon dating:** The weakly radioactive carbon isotope, carbon-14, decays at a known rate. Relatively young sediment samples (less than 60,000 years old) can be dated by measuring the amount of carbon-14 they contain.
- **Optically stimulated luminescence dating:** Sunlight ionises electrons in a mineral, and by measuring the behaviour of a mineral's electrons, geologists can estimate how long

sediment has been buried and unaffected by sunlight.

CHANGING IDEAS

“For a long time, people thought that the Asian monsoon gathered strength around 8 million years ago,” Peter says. “However, our work in the South China Sea indicated it’s actually much older, strengthening by at least 24 million years ago, if not before.” The Tibetan Plateau formed when the Indian subcontinent collided with Asia around 50 million years ago, with enough force to drive rock thousands of metres above sea level. However, the landscape looked very different to the mountains we are familiar with today – until the monsoon gathered power.

“I revealed that the Himalayas were formed from the rocks of the Tibetan Plateau as a result of the monsoon’s erosive power,” explains Peter. “Stronger rains removed sedimentary rocks at the surface, allowing deep-buried rocks to rise to the Earth’s surface.” The distinctive jagged peaks and deep valleys of the Himalayas are the result of this erosive process, carving them out of the plateau from the top down.

CIVILISATIONS PAST AND PRESENT

The Indus delta and flood plains in Pakistan, though arid today, were one of the most fertile regions in the world back in the Bronze Age. Peter has unpicked how this fertility, and the benefits it brought for early civilisations, are connected to the monsoon. After extracting sediment cores from the Indus delta and flood plains inland, Peter dated the sediment using carbon-14 dating and optically stimulated

luminescence, analysed the sediment chemistry to determine the intensity of weathering, and examined the variety of pollen in the sediment that reflects the vegetation that grew in the region.

Around 4,000 years ago, the Indus civilisation collapsed. Peter believes his sediment cores shed light on why this happened. “We conclude the collapse of these early urban societies was linked to the weakening of the monsoon,” he explains. This weakening led to reduced rainfall and diminishing agricultural productivity, forcing the population to migrate to the more fertile regions of what is now northern India.

These findings have implications for the modern world. “The sensitivity of human society to changes in monsoons is quite striking,” says Peter. Today, global climate change is affecting monsoon patterns. As billions of people rely on the Asian monsoon, this is troubling. “Climate change will mostly make monsoons stronger, but will also make them less reliable and stormier,” says Peter. This will threaten crop viability, not to mention bring risks to people’s lives and livelihoods through flooding and storms. Understanding what drives monsoons and using this information to predict their future behaviour will help society mitigate these risks.

ABOUT SEDIMENTARY GEOLOGY

Peter tells us more about being a sedimentary geologist:

WHAT INSIGHTS CAN SEDIMENTARY ROCKS LEND US?

The preservation of sedimentary rocks usually reflects large-scale tectonic processes, so studying them can help geologists understand how continents form and what they looked like in the past. They also record the long-term erosion of mountain belts, and when combined with structural measurements of the mountains themselves, we have a powerful way of understanding what controls the surface processes of the planet. Sedimentary records are also a reliable archive of long-term

geological processes, such as changes to the climate and the evolution of life.

WHAT DO YOU ENJOY MOST ABOUT YOUR WORK?

My work takes me to interesting places around the world, including beautiful and remote regions that few travellers ever visit. I love fieldwork, though much of my work is done back in the lab. I enjoy the challenge of reconstructing how the Earth has changed over time and discovering the unexpected links between different areas of Earth science. This process is especially rewarding when done alongside students, supporting them in their own research growth and understanding. It's

very satisfying to complete a project and see our final publications.

AND WHAT DO YOU FIND MOST CHALLENGING?

The open-ended nature of my work means there can be a challenge in deciding what to do next – thinking of something really novel, rather than just repeating past studies in a new place. Linking sediments to climate is particularly challenging but is aided by international collaboration. I enjoy facing these challenges by building teams of geologists from around the world, combining our skillsets to tackle a particular problem.

EXPLORE A CAREER IN SEDIMENTARY GEOLOGY

- Historically, many sedimentary geologists worked in the oil and gas industries, using their skills to locate new reservoirs of fossil fuels. Today, sedimentary geologists are using these same skills in the carbon capture industry, locating subsurface rock units that can store carbon, thereby reducing atmospheric carbon dioxide levels. Sedimentary geologists can also be found working in environmental consultancy, engineering geology, marine geology and even in forensic investigations.
- Peter recommends joining local or national geological societies that often organise fieldwork opportunities and scientific meetings, and provide educational resources and information about geology careers. Examples include The Geological Society of America (www.geosociety.org) and The Geological Society (www.geolsoc.org.uk).
- The Department of Geology and Geophysics at Louisiana State University, where Peter works, offers many outreach opportunities. The Science Café (www.lsu.edu/research/news/LSU-science-cafe.php) provides public evening lectures on a range of scientific subjects, while EnvironMentors (www.lsu.edu/cce/experience/environmentors.php) connects high school students with LSU students to conduct joint science research projects.
- Many research groups in Peter's department host high school students who participate in research projects. Contact the department office at geology@lsu.edu, which can help connect schools with professors who provide educational opportunities.
- Look for opportunities such as work experience, internships and summer schools that will provide you with invaluable insights and geological experience. For instance, the US Geological Survey has a long-standing Summer Fellowship Program that sponsors interns: www.usgs.gov/science-support/osqi/youth-education-science/geology-summer-fellows-program

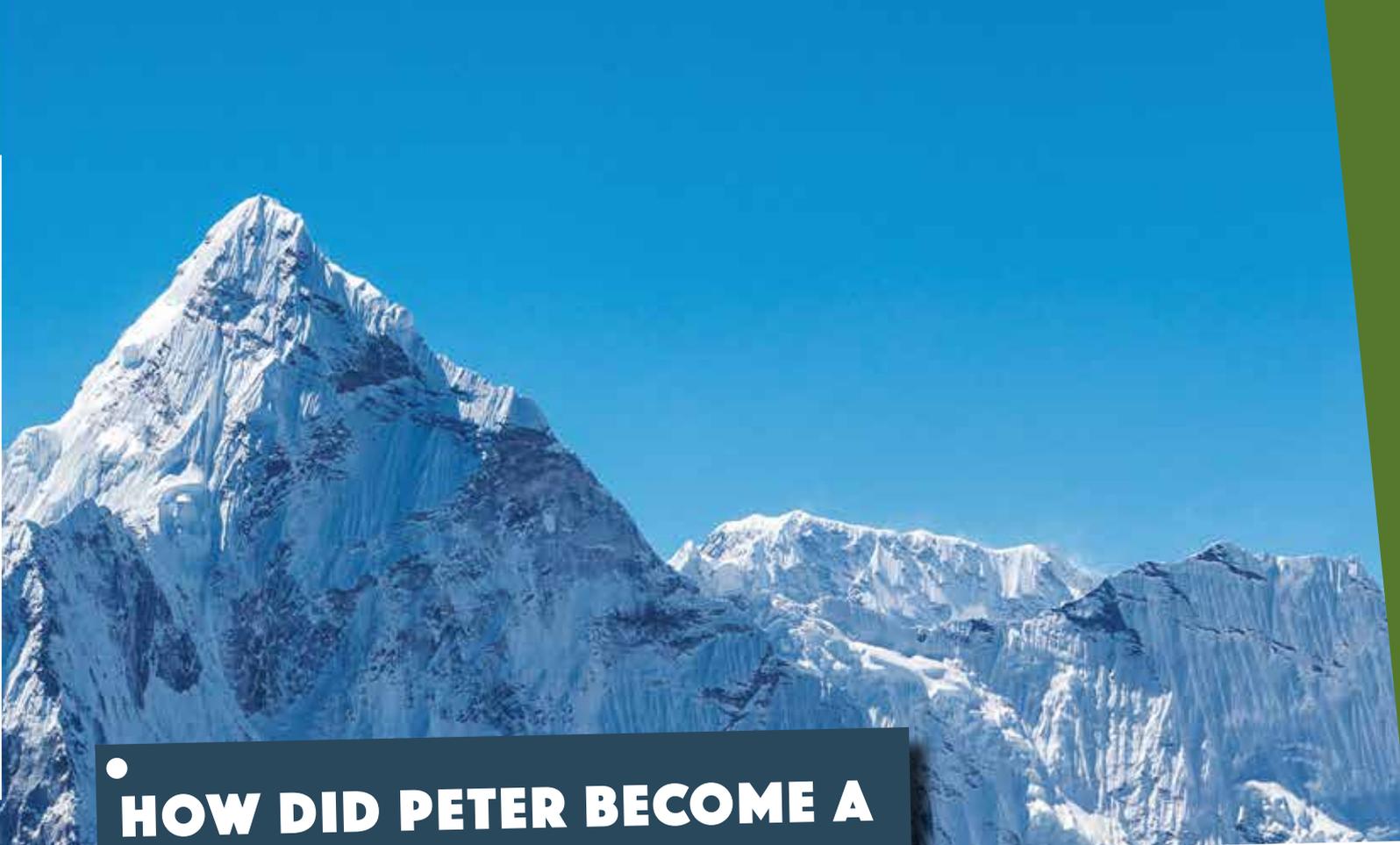
PATHWAY FROM SCHOOL TO SEDIMENTARY GEOLOGY

Peter says there are many pathways to becoming a sedimentary geologist, but a grounding in basic sciences is essential. He studied maths, physics and chemistry at high school, but suggests that geography and biology would also be useful.

Many universities offer degrees in geology or Earth sciences, which will include courses in sedimentary geology. Peter advises maintaining a broad scientific understanding rather than focusing on a specialised area too early in your studies, as geologists draw on many different methods to solve complex problems.

PETER'S TOP TIPS

- 01** Get a good, solid foundation in the physical sciences. Don't give up maths and physics just because they are difficult – they are important for the modern scientific world.
- 02** Make sure you work on something that inspires you. Success depends on being excited and passionate about your career.



● HOW DID PETER BECOME A SEDIMENTARY GEOLOGIST?

WHAT WERE YOUR INTERESTS GROWING UP?

I was always interested in the natural world and being outside, coupled with an academic interest in physics. I loved camping with friends and with the school cadet force, and the notion of travelling around the world and witnessing different environments and cultures appealed to me. I've always loved ships too, which perhaps influenced my choice to pursue marine geology.

WHAT INSPIRED YOU TO BE A GEOLOGIST?

My love of mountain landscapes, first and foremost. They seemed very exotic compared to the rather flat landscape of southern England where I grew up. Also, my father worked for an oil company, which made me consider a career in geology. It seemed a nice coincidence to be able to pursue a career that involved both science and travelling to faraway places.

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

Being able to show how closely the geology of Asia and its monsoons are coupled over long periods of time was a great achievement for me. In the future, I aim to decipher why

the monsoon got stronger only 24 million years ago, rather than immediately after the collision of India and Asia, 50 million years ago. I hope to work with quantitative modelling scientists to develop conceptual models of how Earth's geology interacts with its biosphere and atmosphere.

WHAT HAVE BEEN YOUR FIELDWORK HIGHLIGHTS?

I've had the good fortune to work in many interesting places, but perhaps my favourite is Vietnam. The country has fascinating geology, friendly people and delicious food. I have also had wonderful experiences hiking and camping in the Indian Himalayas. It's incredible to wake up to see snow-capped mountains from your tent. I also enjoyed fieldwork in remote and beautiful locations in Alaska, though we had to be careful about the wild animals. The most important factor for enjoyable fieldwork is to do it in good human company!

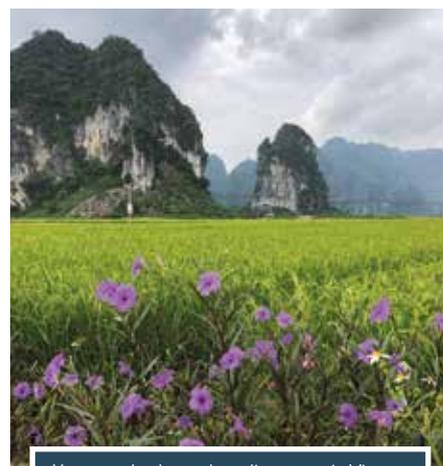
WHAT IS IT LIKE TO BE AT SEA FOR MONTHS AT A TIME?

Ocean drilling expeditions involve a long time away from home in an environment with very little privacy – we share cabins and all eat together, so there is no escaping from people. But, as long as the team members are nice (which they normally are!), expeditions are great fun and you make lifelong friendships.

The pace of work ensures it is never boring as there are always things to do. It's always exciting to come back to dry land, and the samples collected keep us busy for years after the expedition.

DOES YOUR LOVE OF GEOLOGY SPILL OVER INTO YOUR FREE TIME?

For me, geology is more of a lifestyle than a career. I am a complete fanatic! Most of my friends are also geologists, my house is full of interesting rock specimens and my holidays involve seeing rocks in exotic places! Some people might think I spend all my time working, but for me it feels like being paid to pursue my hobby.



Monsoon clouds over karst limestones in Vietnam

“SCIENCE BUSKERS HAS KINDLED PASSION, DETERMINATION AND SCIENTIFIC CURIOSITY AMONG YOUNG AFRICANS.”

KNOWLEDGE CHIKUNDI IS THE FOUNDER OF THE SCIENCE BUSKERS FESTIVAL, AFRICA’S ONLY INTERNATIONAL SCIENCE COMMUNICATION COMPETITION FOR PRIMARY AND HIGH SCHOOL STUDENTS AND TEACHERS. HE TELLS US WHY THE FESTIVAL IS HELPING THOUSANDS OF STUDENTS ACROSS THE AFRICAN CONTINENT DARE TO DREAM



Knowledge is not only the founder of the Africa Science Buskers Festival, he is also the founder and director of the Zimbabwe Science Fair, a platform for recognising and empowering the country’s most promising young scientists and engineers. These young people are developing ideas that could solve society’s grand challenges.

I have always been passionate about teaching. In junior high school, I would teach maths and science to my classmates. Then, in senior high school, I taught a maths class of over 40 students in my own home. This class included older members of the community who needed to retake national maths exams. My deep love for empowering more people in science and maths also drew me towards teaching physics.

Students and teachers in Zimbabwe often face challenges when accessing STEM education, due to a lack of resources, opportunities and support infrastructure. However, the adoption of science and technology creates possibilities for economic and societal growth.

I founded the Africa Science Buskers Festival, a science communication platform where primary and high school students are celebrated and

rewarded for their science communication, research and innovation skills. The platform encourages the dissemination of scientific concepts using low-cost, locally available materials in interactive and engaging ways.

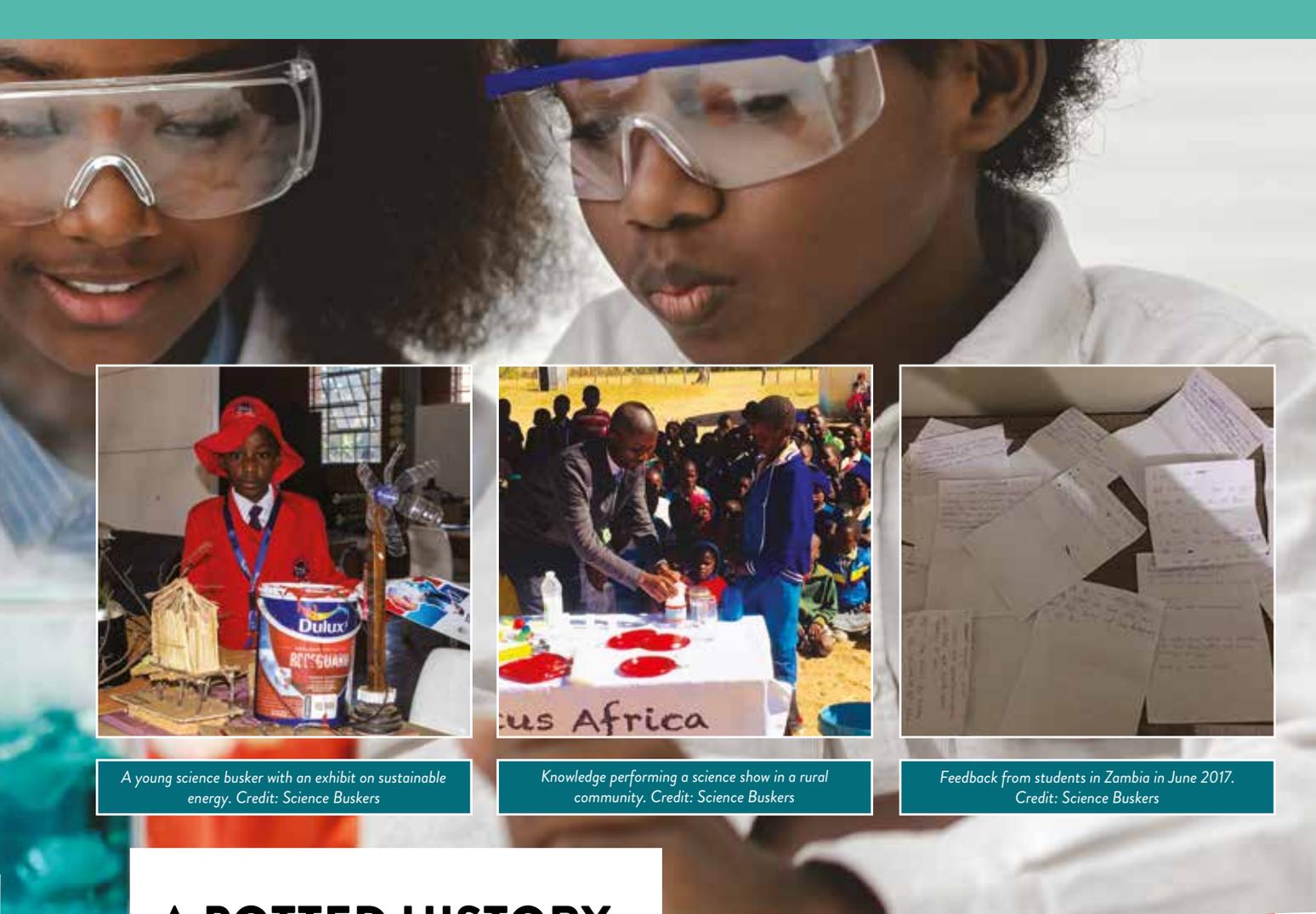
We have seen our science shows sparking a love for science in young people. Between 2016 and 2019, we engaged over 100,000 students in Zimbabwe, Zambia, Botswana, Malawi and South Africa. It is touching to receive messages from these children saying they want to be like us – they too want to communicate science.

Science Buskers has kindled passion, determination and scientific curiosity among young Africans. It has inspired them to use science and technology to solve some of the greatest challenges in their communities. Participants have gone on to have asteroids named after them, receive scholarships into their dream research universities, get into prestigious internship programs and start their own companies.

Witnessing Science Buskers transforming dreams, opening opportunities, uncovering talent, unlocking potential and empowering possibilities in young people has been the major highlight of the program. We have been amazed by the aspirations and ambitions of students once they participate in Science Buskers.

My favourite experiment to do for schools is the film-canister rocket experiment. All that’s needed is bicarbonate of soda, vinegar (both of which can easily be found in most kitchens) and a film canister. Students love it because they experience the loud popping sound the film canister makes when it flies into the air. I have seen this simple experiment inspire students to dare to dream.

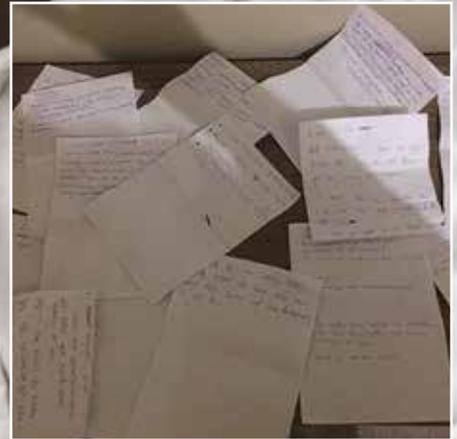
When I’m not working, I like to hike in the mountains. And my top tip for young people is never give up!



A young science busker with an exhibit on sustainable energy. Credit: Science Buskers



Knowledge performing a science show in a rural community. Credit: Science Buskers



Feedback from students in Zambia in June 2017. Credit: Science Buskers

A POTTED HISTORY

In September 2013, Knowledge, then an undergraduate chemistry student, worked with the University of Zimbabwe and the Ministry of Primary and Secondary Education to set up a STEM education programme for primary and secondary schools. Launched under the banner of a project called START Science, the programme involved university students going into two schools in the capital city, Harare. The students started helping pupils with their projects for the Zimbabwe Science Fair, which was set up by Knowledge in 2014.

As the schools' science pass rates dramatically improved, the programme was rolled out to more schools across Zimbabwe, and, in 2016, Zimbabwe sent its first national science fair winner to the Intel Science and Engineering Fair in Arizona, USA.

Buoyed by this success but still wanting to achieve more, Knowledge took inspiration from The Science Circus, an initiative of the Australian National Centre for Public Awareness (CPAS). CPAS master's students deliver 'jaw-dropping performances' in Australian schools, teacher development workshops and hands-on exhibitions for the wider community.

Realising that the Zimbabwe Science Fair was a huge draw for students, Knowledge started the Science Buskers Festival in 2017. At the inaugural event, 20 teams from secondary and primary schools across the African continent presented their most creative science projects, and the winners were presented with a shield and \$500 Zimbabwean dollars for books of their schools' choice.

FIND OUT MORE

-  www.facebook.com/africasciencebuskersfestival
-  www.instagram.com/ZimScienceFair/
-  www.youtube.com/channel/UC_ZXymnU0wsEsdHuQjgJ5iw
-  twitter.com/science_buskers
-  sciencebuskers.org
-  www.zimsciencefair.com



Students at the Africa Science Buskers Festival in August 2019. Credit: Science Buskers

UNDERSTANDING THE LANGUAGE OF SCIENCE THROUGH THE SCIENCE OF LANGUAGE

HOW DO PEOPLE LEARN NEW LANGUAGES? HOW CAN LANGUAGE BE STUDIED SCIENTIFICALLY? HOW IS SCIENTIFIC RESEARCH CONDUCTED? AT THE OHIO STATE UNIVERSITY AND NEW YORK UNIVERSITY IN THE USA, A TEAM OF RESEARCHERS HAVE ESTABLISHED THE COGNITIVE SCIENCE DIY PROJECT, TO PROVIDE THE PUBLIC WITH THE ANSWERS TO THESE VERY QUESTIONS WHILE IMPROVING THEIR UNDERSTANDING OF THE SCIENTIFIC PROCESS



If the pandemic has taught us anything, it is that many members of the public do not trust science. The spread of misinformation about the virus and vaccines stems from a lack of trust in the science behind them. If the public understood a bit more about what goes on behind-the-scenes in scientific studies, then perhaps their confidence in science and scientists would increase.

One method to involve the public in scientific research is through ‘citizen science’, where members of the public collect data (e.g., taking photos or measurements) that they send to a researcher. While this has benefits for both the researcher (they can acquire large quantities of data) and the public (they can contribute to research), in most citizen science projects, the public are just providing a service for the researcher who conducts the actual ‘science’.

Dr Laura Wagner, at The Ohio State University, and Dr Sudha Arunachalam, at New York University, decided to turn the concept of citizen science on its head. Why not let the public do the science? “While taking part in citizen science projects is one way to

learn about science, it’s also important to show what happens ‘backstage,’” explains Laura. “How do scientists come up with research questions? Why do scientific studies look the way they do? What do scientists do with the data? We wanted a way to show people what goes on in a scientific study.”

CogSciDIY

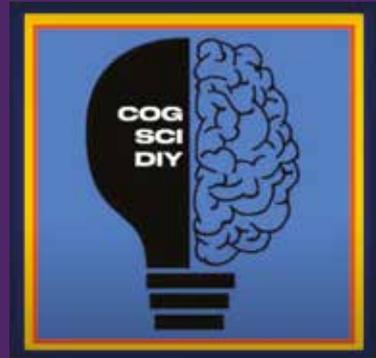
Laura and Sudha are experts in language development, with a passion for communicating what real behavioural science looks like. So, along with team members Dr Lindsay Burns, Maria Cobo Nieto and Nick Bednar, they established the Cognitive Science DIY (CogSciDIY) project. The purpose was to teach the public about the scientific process, while answering questions about language through scientific research. “People who aren’t language scientists have such fascinating ideas for research questions! We wanted a way to involve the interested public so they could get some of their questions answered,” says Sudha. “It’s often frustrating to see the mistrust and misconceptions that are present in the public’s relationship with science. My hope is that projects like CogSciDIY will expand public understanding of the scientific process.”

The CogSciDIY programme ran for five weeks. Lindsay designed a science curriculum to accompany the language curriculum, so that each week participants learnt about different aspects of the scientific method while developing their own scientific research project about language. “At the beginning, we taught them about the scientific method,” says Sudha. “Then each week we led them through a component of the scientific process.”

ASKING QUESTIONS

In the first week, participants learnt about designing a research question. They were asked what questions they had about language. “People wanted to know all kinds of things about language!” says Laura. How do children learn their first language? How do adults learn new languages? Why do people speak in different accents? “Many of their questions were tied to their own personal experiences of learning languages,” explains Sudha.

The team collected all these questions and condensed them into a selection of potential research questions. In the second week, the participants voted on which research question they wanted to address in their study. The



COGNITIVE SCIENCE DIY

The Ohio State University and New York University, USA

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FIELD OF RESEARCH

Language Science

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RESEARCH PROJECT

Teaching the public about the scientific method through language science

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FUNDERS

Ohio State BETHA (Battelle Foundation) Endowment Grant, New York University Institute of Human Development and Social Change (IHDSC) Seed Award

chosen option was “Does it help or hurt to learn a language if you hear it spoken by just a single person compared to hearing it spoken by many different people?”

CONDUCTING EXPERIMENTS

In the third week, participants learnt about conducting a scientific experiment. Maria designed an experiment to answer the chosen research question, but the participants voted on the design details. “We used a classic word-learning method where people have to learn the names of new objects,” explains Laura. This can either be done using nonsense words for the objects, or real words from unfamiliar languages. Both are valid options, and neither is perfect, as is so often the case with scientific research. Nick created videos explaining the pros and cons of each method, and after watching these, the participants voted to use nonsense words in their experiment.

In the fourth week, the experiment was conducted on a different set of participants. The CogSciDIY participants learnt about formulating hypotheses and were asked to guess what the results of the study would be. “Some expected the single-person condition to yield better

learning while others expected the multiple-people condition to yield better learning,” says Sudha. It transpired that the experimental participants were good at learning the nonsense names of new objects both when they heard them from a single person speaking and when they heard them from multiple people speaking.

ANALYSING RESULTS

The team posted the experiment data for the CogSciDIY participants to view. “We were really excited how people got into the data,” says Laura. “Some people were so enthusiastic that they created their own graphs to display the data!” In the final week of the programme, participants learnt how to analyse and interpret the results.

One of the most exciting elements of this project was that the participants genuinely helped create and shape the study, providing them with a scientist’s-eye view of what research involves. “It is important for people to learn about how scientific studies really happen,” says Laura. “It’s a creative process that involves lots of decision making, and often there isn’t a right or wrong answer when considering how best to design an experiment. But it’s helpful to see how

the choices you make can influence the data you get.”

“CogSciDIY allowed members of the public to see the messy parts of science,” says Sudha. “Science is a slow process and there’s no such thing as a perfect research study. A big part of the process is thinking about what the next step would be to increase our understanding of the phenomenon. What would our participants do differently next time?”

WHAT NEXT?

“We think our CogSciDIY project can help people learn about how science works, build trust in science and show people how language can be studied scientifically,” says Laura. The next step will be to rerun the project, this time studying the participants themselves to investigate whether this is the case.

Why don’t you take part? The team will be back with another iteration of CogSciDIY, where you can learn about language science while helping design your own scientific research study. You can sign up to their mailing list (create.nyu.edu/cogscidiy) to be notified when they go live.

ABOUT LANGUAGE SCIENCE

While most animals communicate with each other, as far as we are aware, ‘language’ is unique to humans. It is estimated that about 6,500 languages are spoken in the world today. Some, like English, Spanish and Mandarin, are spoken by millions of people around the world. Others, like Ongota in Ethiopia, Liki in Indonesia, and Paakantyi in Australia, are spoken by only a handful of individuals. “Language is an astonishing product of the human mind,” says Laura. “And, like any other piece of human cognition, it can be studied scientifically.”

HOW CAN LANGUAGE BE STUDIED SCIENTIFICALLY?

As scientists, Laura and Sudha are not concerned with how people ‘should’ use language but are interested in how people

really do use it. “Language scientists study everyone, from infants to adults, users of spoken languages to users of sign languages, and industrialised nations to hunter-gatherer societies,” explains Sudha. We use language at all stages of our life, and it develops as we grow. Language scientists explore how and why this happens. This includes studying how children learn their first languages and how adults learn new languages later in life, and the different challenges that these groups face.

Language scientists also examine how languages themselves evolve through time, and why languages develop in different ways. Languages in different parts of the world often have very different structures and properties.

“Language scientists use all different kinds of methods to study how language works and how people use it, including brain imaging, eye-tracking, surveys, behavioural experiments and observations in the field,” adds Laura. This means that language scientists are addressing issues of language from a wide range of perspectives, from psychology to anthropology.

There is no single pathway into the field of language science, so you can enter from whichever direction most interests you. Language is a vast topic and scientists are interested in every aspect of it. The beauty is that as language is always evolving, so too are the methods and topics of inquiry. It is a field that can never truly be exhausted.

EXPLORE A CAREER IN LANGUAGE SCIENCE

- Visit the CogSciDIY website (create.nyu.edu/cogscidiy) to take part in the next iteration of their project. Experience what it is like to be a language scientist while learning about fundamental concepts of language science and answering your own scientific questions about language.
- With a degree in language science or linguistics, you could become an academic, studying whatever aspect of language fascinates you. You could work in education, using your expertise to help those who have trouble learning languages, or you could try to prevent endangered languages going extinct. Language science skills will also be useful for careers in publishing, marketing, translating and in the media.
- *Times Higher Education* (www.timeshighereducation.com/student/subjects/what-can-you-do-linguistics-degree) and *Prospects* (www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/linguistics) both have a wealth of information about what you could do with a linguistics degree.

PATHWAY FROM SCHOOL TO LANGUAGE SCIENCE

- At school, English, foreign languages and psychology will all be useful for studying language science at university.
- Many universities will offer undergraduate degrees in language science or linguistics. Postgraduate degree options include communicative sciences, applied linguistics, and speech and language therapy.
- Laura is keen to emphasise that people can study language from a wide range of perspectives. She took classes in psychology, foreign languages and computer science. “Any class that focuses on what language is and how it works is good training for language science.”
- “Language science is inherently an interdisciplinary topic area,” says Sudha. “It is made up of connections to linguistics, cognitive psychology, developmental psychology, neuroscience, education, speech-language pathology, computer science and philosophy.”

be a scientist yourself.
work with us to make it real.



Join the next iteration of CogSciDIY to conduct your own language science research!

MEET THE TEAM



LAURA'S TOP TIP

Don't be afraid to explore language in a new way. I started off really excited about learning foreign languages and ended up spending most of my time doing experiments with children learning their first language.

DR LAURA WAGNER

FIELD OF RESEARCH: LANGUAGE DEVELOPMENT
THE OHIO STATE UNIVERSITY, USA

I have always loved learning languages. I took classes in French, Latin and Japanese in high school and came to realise that I was mostly interested in what all these languages had in common. That led me to the field of linguistics and especially to the human cognition that creates language. After all, what languages really have in common is that they are a product of the human mind.

As an undergraduate, I double majored in language studies and cognitive science. I went on to get my PhD in linguistics and picked up a master's degree in psychology along the way.

I established the Language Pod, which is a fishbowl-style research lab in the middle of our local science museum. In there, we conduct studies on many different language topics, including how people perceive regional dialects, how children learn about verb endings and how the melodies of speech influence language processing. Visitors to the museum volunteer to be our research participants!

Our lab is actually a museum exhibit that shows people what language science really looks like. As well as conducting research, we also train students to engage with the public using hands-on demonstration activities that show off classic results from the field of language science.

Given that I enjoy both languages and puzzles, it was amazing when I realised that language can be seen as the best puzzle ever! One of the most rewarding aspects of my work in the field of language science is that I get to think about language all the time and figure out new things about how it works.

Loving what you do is half the battle and I really think that my love for language science has made me successful at it. I truly do not mind spending a lot of time doing it!



SUDHA'S TOP TIP

Seek out elements of language that interest you and pursue them. Explore podcasts, documentaries and popular science books – there are tons of these about all different aspects of language science. Once you find a topic that interests you, try to learn more about it.

DR SUDHA ARUNACHALAM

FIELD OF RESEARCH: COMMUNICATIVE SCIENCES AND DISORDERS
NEW YORK UNIVERSITY, USA

I took a class called 'Introduction to Linguistics' during my first year of college, despite not knowing what linguistics was. I was hooked, so I took more linguistics classes and got involved as a research assistant on a project at my university. During my PhD in linguistics, I became interested in the human mind, how language is represented in our minds and how children manage to acquire those representations.

As a researcher in the field of communicative sciences and disorders, I work with children who are struggling to learn language. Many of these children are on the autism spectrum, and others have language delays with no known cause. I look for strengths in their language and cognition and make hypotheses about how those strengths can be applied to help them improve their language abilities.

Thinking about how language works is fun! And so is teaching others about it. Everyone uses language, so we all have intuitions about how language works. It's rewarding to help people apply the scientific method to

questions about language which enables them to think about language in new ways.

I loved seeing how engaged people were with our CogSciDIY project. Our participants contributed to every part of the scientific process – not only the fun, easy parts of asking a research question, but also the challenging, nitty-gritty parts of experimental design and analysing the data.

Human infants are the biggest source of inspiration to me. They learn to use the languages they are surrounded by in just a few years, making some adorable (and very revealing) mistakes along the way.

I think the most useful quality for a researcher is curiosity. Wondering how things work or why things happen is the starting point for coming up with a research question. Curiosity to find the answers to these questions keeps you going during the tedious parts of doing science.



DR LINDSAY BURNS

EVALUATION SPECIALIST
PARAGON-TEC/NASA, USA

After an undergraduate degree in middle childhood education, I completed a master's in education, alongside teaching a sixth-grade math class. Early on in my teaching career, I realised my interest lay in curriculum and leadership. So, I returned to university for a degree in curriculum, instruction and professional development, while also teaching physical science and integrated STEM to eighth- and ninth-grade classes. Teaching integrated STEM inspired me and completing the Endeavor STEM Teaching Certificate Project through NASA encouraged me to pursue a PhD in informal science education.

I am currently an evaluation specialist at Paragon-TEC and a NASA support contractor for NASA's Office of STEM Engagement. I am part of a team that manages a grant for minority-serving colleges and universities to implement K-12 NASA STEM programming for after-school clubs and summer events.

The CogSciDIY group was an amazing team to be a part of! I learned so much about language. With my background in integrated STEM, it was awesome to apply integration to science and language. I really appreciate this experience as, in my current role, we spend a lot of time discussing ways to integrate content. My experience with CogSciDIY helped me to better understand the planning and implementation of science in ways that are impactful for participants.

I have always loved maths, science and building things. Both of my parents are engineers who encouraged me to design and build things. My high school chemistry teacher inspired me to be an educator. He was consistent in pushing us to be the best we could be while supporting our goals. I want to make a similar impact with my students.

LINDSAY'S TOP TIP

If you want to work in education, teach something you are passionate about! It is so much more fun to teach something you enjoy. Your passion will radiate from you and positively impact your students and colleagues.



MARIA COBO NIETO

MASTER'S STUDENT IN COMMUNICATIVE SCIENCES AND DISORDERS
NEW YORK UNIVERSITY, USA

I've always been interested in language, especially when it comes to language acquisition in bilingual children. My older brother Mariano inspired my interest in language science as he was diagnosed with autism at the age of two. When I was younger, I always enjoyed playing 'speech therapy' with him. I would design activities to teach him new words and help him learn how to communicate. The most rewarding thing about studying in the field of speech-language pathology is helping others to communicate.

I obtained a BSc in speech-language pathology and audiology, with minors in psychology and Spanish for the health professions for native speakers. While at university, I worked with two different research labs, the Marquette Autism Project and the Speech and Swallowing Lab, working on the English Accented Spanish Project. Being a research scholar sparked

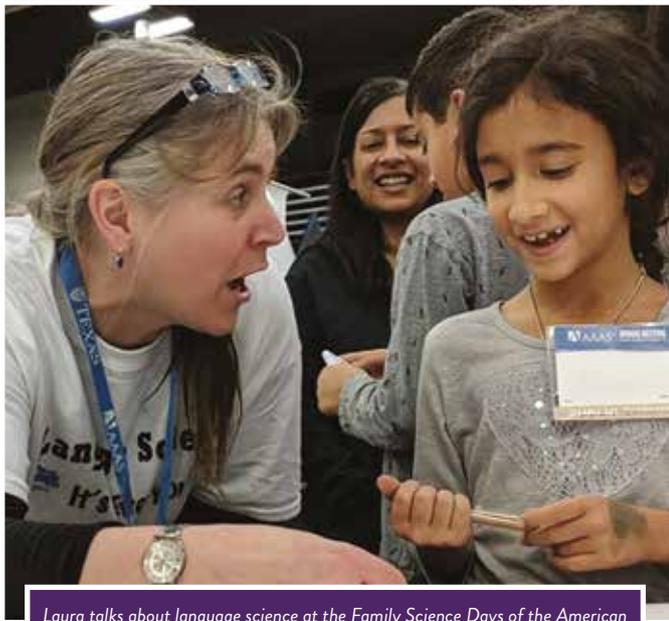
my interest in the interdisciplinary approaches surrounding clinical work and research.

I am now studying for a master's in communicative sciences and disorders with a bilingual extension. My research interests include language acquisition and language development in bilingual children, as well as children on the autism spectrum. I am also a research assistant and have worked on various language-related projects in both English and Spanish.

My involvement in the CogSciDIY project gave me numerous skills, such as time management, teamwork and effective communication. These were especially useful during the pandemic when everything was done remotely. I am applying these skills as a master's student and will continue to apply them in the future, hopefully as a PhD student.

MARIA'S TOP TIP

Do something that you are passionate about and keep an eye on the prize, regardless of people you may encounter along the way who may not believe in you. Also, always ask questions and reach out when in doubt.



Laura talks about language science at the Family Science Days of the American Association for the Advancement of Science.



Sudha speaks to kids and parents about language development at the Brooklyn Children's Museum.



NICK BEDNAR

MANAGER OF OPERATIONAL VOLUNTEER EXPERIENCES
CENTER OF SCIENCE AND INDUSTRY, USA

I loved working with the CogSciDIY project! Apart from the amazing team, I think the highlight was being able to share something that we all care so much about. Language is awesome, and it was so fun to get others involved with language in such a unique, hands-on way.

I studied linguistics at university, and I now work at a science museum as the manager of operational volunteer experiences. It is my job to keep volunteers supporting the outreach goals inside our museum. I'm currently creating new ways of getting volunteers started and skilled at doing what we need them to do. That means writing proposals and plans, designing our online scheduler, and thinking about how we can best serve our institution and community.

Part of the fun of CogSciDIY was that I got to wear a lot of different hats! Many of the skills I learnt during the project help me now in my current role. For example, learning how to make the videos has made it so much easier for me to make polished content for our volunteer program website and the data management skills I acquired make record-keeping at the museum a breeze!

So many people have inspired me to follow this path, with my university professors and all the museums I've visited being particularly notable. I've learned to love getting to do science while also teaching science to others. I enjoy connecting with people, and it is so rewarding to give them that 'ah-ha' moment when they learn something new.

NICK'S TOP TIP

Embrace what you find exciting. Say 'yes' to opportunities that come your way and make the best of them. Who knows where you'll end up!

TEACHING COMPUTERS TO UNDERSTAND OUR LANGUAGE

ARTIFICIAL INTELLIGENCE HAS ADVANCED IN LEAPS AND BOUNDS IN RECENT YEARS AND HAS BECOME AN INCREASINGLY INTEGRATED PART OF OUR LIVES. HOWEVER, IT STILL LACKS THE CAPACITY TO TRULY UNDERSTAND HUMAN LANGUAGE; SUBTEXT, CONTEXT CLUES AND EMOTIONAL EMPHASIS REMAIN DIFFICULT TO INTEGRATE. PROFESSOR YULAN HE, AT THE UNIVERSITY OF WARWICK IN THE UK, IS WORKING ON NOVEL METHODS TO CROSS THIS BRIDGE

TALK LIKE A COMPUTER SCIENTIST

ARTIFICIAL INTELLIGENCE (AI) – computer systems able to perform tasks that typically require human intelligence

COGNITIVE PSYCHOLOGY – the study of mental processes, such as language use and memory

CONTEXT – the circumstances surrounding an event

EVENT TRIPLE – the three constituent parts of an event: subject, predicate and object

NATURAL LANGUAGE PROCESSING – a branch of AI that aims for computers to be able to fully understand the meaning of human language

SEMANTIC – related to the meaning of language

SITUATION MODEL – a representation of an event from a cognitive perspective

‘Are you up to anything this weekend?’ This sentence provides a simple example of how different contexts can alter a sentence’s intended meaning. If you are asked this by a colleague or teacher, they are likely just making small talk. However, if you are asked this by a friend, they might be seeking to find out whether you have any free time to socialise with them. As social animals, we naturally understand and interpret subtle differences like this, which occur during hundreds of our interactions every day. But, this concept of understanding the subtleties of language is very difficult to instil in computers.

Professor Yulan He is a computer scientist at the University of Warwick, working in the field of natural language processing. She is training artificial intelligence (AI) to overcome this challenge through sophisticated reading comprehension exercises. “Language understanding is extremely difficult for computers due to the variety, ambiguity, subtlety and expressiveness of human languages,” she says. She is drawing information from a multitude of sources to provide a knowledge base that computer models can ‘learn’ from, and contribute to, to build the models’ understanding of how we use language.

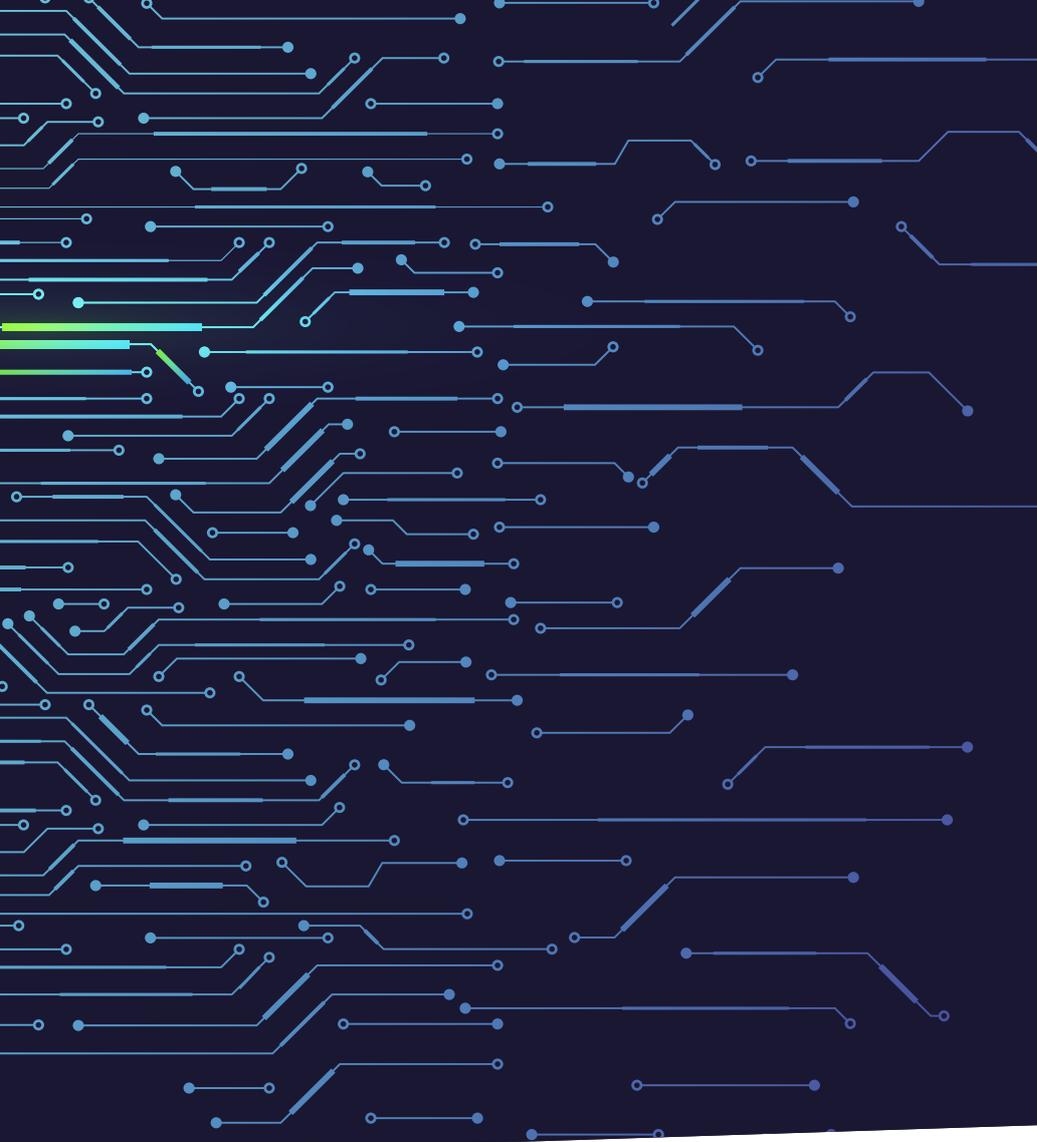
READING COMPREHENSION

“When we read a passage of text, we usually have an understanding of the meaning of words in the context of the events described, and can then refer back to the ‘theme’ of the passage as we read onwards,” says Yulan. “We can ‘read between the lines’ to establish a deep semantic understanding of text.” Our reading comprehension depends on us building an event structure that represents what is happening in the text, referred to as a situation model in cognitive psychology.

Consider the following pair of sentences: ‘I went to a coffee shop. I had a flat white.’ Even though it’s not explicitly stated, we safely assume the narrator bought the flat white from the coffee shop, given that fits best within the context. We build an event structure of the narrator entering the shop, buying a coffee and drinking it. We also use our background knowledge to know that ‘flat white’ is a type of coffee, despite both words being adjectives that can be used for many other purposes. Yulan is trying to find ways for computers to build similar event structures, using context clues and background knowledge to help them ‘infer’ exactly what is going on in a situation.

FLUENCY IN COMMON SENSE

“A common way of teaching computers to



PROFESSOR YULAN HE

Department of Computer Science,
University of Warwick, UK



FIELD OF RESEARCH

Natural Language Processing



RESEARCH PROJECT

Building artificial intelligence models that can understand written language, by incorporating background knowledge, context and associated emotions



FUNDER

Engineering and Physical Sciences
Research Council (EPSRC)

Yulan He is supported by a Turing AI Fellowship funded by the EPSRC (grant no. EP/V020579/1).

understand text is to first train a language model on large bodies of text, to capture word correlation patterns,” says Yulan. “These models can then be fine-tuned depending on the task they are needed for, such as answering questions.” This is the way that search engines or voice-activated virtual assistants work, for instance, but there are obvious limitations. “Even a small change in an input, such as paraphrasing a question, can decrease the model’s performance,” says Yulan. “They also struggle to automatically acquire common-sense or background knowledge to help their understanding.” For example, think about the times you have used voice-activated assistants to check a fact or play some music. Chances are, there have been times when the assistant has not understood your command or has not picked up on the context.

“We have made some attempts on building in common-sense knowledge for emotion analysis in text,” says Yulan. She gives the example of ‘Boxing Day’, a phrase which, when alone, generally has positive connotations given it is a public holiday. However, if someone texted you saying, ‘I need to work on Boxing Day’, you will assume the phrase was said with little enthusiasm and it is now associated with negative connotations. “We have developed a novel approach which adds an additional layer to existing language

models to capture topic transition patterns in human conversations,” says Yulan. “Both topics and common-sense knowledge are stored in a knowledge base that the model uses, or adds to, when attempting to detect emotion in written conversations.” This layer helps the model learn associations between particular phrases, the surrounding context and commonly related emotions.

PICTURES AND WORDS

Yulan is building a framework that extracts events from text, which follow a simple structure called an event triple: a subject (the thing performing the action), the predicate (the action that is taking place), and the object (the thing the action happens to). “Event representational learning aims to map these triples within a multi-dimensional space, where triples with similar semantic meanings are found in nearby locations,” says Yulan. “However, we argue that textual descriptions alone can only go so far.” The phrase ‘a picture is worth a thousand words’ has some truth to it, which is why Yulan’s team are using images as a less abstract way of teaching these models.

Think about the coffee shop example: ‘I went to a coffee shop. I had a flat white.’ An image of this event could tell you a lot more: how busy the

coffee shop is, the weather outside, the size of the coffee, the mood of the narrator, to name just a few. “We’ve developed a framework to learn event representations based on both text and images simultaneously,” says Yulan. “Experimental results show that our proposed framework outperforms many simpler frameworks.”

BENEFITS TO SOCIETY

“Since spoken and written communication play a central part in our lives, frameworks like ours could have profound impacts for society,” says Yulan. “It has applications for intelligent virtual assistants, drug discovery, or answering complex questions about financial or legal matters.”

Yulan’s team is already working on practical applications, including collaborating with pharmaceutical giant AstraZeneca to detect adverse drug events from biomedical literature. This use of AI will help extract important information about undesirable side-effects that otherwise might never be detected.

With AI becoming increasingly integrated in our lives and societies, we need computer scientists like Yulan to ensure these systems understand us.

ABOUT ARTIFICIAL INTELLIGENCE

Yulan tells us more about the joys and challenges of developing AI:

WHAT DO YOU FIND MOST REWARDING ABOUT YOUR WORK WITH AI?

AI has the potential to transform a wide range of sectors, from health and social care to financial services, from citizen services to manufacturing. The technologies and algorithms developed for AI can be used to make people's lives better and being part of this research process is very rewarding for me.

WHAT PRACTICAL CHALLENGES ARE ASSOCIATED WITH DEVELOPING AI?

Existing AI technologies are far beyond human capabilities in terms of computational intelligence. They have almost reached similar performance levels to us in sense intelligence, such as speech or image recognition. Yet,

they are still far away in terms of cognitive intelligence: understanding language, and knowledge abstraction and inference.

While we can learn from past experiences to perform abstract reasoning, it is difficult to train an AI model to emulate this. This is due to the challenges in collecting training data, and the near-infinite combinations of contexts that define real-world problems.

WHAT ETHICAL CHALLENGES ARE ASSOCIATED WITH DEVELOPING AI?

Different social groups behave differently, and if the systems we develop are based on data that exclude certain groups, this will cause issues. There is also the possibility of AI developers unconsciously introducing our own biases into the algorithms, so we make sure to take steps to mitigate this. Additionally, these large-scale models require significant resources to train, which are only accessible to a handful of giant tech companies. This

could lead to a monopoly for applications of AI, which could make the benefits it brings inaccessible for many.

WHAT ATTRIBUTES DO SUCCESSFUL AI COMPUTER SCIENTISTS HAVE?

Curiosity, passion, deep thinking, and an ability to set big goals are the most important. A strong mathematical background and good programming skills are also essential for developing models and algorithms in AI.

WHERE IS AI FOUND IN OUR DAILY LIVES?

AI can be found almost everywhere in our life. Google's search engine, and virtual assistants such as Apple's Siri and Amazon's Alexa, are all examples of AI. Face recognition software uses AI, many cars and homes now have AI-integrated sensors, and AI provides personalised recommender services in Netflix and YouTube.

EXPLORE A CAREER IN ARTIFICIAL INTELLIGENCE

- Yulan names Google (www.ai.google), Open AI (www.openai.com) and DeepMind (deepmind.com/careers) as major AI researchers. All have plenty of information about the latest AI developments and careers in AI on their websites.
- Yulan recommends learning a coding language as soon as possible. She says that HuggingFace (www.huggingface.co) provides an open-source library for many natural language processing technologies, as well as programming tutorials.

YULAN'S TOP TIPS

- 01** Build a strong mathematical foundation. This is important to help you understand the theories behind AI algorithms in your future studies.
- 02** Learn at least one programming language, such as Python. Then, practise using it to develop simple AI systems to solve problems that interest you.

PATHWAY FROM SCHOOL TO ARTIFICIAL INTELLIGENCE

At school, a strong mathematical background is essential, and computer science would also be advantageous if available. Studying psychology will lend useful insights into how humans process language.

Most universities offer undergraduate degrees in computer science or mathematics, which would provide the clearest path to a career in AI. Yulan recommends taking as many mathematics modules as possible at university. She particularly suggests linear algebra, calculus, statistics and probability, graphical models and convex optimisations. She says that subjects such as cognitive science, statistical modelling, machine learning, data science, natural language processing, computer vision, robotics, multi-agent systems, computational intelligence and human-computer interaction are also relevant.

HOW DID YULAN BECOME A COMPUTER SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER?

I loved literature and won quite a few writing competitions while at secondary school. I was always fascinated by how language can influence our perception of the world and our thought processes. I was equally interested in mathematics and coding. I wrote my first computer program using BASIC at the age of nine.

HOW HAVE YOUR PREVIOUS STUDIES HELPED PREPARE YOU FOR YOUR CURRENT PROJECT?

My master's in computer engineering focused on developing algorithms for the retrieval

of scientific publications over the internet. I then pursued a PhD in spoken language understanding, under the supervision of Professor Steve Young, a world-renowned expert in spoken dialogue systems. Both these qualifications helped build my knowledge of statistical model learning, information retrieval and semantic understanding of languages, providing a solid foundation for my current project.

WHAT MOTIVATES YOU IN YOUR WORK?

The ultimate goal of AI is to create a thinking machine skilled in all aspects of intelligence. Achieving this ambitious goal requires a deep

understanding of how intelligence emerges. Language is crucial to general intelligence and natural language processing is a key area in AI.

HOW DO YOU SPEND YOUR FREE TIME?

I still love reading. I also like being active in the outdoors, through jogging and cycling.

(a): Food and Restaurant

A: Could I have some fish?

B: Certainly. And what vegetables would you like? 😊

A: Oh , spinach , I think.

A: I like drinking tea at teahouses. 😊

B: Oh, so do I.

A: Why don't we go for one now?

😊 B: Great. We can chat while enjoying a cup there.

A: Let's go! 😊

Utterances on particular topics carry certain emotions in dialogues. Yulan, and the Natural Language Processing Group at the University of Warwick, is training computers to recognise and understand these emotions conveyed within text.

HOW CAN WE READ GENETIC CODES IN A SINGLE PIECE OF DNA... QUICKLY?

GENE SEQUENCING IS AN INCREDIBLY USEFUL TOOL FOR READING THE VAST AMOUNTS OF INFORMATION DNA CONTAINS. WITH A CUTTING-EDGE TECHNIQUE CALLED 'NANOPORE GENE SEQUENCING,' THIS CAN BE DONE USING JUST A SINGLE PIECE OF DNA. HOWEVER, ONE CRUCIALLY IMPORTANT PART OF THIS PROCESS CAN ONLY BE DONE EXTREMELY SLOWLY. DR LEI JIANG, AT INDIANA UNIVERSITY BLOOMINGTON IN THE USA, AIMS TO SOLVE THIS CHALLENGE, USING THE LATEST TECHNIQUES IN COMPUTER SCIENCE

TALK LIKE A COMPUTER ENGINEER

DNA – long, stringy molecules containing the genetic instructions for all living organisms. They contain two ribbons of atoms, which coil around each other in a 'double-helix' pattern, and are bonded together by chemicals called 'nucleobases'

NUCLEOBASE – the building blocks of DNA molecules, which come in four possible types: cytosine, guanine, adenine and thymine. Within DNA molecules, they are always found in pairs

GENE SEQUENCING – a set of techniques that allows geneticists to find

out the order of nucleobase pairs within particular DNA molecules

BASE CALLING – an important part of the gene sequencing process, that involves translating the complex signals produced by gene sequencing into orders of nucleobase pairs

NEURAL NETWORK – computing systems that can be trained to recognise incredibly complex patterns, by mimicking exchanges of electrical signals within our own brains

In the world of nanoscience, things are done at an incredibly small scale. A nanometre is one thousand-millionth of a metre, and a nanopore is a very small hole measuring only a few of these nanometres. Amazingly, it is at this almost unimaginably small scale that researchers are making some huge advancements.

Nanopore gene sequencing is one of the latest approaches to gene sequencing and can be

used to read the genetic information carried by single molecules of DNA. Within a DNA strand, nucleobase building blocks always come in pairs (either cytosine with guanine, or adenine with thymine), and the information they carry is hidden in the order that these pairs appear within the DNA molecule. When studied using a piece of equipment called a 'sequencer,' the molecules can then generate distinctive patterns, which vary depending on these nucleobase orders.

In nanopore sequencing, this is done by stringing long strands of DNA through tiny holes, called 'nanopores', in a thin synthetic material. In the process, they generate tiny electrical currents in the material, which vary slightly depending on the order of nucleobase pairs that pass through the hole. By picking up these currents, geneticists can identify the unique genetic code contained in the DNA molecule, using a piece of computer code named a 'base caller'.

Compared with previous gene sequencing techniques, geneticists now hope that nanopore sequencing could soon be carried out using cheaper and more easily transportable equipment, which could produce results far more quickly. But before this can happen, there are still many improvements which need to be made, particularly to the base calling process. Dr Lei Jiang, a computer engineer at Indiana University Bloomington, aims to show how these improvements can be made.

HOW DOES THE BASE CALLER WORK?

In the latest methods, geneticists train neural networks to detect extremely subtle



patterns in the currents produced by nanopore sequencing. Once trained, they can be used to pick up patterns that would be all but invisible to even the most observant human scientists! In theory, this would make them ideal for identifying the unique orders of nucleobase pairs carried by DNA molecules – but today, the technology is still far from perfect.

Currently, even the smartest neural networks can only identify the order of about 1 million nucleobase pairs per second. That might sound fast, but since DNA molecules contain billions of nucleobase pairs, base calling is actually incredibly time-consuming. At this speed, it takes some 25 hours to analyse a single strand of human DNA (containing 3 billion nucleobase pairs) in enough detail to be useful to geneticists. Because of this, base calling takes far longer than any other part of the nanopore gene sequencing process and needs huge amounts of computing power to run.

HOW CAN BASE CALLING BECOME FASTER?

To solve such a challenging problem, Lei and his colleagues can make improvements to the neural network algorithms involved in base calling – but this is just one part of the solution. Alongside these improvements, they are also aiming to improve the physical equipment involved in collecting and analysing electrical currents – known as hardware. Through its research, Lei’s team is working towards a ‘co-design’ of new algorithms and hardware, which aims to make base calling more efficient, and analyse nucleobases at faster rates.

To achieve this, the researchers will aim to reduce the number of errors made during base calling measurements, while reducing the amount of power it requires to run. On top of this, the team also hopes to make nanopore genetic sequencing more accessible to geneticists – without the need for expensive equipment, or specialist training in how to use it. Ultimately, the team’s work is leading to base calling techniques that can identify nucleobase sequences far more quickly than ever before, allowing researchers to read genetic information whenever they need it.

WHO ELSE IS GETTING INVOLVED IN LEI’S PROJECT?

One of the most exciting and challenging aspects of Lei’s co-design project is that it involves two completely different fields of cutting-edge research. While most computer scientists probably do not know much about how gene sequencing works, neither will the average geneticist have the necessary skills to build and train neural networks. To bridge this gap, Lei is encouraging scientists working in the two different areas to work closely together and communicate their ideas clearly with each other.

An important part of the team’s goal is to make its results freely available online. This will allow scientists across the globe to benefit from the team’s discoveries. Lei and his colleagues are also looking out for new graduate and undergraduate students to join them and contribute to the research with their own fresh perspectives.



DR LEI JIANG

Assistant Professor of Intelligent Systems Engineering, Indiana University
Bloomington, USA

FIELD OF RESEARCH

Computer Engineering

RESEARCH PROJECT

Developing a co-design of neural network algorithms and nanopore gene sequencing hardware, to speed up the base calling process

FUNDER

National Science Foundation (NSF)

WHAT DOES THE FUTURE HOLD FOR THE PROJECT?

Already, Lei’s co-design approach has caused a stir in the gene sequencing community with companies including Pacific Biosciences, in the US, and Oxford Nanopore Technologies, in the UK, expressing a keen interest in his team’s work. With this backing, the researchers will have access to the funds, techniques and minds they need to improve base calling speeds even further.

Lei and his team now hope that their improvements to nanopore gene sequencing could soon be used to solve a diverse variety of real-world problems, including safer and more effective medicines that could be personalised to individual patients. In addition, they could lead to new farming techniques for growing crops that are more nutritious, and more resistant to diseases and natural disasters. This could improve food security for many millions of people in the developing world.

Even further, the team’s techniques could allow conservationists to better monitor the populations of animals, plants and fungi. This will help them to learn more about the threats that these wild species face, and the measures we will need to take to protect them in a rapidly changing world.

ABOUT COMPUTER ENGINEERING

WHY ARE COMPUTER ENGINEERS GETTING INVOLVED IN GENE SEQUENCING?

Since the two fields are so different, it might, at first, be hard to see how researchers in computer engineering and gene sequencing could come to work together. In his research, Lei used to focus completely on computer hardware, but like many other researchers in his field, he soon realised that he could not just focus on one aspect of computer engineering.

To develop better hardware, Lei saw that he also needed to study the software and algorithms that computers run, and how they are being used in real scientific research. This soon led his team to consider how the co-design of hardware and neural network

algorithms could be used to solve key challenges in gene sequencing.

WHAT IS REWARDING ABOUT A CAREER IN COMPUTER ENGINEERING?

For Lei, it is incredibly rewarding to guide his students, and to watch them as they master cutting-edge techniques in hardware design and ‘artificial intelligence’, and computer programs including neural networks, which can learn about the world around them by themselves and will likely be a centrally important part of future technologies.

Recently, Lei’s first student has joined the Samsung Artificial Intelligence Center – just one of many exciting opportunities that are now available in the ever-growing field of computer engineering.

WHAT ISSUES WILL THE NEXT GENERATION OF COMPUTER ENGINEERS FACE?

Until just a few years ago, computers seemed to follow a reliable trend called ‘Moore’s law’ – where they became roughly twice as small and twice as powerful every two years. But recently, it seems that this rapid progress has slowed down.

This presents an enormous problem for computer engineers, who are constantly aiming to build computers that consume lower amounts of power and perform better than devices that came before them. It will be up to the next generation of computer engineers to find new ways around this problem.

EXPLORE A CAREER IN COMPUTER ENGINEERING

- The Luddy School of Informatics, Computing, and Engineering at Indiana University Bloomington offers exciting opportunities for students from diverse backgrounds: luddy.indiana.edu/about/diversity/lodi.html
- Lei recommends you visit the Institute of Electrical and Electronics Engineers (IEEE) Spectrum website to find out about the exciting new directions that computer science is taking: spectrum.ieee.org/
- Indeed.com has a useful computer engineering guide: www.indeed.com/career-advice/careers/what-does-a-computer-engineer-do

LEI’S TOP TIP

Take STEM classes. STEM is cooler than NFL or the Premier League!

PATHWAY FROM SCHOOL TO COMPUTER ENGINEERING

- Lei says that mathematics – at school, college and university – is very important for all areas of computer science.
- Most computer engineers obtain a bachelor’s and many have a master’s degree.
- Leveragedu.com has useful information about the different degree-level subject areas related to computer engineering: leveragedu.com/blog/computer-engineering-subjects
- Find out more: www.learnhowtobecome.org/computer-engineer/

HOW DID LEI BECOME A COMPUTER ENGINEER?

WHO OR WHAT INSPIRED YOU TO BECOME A SCIENTIST?

I enjoyed reading when I was growing up, but it was my high school chemistry teacher who inspired me to become a scientist.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL AS A SCIENTIST?

For me, being open-minded and giving students more freedom are two keys to

being successful. Sometimes, my students understand the details of a problem better than me!

HOW DO YOU OVERCOME OBSTACLES IN YOUR WORK?

I solve a lot of problems by talking to senior colleagues, collaborating with peers, and interacting more with PhD students. Discussing ideas with a range of people has

helped me make many right decisions and tackle many challenges.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS, SO FAR?

My first PhD student graduated last summer, which was a great career highlight for me. I now plan to build a larger research team and collaborate with more PhD students.



Lei with colleagues



Lei leading a presentation at Indiana University

WHAT ARE ENGINEERS LEARNING FROM INSECTS?

BASED AT TEMPLE UNIVERSITY IN THE US, PROFESSOR PARSAORAN HUTAPEA AND HIS MECHANICAL ENGINEERING RESEARCH TEAM HAVE TAKEN INSPIRATION FROM HONEYBEE AND MOSQUITO STINGERS TO DESIGN A NEW SURGICAL NEEDLE THAT IS MORE ACCURATE AND LESS LIKELY TO CAUSE TISSUE DAMAGE

TALK LIKE A MECHANICAL ENGINEER

SURGICAL NEEDLE – a type of needle used in surgical procedures, which is usually long, thin and hollow and may be used to inject treatments into a specific area of the body or to remove cells that are then tested to diagnose a patient’s condition

SIDE EFFECT – an unintended, and usually unwanted, effect of a particular intervention

BIOINSPIRED – new materials or devices with designs inspired by nature, and particularly species’ adaptations, which could act as solutions to human problems

BARB – a sharp point, such as on barbed wire

ASYMMETRIC – something that is not symmetrical

DYNAMIC – something that is moving, as opposed to static (still)

FREQUENCY – the rate of something, such as the number of vibrations per second

3D PRINTING OR MANUFACTURING – a method of creating a three-dimensional object layer by layer based on a digital design

PROTOTYPE – an early sample or model of a new design, used to test how well the design works

Surgical needles are used by doctors to diagnose and treat patients with a variety of conditions. For example, brachytherapy is one of the most successful types of radiotherapy where a surgical needle is used to target cancer cells with radiation, which stops the cells from dividing and growing. However, procedures like brachytherapy require high levels of precision to be successful. If the surgical needle accidentally passes through sensitive tissues like bones, arteries or organs, or bends and moves tissues, there can be harmful side effects for the patient.

Parsaoran (Chai) Hutapea is a professor of mechanical engineering and Director of Composite Laboratory and the Nanoscale Instrumentation Center at Temple University

in the US. Chai is using his expertise in engineering, as well as inspiration from insects, to design better surgical needles that require less force to be inserted and could, therefore, reduce tissue damage in patients who need procedures like brachytherapy.

WHAT CAN WE LEARN FROM INSECTS TO IMPROVE SURGICAL NEEDLES?

Researchers often look to nature for innovative solutions to scientific challenges, making new bioinspired devices and materials. Different species have adaptations which are perfectly suited to performing specific tasks. For example, honeybees have sophisticated stingers used as a defence against predators. It was these barbed stingers that interested Chai and his team as they thought about how to reduce

the insertion force of surgical needles. A lower insertion force means that a needle is less likely to bend or to move the tissue it is passing through. It would, therefore, cause less damage to tissues and is more likely to be on target. “It is counterintuitive, but the barbed structure actually helps to reduce the amount of force needed to insert the needle and reduce tissue damage,” says Chai. Decreasing insertion force could reduce pain, trauma and swelling caused by needles and, potentially, reduce a patient’s recovery time.

However, honeybee stingers do not provide the perfect model surgical needle. One reason for this is that stingers are asymmetric, which reduces accuracy when stinging a target. This does not matter too much for honeybees as



**PROFESSOR
PARSAORAN HUTAPEA**

Professor of Mechanical Engineering and Director of Composite Laboratory and the Nanoscale Instrumentation Center at the College of Engineering, Temple University, Pennsylvania, USA

.....
FIELD OF RESEARCH

Mechanical Engineering

.....
RESEARCH PROJECT

Designing a new surgical needle inspired by insect stingers with the aim of reducing harmful side effects for patients

.....
FUNDER

National Science Foundation (NSF)

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they just need to sting a predator somewhere on its body. Placement accuracy is, however, very important for surgical needles, which need to reach specific tissues and cells, so they must be symmetrical to be more easily controlled by a surgeon.

HOW DO YOU TEST WHETHER A BIOINSPIRED NEEDLE CAN BE USED ON A HUMAN PATIENT?

“First, we designed and 3D-manufactured the bioinspired needle,” explains Chai. The 3D-printed prototype needle was then inserted into an insertion test set up, also designed by Chai and his team. The insertion test setup includes a plastic gel – or in some experiments, animal tissues – which mimics the properties of human tissues, and sensors that can calculate the force of the needle as it is being inserted and pulled out of the gel. This provides a measure of the tissue damage that would be caused by the needle. Other things like

deflection (how far the needle strays from its intended target) were also measured.

Chai and his team tested inserting the surgical needle into the gel or animal tissues while it was vibrating (dynamic) and when it was not (static). The idea for dynamic needle insertion was also inspired by insects. Chai says, “Insects sting with vibration, so we mimic what they do.” The tests found that the needle performed better when it was vibrating. “At certain frequencies, vibration helps to reduce the insertion force of the needle on tissues and thus decreases the damage,” he explains. The needle also has a special coating to reduce the friction between it and human tissue, which was also found to reduce insertion force and tissue damage.

WHAT IS THE HARDEST THING ABOUT DESIGNING NEW SURGICAL NEEDLES?

Such precise mechanical engineering comes with challenges. Surgical needles are used

in many different parts of the body and in different tissues, so there is no ‘one size fits all’ solution to designing new ones. Chai explains, “One can understand specific needle mechanics in one tissue in the lab, but it is extremely difficult to understand the many factors related to different tissues. More research is needed to study needle mechanics in a wide range of tissue types.”

WHAT IS THE NEXT STEP FOR BIOINSPIRED SURGICAL NEEDLES?

Chai and his team have successfully demonstrated in a lab that their bioinspired needle reduces insertion force compared with conventional surgical needles. They are now testing their needle prototypes – which are about 2 mm wide – on live pigs. The next major stage of the work is to 3D print a 1 mm wide metal version of the needle, the kind that could be used on humans in the future.

ABOUT MECHANICAL ENGINEERING

Mechanical engineers combine physics, maths and materials science to design, build, test and maintain objects with moving parts. Mechanical engineers can work on all sorts of products – from aeroplanes to robotics to medical devices.

WHAT ARE THE REWARDS OF MECHANICAL ENGINEERING?

There is a lot of creativity in mechanical engineering, as researchers produce their own designs and test their hypotheses. In addition, mechanical engineers often collaborate with people working in other fascinating areas of science and research. Chai works with medical scientists and radiologists, amongst many other experts.

WHAT DOES THE NATURAL WORLD HAVE TO DO WITH MECHANICAL ENGINEERING?

Insects and other animals are natural mechanical systems. Chai explains, “Humans have created and designed cars, trains, planes, medical devices, and much more – but nature provides inspiration that we have not yet explored fully, which could be used to improve human-made mechanical systems.”

WHICH PROBLEMS WILL MECHANICAL ENGINEERS BE SOLVING IN THE FUTURE?

Mechanical engineers have a vital role to play in addressing the world’s biggest challenges, such

as climate change. “We should study nature and learn new ways to create a more efficient and sustainable mechanical system – whether it is a car, a train, a coffee machine, or a medical device,” says Chai.

PATHWAY FROM SCHOOL TO MECHANICAL ENGINEERING

- Mechanical engineering uses principles from maths and physics and it is usually required that you study one or both subjects, and perhaps another science subject, at college to be admitted to a university course in mechanical engineering.
- Chai recommends that you learn other subjects that interest you – be it biology, history, English or foreign languages. “Learn a range of things to be a well-rounded person and engineer,” he says.
- After studying mechanical engineering, you may go on to become a licensed engineer. There is more information about this process in the US here:

www.asme.org/topics-resources/content/the-path-to-professional-licensure

EXPLORE A CAREER IN MECHANICAL ENGINEERING

- There are many organisations around the world that provide information and resources about mechanical engineering, and even opportunities for internships. Chai recommends exploring the following websites:

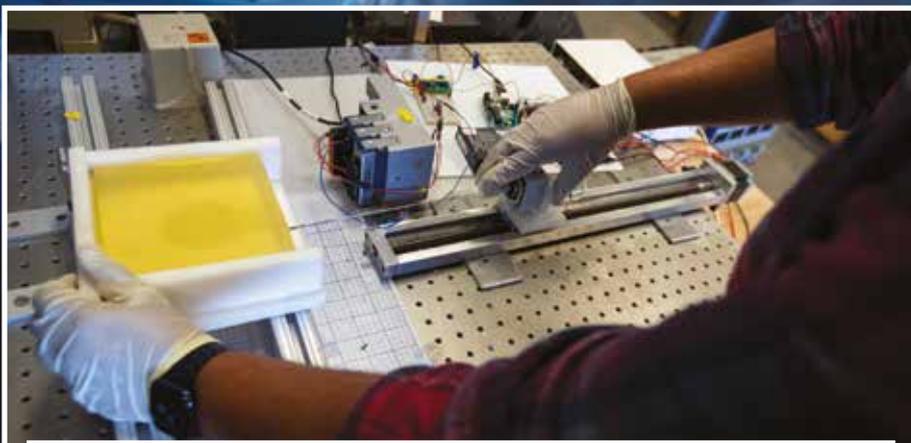
The American Society of Mechanical Engineers in the US: www.asme.org
Institution of Mechanical Engineers in the UK: www.imeche.org

- The College of Engineering at Temple University runs outreach schemes for young people, such as summer programmes for high school students: engineering.temple.edu

Universities elsewhere run similar programmes, so find out what is going on in your local area!

- According to **Salary.com**, salaries for mechanical engineers in the US range from around \$66,000 as a starting salary to a mean of \$112,000. The top earners in mechanical engineering have an annual salary of around \$158,000.

www.salary.com/research/salary/general/mechanical-engineer-salary



PhD student Kavi Patel performing insertion test of a bioinspired needle on gel tissue phantom (credit Temple University)



Chai and PhD student Kavi Patel in the lab (credit Temple University)

HOW DID CHAI BECOME A MECHANICAL ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?
I wanted to be a soccer (football) player!

WHAT INSPIRED YOU TO BECOME A MECHANICAL ENGINEER?
Looking back, I really don't know! It just happened that I liked it.

HOW HAS BEING A MECHANICAL ENGINEER CHANGED THE WAY YOU THINK?

I can think more critically and make links between seemingly unrelated things – for example, thinking about how the movement of an animal relates to a mechanical system.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS AND HOPES FOR THE FUTURE?
I feel very proud to see my students succeed in their careers. Of course, my future ambition is to see one of my devices used in hospitals!

CHAI'S TOP TIPS

- 01** Do not be afraid to fail.
- 02** Be explorative to find out what you like – enjoy reading books that interest you and go to parties with interesting people!

MEET DOYOUNG



DOYOUNG KIM
PHD STUDENT

Doyoung is conducting her PhD research in Chai's lab.

WHAT IS A TYPICAL DAY LIKE FOR YOU?

I usually attend university classes, study independently and read research papers related to my research. Sometimes, I attend lab meetings and work in the lab office.

HOW HAS YOUR EDUCATION LED YOU TO THIS RESEARCH?

I was determined to find something I was interested in, so, as a younger student, I took a range of classes and did internships in different fields. Having an open mind, exploring different areas and looking for what really intrigued me led to this research.

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

When I was younger, I was interested in creative activities such as dancing, painting, martial arts (Tae-kwon-do) and crafting. As I moved into middle school, I got into maths and science, especially physics. I enjoyed working in labs and doing hands-on work.

WHO OR WHAT INSPIRED YOU TO BECOME AN ENGINEER?

My dad, who is also a mechanical engineer, was my role model. When I was in middle school, my dad brought a lot of scratch papers from his work, so I could see complex equations and machine drawings, but I didn't fully understand them back then! My curiosity about his work led me to engineering and when I had to choose my major, he gave me lots of advice. He explained that mechanical engineering has various branches, so would enable me to explore different areas until I found the one right for me.

WHAT ATTRIBUTES HAVE MADE YOU SUCCESSFUL?

My habit of asking questions! Engineers are problem solvers,

and we cannot answer questions if we don't ask questions. Also, I am not afraid of asking for feedback, as well as reviewing what I've done wrong. I have always studied hard and reviewed my mistakes in order to improve.

WHAT DOES IT FEEL LIKE TO BE THE RECIPIENT OF TEMPLE UNIVERSITY'S 2021 PRESIDENTIAL FELLOWSHIP?

I am honoured to have received this fellowship, which my advisor, Professor Hutapea, nominated me for. I had two internships at medical device companies that led to my research focus of medical device design, which led me to receiving this award. As this is such a prestigious award, I feel proud of myself but, at the same time, I feel responsible. More than ever, I am determined to do my best to be a successful PhD student.

HAVE THERE BEEN ANY EUREKA MOMENTS IN YOUR CAREER?

When I was doing an internship at a dental X-ray medical device company, I had to design a headrest that would satisfy both patients and engineers. I researched various mechanisms

and watched online videos, but, for a few days, I was struggling to find inspiration. Two days before a progress meeting, I was staring at a headrest for about 20 minutes and, suddenly, a mechanism popped into my head! I completed my design and the meeting was a success. This goes to show, you need to be patient and keep focused – the ideas will come.

WHAT ARE YOUR AMBITIONS FOR THE FUTURE?

I want to use my knowledge to contribute to a better world. I would like to be a leader and an innovator of creative research in my field. Lastly, I want to be an educator, so I can help students find their own path in becoming influential scholars and engineers.

WHAT IS YOUR TOP TIP FOR YOUNG PEOPLE HOPING TO FOLLOW IN YOUR FOOTSTEPS?

I know it is hard, but it is helpful to know what you are interested in. To know this, it is important to try different things, so I would encourage people to explore various areas. Don't be afraid, be adventurous!



EXTRAORDINARILY SMALL MATERIALS WITH BIG WORLD APPLICATIONS

PROFESSOR JOSHUA ROBINSON IS A MATERIALS SCIENTIST AND ENGINEER BASED AT THE PENNSYLVANIA STATE UNIVERSITY IN THE US. HIS RESEARCH FOCUSES ON 2D MATERIALS, SUCH AS GRAPHENE, AND HE IS NOW EXPLORING OTHER MATERIALS FOR NEXT GENERATION ELECTRONICS

TALK LIKE A MATERIALS SCIENTIST

QUANTUM – the minimum amount of any physical entity involved in an interaction

SEMICONDUCTOR – a material with properties somewhere between an insulator and a conductor

COMPOUND SEMICONDUCTOR – a semiconductor made of more than one element on the periodic table

TWO-DIMENSIONAL (2D) MATERIALS – crystalline solids consisting of a single layer of atoms or group of atoms

GRAPHENE – a single layer of carbon atoms arranged in a 2D honeycomb nanostructure

HETEROSTRUCTURE – a layered structure in which the chemical composition changes as you move from layer-to-layer

OPTOELECTRONIC – while the majority of electronic devices are silicon based, optoelectronic devices perform their best when made using compound semiconductors made of elements from the group III and group V columns in the periodic table

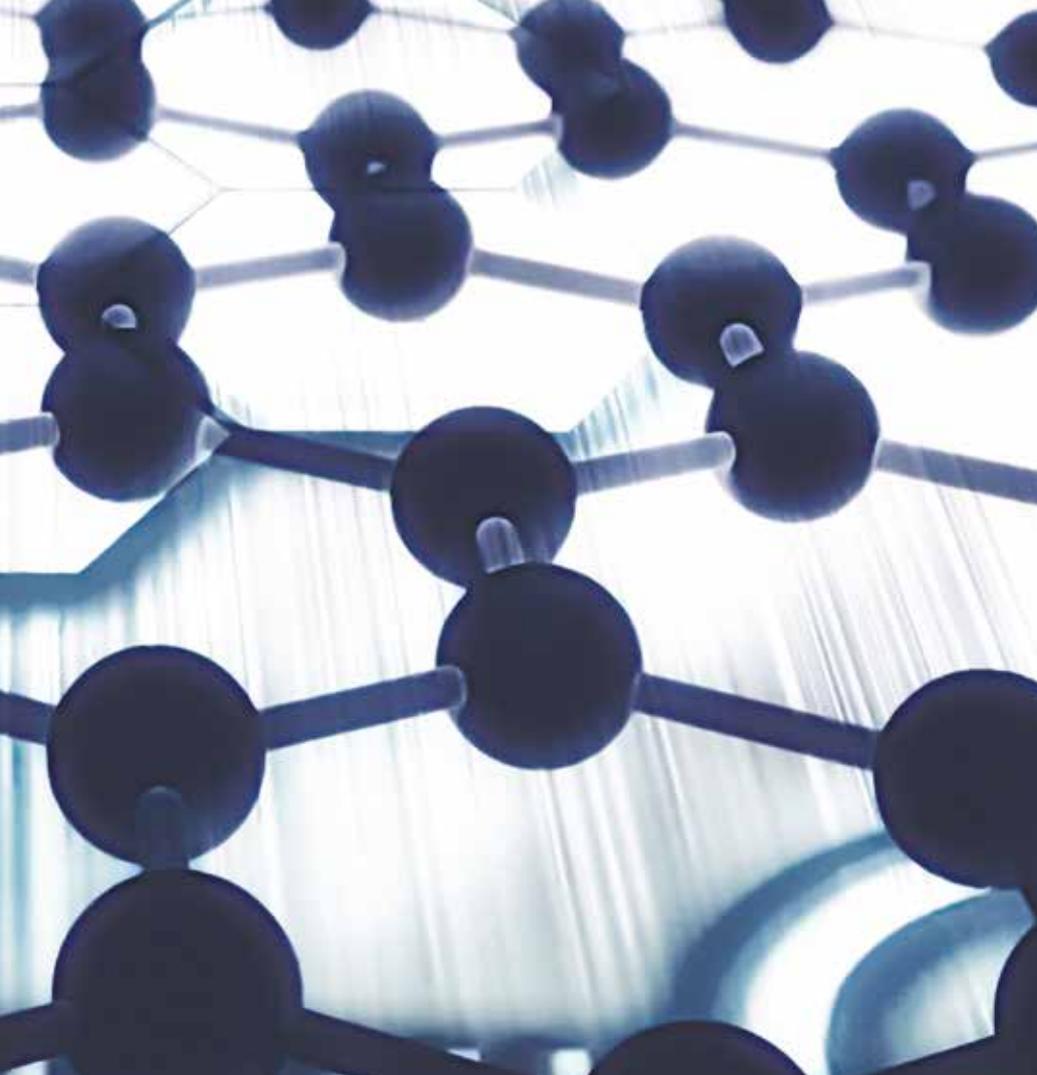
SUPERCONDUCTOR – a material that conducts electricity without resistance

CHEMICAL VAPOR DEPOSITION – a technique for artificially growing thin layers of crystalline materials

“One of the superstar materials of the 21st century is graphene. Because graphene is only an atom thick, it has extraordinary properties which we could never find inside 3D materials, such as electrons that move faster than in any other material!” So says Alexander Vera, a member of Professor Joshua Robinson’s research team based at The Pennsylvania State University. When a material with such unprecedented properties is created, the scientific community is understandably excited – the potential applications are so far-reaching that there are some we cannot yet envision or comprehend... but Joshua and his team are striving to achieve them, with a view to facilitating next generation electronics.

CHANGING PROPERTIES

Typically, when traditional materials are shrunk to just a few atoms thick, they start behaving very differently – metals can become semiconductors, superconductors can work at higher temperatures, and optical materials can emit light with extraordinary efficiencies. If the team can understand and harness these materials, such phenomena can lead to far



superior technologies. For instance, graphene boasts exceptional electronic properties, where electrons can travel through it like a superhighway, which is not possible with materials when they are significantly bigger.

MAKING THE ULTRA-THIN

There are a lot of different ways that you can make 2D materials, from mixing powders in a blender to using multi-million-dollar technologies like molecular beam epitaxy. “Our aim is to use techniques that are industrially compatible, such as chemical vapour deposition, which is the most popular way to make semiconductors for the electronics industry,” explains Joshua. “It starts with special chemical compounds or vapour that contain the elements we want to combine, such as molybdenum and tellurium.” From there, the team puts a very small amount of those vapour into a high temperature oven. Once the oven has cooled, the substrate is removed and covered with a layer of material between one and three atoms thick!

MOVING BEYOND GRAPHENE

Graphene is considered the keystone of 2D materials, but it is only the tip of the iceberg. While graphene has tremendous properties, there are some applications it is unsuitable for, which is where large parts of the lab’s research come into play. With a focus on the development of ‘beyond graphene’ materials,

the team is seeking to uncover new materials that complement graphene or perform in entirely different ways. “Graphene is not a semiconductor – we cannot stop the electrons from flowing in graphene – so we cannot use it as a nano-switch in electronic applications, which is important since we get the ‘1s and 0s’ in computer code from these nano-switches,” says team member Cindy Chen. “There is a whole other family of 2D materials, known as transition metal dichalcogenides, that can be used in these little nano-switches, and, therefore, are more appropriate to explore for next generation electronics.”

THE CHALLENGES

Importantly, the team works closely with industry to pass on information and discoveries. Indeed, some of its industrial collaborators are already making 300mm wafers which are perfect for the electronics industry. Still, scaling up is not without its challenges, especially considering that the materials are 2D. “Everything you do to these materials impacts their properties because they are all surface!” says Joshua. “That means putting a metal or oxide on top of them changes the environment of the whole layer, not just the top surface as happens in a 3D material. Therefore, integration of these 2D layers, and understanding and controlling what happens when you sandwich them between other materials are major focuses for today’s scientists.”



PROFESSOR JOSHUA ROBINSON

Department for Materials Science and Engineering, Center for Atomically Thin Multifunctional Coatings, The 2D Crystal Consortium, Center for Nanoscale Science, The Pennsylvania State University, USA



FIELDS OF RESEARCH

Materials Science, Engineering



RESEARCH

Developing 2D materials, such as graphene, which boast exciting properties and have a broad range of applications within the fields of computing, energy and sensing



FUNDERS

National Science Foundation (NSF), Air Force Office of Scientific Research, Semiconductor Research Corporation, Intel, Army Research Office

KEY FINDINGS

The lab has developed methods to make 2D materials that have enabled team members to explore unique phenomena. In addition, it has discovered that when metals are squeezed down to a few atoms, they act very differently to traditional metals. One other major achievement has been the development of methods to carefully control the introduction of small amounts of impurities to 2D materials to control their electronic properties.

NEXT STEPS

“We’re constantly pushing the boundaries of making new forms of 2D materials from traditional 3D materials, and our latest is to explore what happens when you squeeze elements known as the ‘rare-earth elements’ into a 2D space,” says Joshua. “These elements are already exotic and we’re pretty sure even more weird physics is going to ‘pop-up’ when we get them in a 2D form!”

ABOUT MATERIALS SCIENCE

Materials science is the quest to understand how materials are made and what controls their properties. As technology has developed, scientists have advanced the field to create and explore different materials with exciting – and sometimes unprecedented – properties. 2D materials, which are extremely thin (sometimes only one atom thick), form the basis of many scientific enquiries.

2D metals are an exciting avenue for exploration because of the variety of potential they offer. “Some of the applications include superconductors for quantum technologies; metasurfaces for optical computing and quantum

communications; and high surface area materials for ultra-sensitive biosensors to rapidly detect viruses,” explains Joshua. “The opportunity for such materials to impact electronics lies in their ability to be combined, like LEGO blocks. 2D layers can be stacked, twisted, folded and shaped in just about any manner imaginable, making them very useful for engineering any property you like.”

Applying these materials is dependent on how you make them. “Like the rusting of a bike that has been outside for too long, 2D metals start to degrade if we aren’t careful in how we make them – because they are all surface, they can degrade almost instantly!”

explains Alexander. “Part of our work is preventing that from happening, so that we can use them in electronics without fancy and expensive equipment.”

Beyond simply keeping the equipment running, one of the biggest challenges is understanding and analysing the data generated. Researchers must link data back to how the material was made. “Often, we will make a material and it will perform in a certain way, but we don’t know why,” says Cindy. “That’s when we have to rely on the science community around us to dive a bit deeper into the analysis or theoretically model the behaviour to help us understand.”

EXPLORE CAREERS IN MATERIALS SCIENCE

- The best advice Joshua can give to budding students is to get into a lab and explore! “Seek out internships, summer programmes, or even volunteer at a local college/university lab – it’s the best way to identify what you enjoy in the sciences,” says Joshua.
- Joshua is part of the Center for Nanoscale Science. Explore the outreach programmes it offers: www.mrsec.psu.edu/education-outreach-programs
- The US Bureau of Labor Statistics has useful information about careers in material science: www.bls.gov/oes/current/oes192032.htm#ind
It states the average salary of a materials scientist in the US as \$104,000.
- According to Payscale.com, the average salary for a materials scientist in the UK is £32,000 (www.payscale.com/research/UK/Job=Materials_Scientist/Salary).

PATHWAY FROM SCHOOL TO MATERIALS SCIENCE

Joshua recommends taking physics, chemistry and mathematics at school and college. “Materials science is all about the world of materials – how they are made, how they function and how they can be utilised,” he explains. “Understanding the basic physics and chemistry ‘languages’ is critical to being able to dive into the world of materials.”

You will normally need a minimum of a bachelor’s (foundation) degree, with many semiconductor or electronic industries most interested in master’s or PhD degrees. Relevant subjects include materials engineering, materials science, chemistry and solid-state physics, and electrical engineering.

Alexander explains, “Materials science is a broad discipline which can touch on so many fields. So, depending on which path you take, subjects like food science and forensic science could also be useful – you could even end up working on food packaging or be part of a legal case as a materials scientist!”

THE TEAM’S TOP TIPS

- 01** We fail more often than we succeed. The key is not to run from failure, but to learn and grow from it. If you do this, you will succeed many times!
- 02** Be creative and stay true to yourself. So much of science is about novelty, which cannot happen without your unique human experience.
- 03** Find what you love to do and don’t be afraid to put all of yourself into it. It is also important to identify and maintain a supportive network of friends, family and mentors, and support them in the same way as they support you.

HOW DID JOSHUA BECOME A MATERIALS SCIENTIST?

I had many interests growing up and was fascinated about the world around me. My brother and I were always exploring, which I believe is a key ingredient in the way I go about life today. Now, instead of picking up rocks in a creek to see what's underneath, I peel up graphene to look at the atoms!

My route into science is thanks to my encouraging parents and a great undergraduate mentor.

Growing up, I was always curious, but the experiences I had as an undergraduate student were perhaps what sent me down the path of scientific exploration rather than any other. Professor David Schaefer (Towson University) gave me a great opportunity to 'play' in his lab and learn about nanoscale materials.

It's incredibly satisfying to see my students succeed. The research

is exciting, and we seem to be discovering new things on a regular basis, but it's the people that I am surrounded by that gets me up and keeps me going every day. I especially enjoy when a student finally 'gets it' and then starts coming to me with ideas to explore – that means they are thinking at a higher level, and sometimes a few levels higher than I am, which means it's time for them to graduate!

The possibilities for the impact of 2D materials are wide open. There are so many possible applications, from 2D materials in composites for better performing tyres, all the way to advanced nanoscale heterostructures for quantum computing. This provides the opportunity for students to work in a broad spectrum of industry, academia and government.

MEET ALEXANDER VERA



I am a researcher, working on the synthesis of ultra-thin metals, and a safety officer. My day is spent in Joshua's lab performing

experiments, writing manuscripts or engaging in outreach activities.

I enjoyed physics in high school, so I opted for an applied physics degree for my bachelor's. My department was interdisciplinary, so I was introduced to materials science. My undergrad department was also known for 2D materials research, which led to my choosing to work in this unique field.

Growing up, I was always interested in marine life and astronomy. However, I also loved storytelling, fables and fantasy. I liked to play historical strategy games as well!

When I was younger, I rarely saw my identities reflected in my fellow classmates or my instructors. I saw how I was privileged to follow my passion where others like me were not, so I wanted to inspire others to pursue STEM fields.

I can attribute my success in science to patience, listening and creativity. We are given many problems to tackle, not just in the lab, but throughout the whole scientific career. At every problem, surprisingly, my love for storytelling has lent me these attributes and helped me find solutions.

In 2020, I was accepted to the Sloan Foundation, which recognises active students of colour in higher education. With some of the funds awarded, I was able to travel to Oak Ridge National Labs for a week-long site visit, which was exciting!

One of my chief aims in the future is to graduate from Penn State with a PhD. I very much hope to continue working in science and nanotechnology, with a focus on diversity, equity and inclusion.

MEET CINDY CHEN



I design experiments for the synthesis of 2D materials and oversee one of the deposition tools we use to grow materials. I am also a lab manager, so I train new users and make sure they are

always safe around the lab.

Most of the time, I work in the lab and conduct experiments. After materials growth, I take my materials to analytical instruments so I can understand their structures and chemistries better. Some days, I work in the cleanroom, suited up from head to toe to ensure I don't contaminate our samples.

I majored in materials science, and one of my favourite courses was on the electronic properties of materials. This led me to join a research group and present my undergraduate research at

a conference, which was where I met the members of the group I currently work in.

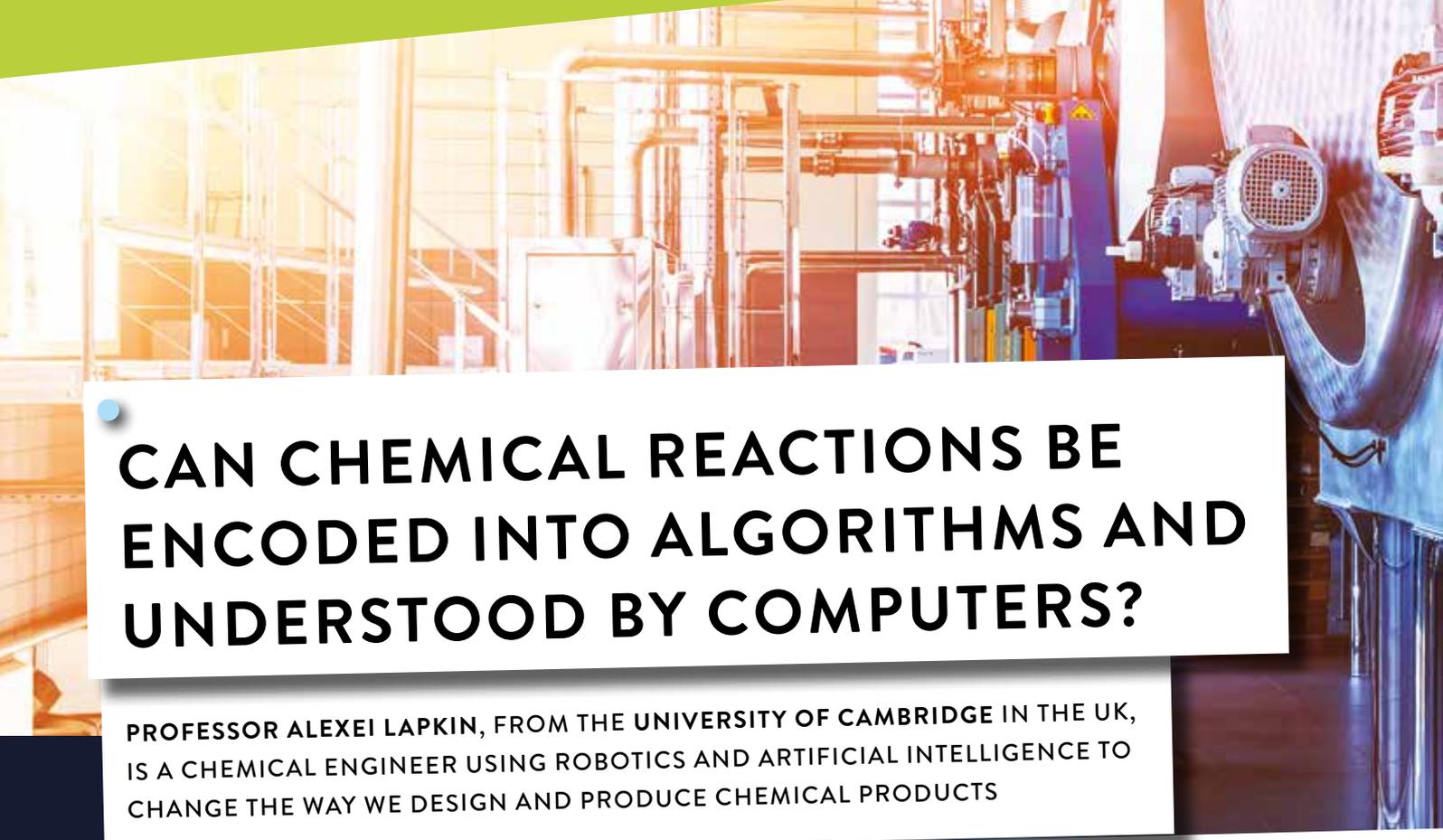
I was a part of my high school's Science Olympiad and Science Bowl teams. It was refreshing to learn new science topics not taught in class, and, more importantly, it was fun. Outside of school, I enjoyed teaching clay art alongside my mom, who is an art teacher.

My high school physics teacher, Mr Slattery, was my biggest inspiration. He always believed in me, even when I lost confidence in myself. I keep in touch with him to this day.

Once I set my mind on something, I am determined to achieve my goals. Failures are lessons for becoming a better scientist!

I am proud that I finally optimised the recipe for growing 2D semiconducting molybdenum ditelluride. This was challenging, with many failed experiments and broken tool parts, but I never gave up and was determined to make the material a reality.

My aim is to work as an engineer in the semiconductor industry, to be part of a team designing the next generation of new electronic technologies.



CAN CHEMICAL REACTIONS BE ENCODED INTO ALGORITHMS AND UNDERSTOOD BY COMPUTERS?

PROFESSOR ALEXEI LAPKIN, FROM THE UNIVERSITY OF CAMBRIDGE IN THE UK, IS A CHEMICAL ENGINEER USING ROBOTICS AND ARTIFICIAL INTELLIGENCE TO CHANGE THE WAY WE DESIGN AND PRODUCE CHEMICAL PRODUCTS

TALK LIKE A CHEMICAL ENGINEER

ALGORITHM – a set of rules or steps to follow in a particular order to solve a problem or complete a process, notably in computing

BAYESIAN OPTIMISATION – a statistical technique which can help to solve problems where the exact relationship between inputs and outputs is not initially known

CRADLE-TO-CRADLE – approach to product design which considers the entire life cycle of the item, from manufacture through use to recycling or repurposing

MACHINE LEARNING – the family of techniques whereby algorithms are trained to identify patterns in data

PROCESS INTENSIFICATION (PI) – the development of new apparatus and techniques which bring dramatic improvements in manufacturing of an existing product; ‘dramatic’ has been roughly enumerated as at least 100 times better (smaller size, higher throughput, etc.) compared to the starting point

From the mid-twentieth century, scientists have understood that some systems, both artificial and natural, are inherently and irreducibly complex. Since around the same time, engineers and mathematicians have been developing the field of machine learning to solve problems beyond the abilities of more traditional analysis,

based on the concept of reduction to smaller problems. At the Department of Chemical Engineering and Biotechnology at the University of Cambridge, Professor Alexei Lapkin is one of a team of chemical engineers using complex systems theory and machine learning to save time, money and energy in industrial production.

WHAT ARE COMPLEX SYSTEMS AND HOW ARE THEY RELEVANT TO CHEMICAL ENGINEERING?

Scientists in many fields have to consider systems of interacting components and the use of equations to represent them. In general, these systems (or equations) can be split into two categories: those that can be described as a sum of simpler component systems (or equations), and those which are indivisible. The former tend to behave predictably, whilst the latter can show unpredictable, and even chaotic, behaviour.

In chemical engineering, the presence of many chemical reactions occurring simultaneously constitutes a complex system. Another example is the behaviour of industry as a whole, where complexity arises from interactions between many individual companies, environmental and economic regulatory agencies, consumers and so on – the ‘actors’ or ‘agents’. The unpredictability of complex systems represents a challenge, since chemical engineers need to be able to reliably produce the required quantities of their products safely, on time and within the acceptable price.

WHAT IS PROCESS DEVELOPMENT IN CHEMICAL ENGINEERING?

Chemical engineering involves confronting the

challenge of translating cutting-edge science into everyday products. “The connecting step is to estimate the size of the market for the product,” Alexei explains. “From this we can work out how much of the molecule we need to produce, which sets the parameters of the challenge.”

Process development is the next stage. Alexei explains, “We figure out how to manufacture the desired molecule at the right production rate, without causing any environmental problems, and at the right price.” In recent years, a combination of increasing consumer demand and developing technology has led to a growth in the academic discipline of process intensification (PI), first introduced by the former British industrial giant Imperial Chemical Industries (ICI).

The idea behind PI is that by intensifying a process of making molecules, it may be possible to achieve reduction in physical size of a chemical plant, or reduction in the amount of energy it consumes. This can be done by exploiting new methods – that is, exploiting the results of recent scientific discoveries to improve chemical reactions and chemical separations. This can also be achieved by designing new machines – designing how the intensified chemical plants work.

HOW ARE NEW APPROACHES TO PROCESS DEVELOPMENT DIFFERENT TO CONVENTIONAL METHODS?

At the root of every chemical engineering challenge is always a new and exciting discovery



at the molecular level. In conventional process development, the next step after discovery is to be able to synthesise the target molecule repeatedly and consistently within a laboratory setting. Then, the properties of the product are systematically studied before the synthesis process is scaled up so that the desired material can be produced at the required production rate to satisfy the market demand. "Following this approach, it takes many years to get to an optimal manufacturing process," says Alexei.

Alexei and his team are advocates of a different approach, whereby multiple steps in the research and development practice are performed simultaneously. This has an added benefit of being able to identify opportunities to intensify the manufacturing methods and machines used. "In our research, we tend to consider steps of researching molecules, their reactions, separation of the desired product, understanding how much the process would cost, as well as its potential environmental impact, all at the same time," says Alexei. This collection of multiple pieces of information and of interactions between many components of the overall system creates a perfect environment for the application of advanced mathematics. "Our breakthroughs came through interacting with mathematicians and explaining the features of our discipline to them," Alexei recalls.

HOW CAN MACHINE LEARNING BE USED IN PROCESS DEVELOPMENT?

The rapid increase in computing power over recent decades has pushed machine learning to the forefront of many scientific disciplines. However, the nature of chemical engineering means that machine learning must be used in a very particular way. "In fields such as image recognition, say for self-driven vehicles, methods can be trained on huge quantities of data, but, with chemical processes, we only have modest-size datasets," Alexei explains. "Therefore, we focus only on those methods that are good at learning from relatively small sets of data".

"We came up with a strategy of how to encode chemical information such that computer algorithms understand it," Alexei says. "We can then use different methods developed in the machine learning community, for example the method of Bayesian optimisation, to connect inputs to outputs".

CAN MACHINES BE TRAINED TO PERFORM JOBS LIKE SCIENTISTS?

A machine that conducts its own chemistry experiments might sound like science fiction, but this ambition is beginning to be realised in the labs of engineers such as Alexei. "In our own lab, we built a machine that performs experiments on its own; it measures results, compares these with previous experiments, and considers what experiments to do next."

"The machine computes the probability of a successful outcome for each of these possible experiments, and then chooses which one to actually run," Alexei adds. "The machine can repeat this process hundreds of times, which can take weeks off the time needed to complete a development project."

HOW CAN IMPROVED PROCESS DEVELOPMENT MAKE MEDICINE FAIRER?

"By learning how to encode chemistry into algorithms, we hope to make chemical development significantly faster and more accessible," says Alexei. Part of this greater accessibility lies in lower costs, which can then be passed on to consumers.

"As we reduce the cost of drug development and drug manufacture, we can reduce the retail price of medicines, which in turn makes medicines accessible to a greater number of people," he explains. The COVID-19 pandemic has focused minds everywhere on the need to distribute medicines worldwide in a fair way, and chemical engineering is going to have to play a key role in addressing this challenge.

HOW CAN IMPROVED PROCESS DEVELOPMENT BENEFIT THE CLIMATE?

"By making sure every industrial process is highly optimised, we can reduce energy consumption, and thus reduce our impact on the climate," Alexei explains. In recent years, more and more companies have incorporated cradle-to-cradle philosophies into their products, and academics such as Alexei are concerned with the same set of issues.

"We include measures of cleanness in all process development projects – not only in terms of the processes themselves but also the raw materials," Alexei says. Increasingly, engineers specialising in sustainability are looking to imitate the natural world. One new approach,



PROFESSOR ALEXEI LAPKIN

Professor of Sustainable Reaction Engineering, University of Cambridge, UK

FIELD OF RESEARCH

Chemical Engineering

RESEARCH PROJECT

Combining chemical robotics and statistical methods to develop complex functional products

FUNDER

Engineering and Physical Sciences Research Council (EPSRC)

known as industrial ecology, looks to avoid wasting by-products of chemical processes by using them as feedstocks for other processes.

HOW DOES THIS WORK BRIDGE THE GAP BETWEEN ACADEMIA AND INDUSTRY?

"Some of our algorithms and tools have been adopted by companies as well as by other scientists," Alexei says. "One of our industry partners has patented a method of developing products that we helped them to develop." At the same time, Alexei himself has moved into the business world. "We have spun out two start-up companies, in the areas of digital manufacturing tools and clean chemistry."

"In chemical engineering, and in our group in particular, the fundamental sciences are mixed with issues of safety, ecology, business and management," Alexei adds. "We also have a lot of fun, which I think is a success for the group!" A career in chemical engineering might allow you to not only work across several academic disciplines, but also to bridge the gap between academia and industry.

ABOUT CHEMICAL ENGINEERING

WHAT DOES A TYPICAL DAY AS A CHEMICAL ENGINEER INVOLVE?

“As a chemical reaction engineer, a lot of time is spent on preparing the automated systems which run each set of experiments, and on understanding all the prior knowledge of the specific chemistry to ensure experiments are safe to do and meaningful,” says Alexei. “The raw materials have to be prepared, and all the sub-systems checked. Whilst the experiment is running, we may need to check that it is progressing smoothly. If it isn’t, we have to figure out why.”

“Apart from running the experiments, there

is the analysis of results, which in our case involves a lot of work checking on and refining machine learning methods. Finally, there is the time spent reading new and exciting scientific articles from our peers, and describing our own results in the form of scientific manuscripts and conference presentations.”

WHAT WILL BE THE CHALLENGES FACING THE NEXT GENERATION OF CHEMICAL ENGINEERS?

The transition from fossil fuels to sustainable energy sources – sometimes known as the green transition – has become a frontier of science and engineering, as well as a major

topic of political debate. Chemical engineers have a key role in this transition, both by improving efficiency of production lines, and by developing the new materials needed to drive the expansion in renewable energy.

The energy transition is part of a broader move towards sustainability. “We need to replace many of the materials in use today with alternatives that are better performing and less harmful to the environment,” explains Alexei. “We need to scale manufacture of nanomaterials and composites that will go into new construction materials, as well as into new types of medicines.”

EXPLORE A CAREER IN CHEMICAL ENGINEERING

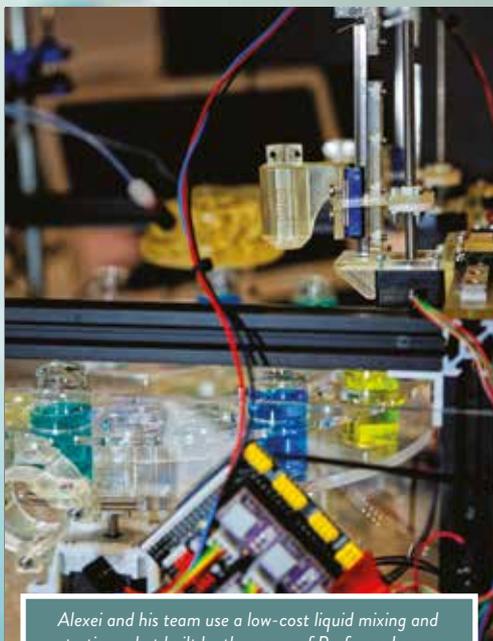
- As well as taking part in Cambridge Science Festival (www.festival.cam.ac.uk) each year, Alexei’s department takes sixth form students on science placements. Explore the department’s website to find out what studying chemical engineering involves (www.ceb.cam.ac.uk/undergraduates/prospective-students).
- Alexei recommends the resources made available by the Institution of Chemical Engineers (IChemE). These include a section explaining the variety of things that chemical engineers do: www.icheme.org/education/whynotchemeng
- According to the UK National Careers Service, average salaries for chemical engineers start at £30,000 and rise to around £65,000 with experience: nationalcareers.service.gov.uk/job-profiles/chemical-engineer.
- A background in chemical engineering may also allow you to move into more managerial roles, banking and finance (where chemical engineers help to assess environmental risk factors), or to work as a consultant.

PATHWAY FROM SCHOOL TO CHEMICAL ENGINEERING

- As well as chemistry, other particularly beneficial A-level qualifications for chemical engineering are maths, physics and biology.
- A list of universities offering chemical engineering courses can be found on the UCAS website: digital.ucas.com/coursedisplay
- Even without an undergraduate chemical engineering degree, you may still be able to transfer from chemistry or engineering once you reach postgraduate level.
- It is also a good idea to search for apprenticeships using the UK government website: www.findapprenticeship.service.gov.uk/apprenticeshipsearch



Undergraduate students learning how to build designs for 3D printing of chemical process equipment during their experimental project; such a project is an integral part of the degree in chemical engineering and biotechnology.



Alexei and his team use a low-cost liquid mixing and testing robot built by the group of Professor Leroy Cronin (University of Glasgow) to work on design of formulations.



Alexei's lab uses a new type of 'chemistry machine', built by a local company based in Royston – Vapourtec. The team develops complex automated experimental systems on the basis of such machines.

HOW DID ALEXEI BECOME A CHEMICAL ENGINEER?

WHAT WERE YOUR INTERESTS WHEN YOU WERE GROWING UP?

As a young child, I enjoyed Meccano and other construction games. Growing slightly older, I became more interested in chemistry, in general, and in my home chemistry set, in particular. Other interests included the natural world – I attended an after-school entomology class – and learning classical music to be able to play cello.

WHO INSPIRED YOU TO BECOME A SCIENTIST?

I was lucky to have a very good mentor in my after-school chemistry club. He promoted

science as a career where I could choose what to do and how to do it, without needing to answer to a boss at the end of the day. Of course, now that I am a professional scientist, I realise that my work is overseen by society and must be scrutinised by my peers – and they can be tough judges!

WHAT KEEPS YOU MOTIVATED IN YOUR WORK?

It can be hard to stay motivated through the hard grind which makes up a lot of scientific work. We cherish the rare Eureka moments – when a solution appears, a difficult experiment runs successfully, or a positive outcome is

obtained from an experiment. It is also very gratifying on those occasions when you can present your best results at a big meeting and get positive feedback from your peers in other research groups.

WHAT ARE YOUR PROUDEST CAREER ACHIEVEMENTS SO FAR?

These days, I take great pride in the achievements of my research group – a large part of my role is to feed initial ideas into the group and then let the younger generation take over and move the ideas forward.

ALEXEI'S TOP TIPS

- 01** To be a professional scientist, you need to be comfortable operating at the edge of knowledge – the learning never stops!
- 02** Learn to re-formulate problems into simpler, generic terms avoiding topical jargon, as well as to link knowledge from different neighbouring disciplines. This will help you to become good at finding solutions to problems.
- 03** Science is not a normal job – it is a vocation! Your mind will keep working on problems even when you leave the office, so it is good to find activities which allow you to focus on something completely different.

DATA AND COMMUNICATION IN THE WORLD OF THE FUTURE

AS OUR LIVES BECOME INCREASINGLY INTERTWINED WITH TECHNOLOGY, WE NEED INCREASINGLY SOPHISTICATED WAYS OF MANAGING DATA AND COMMUNICATING. PROFESSOR JUSTIN COON AND HIS TEAM AT THE UNIVERSITY OF OXFORD IN THE UK ARE WORKING ON A VARIETY OF RESEARCH PROJECTS, INVOLVING MOLECULAR COMMUNICATION, DATA COMPRESSION AND PRIORITISATION, AND SAFEGUARDING THE INCOMING 'INTERNET OF THINGS'

GLOSSARY

DATA COMPRESSION – modifying data (e.g., through encoding or restructuring) to reduce their size

DISTRIBUTED NETWORKS – when the computer in a communication network communicates directly to other computers or devices in the network instead of passing messages through an intermediary

ELECTROPHORETIC – the migration of molecules through a fluid subjected to an electric field

FLUID DYNAMICS – the study of the mathematics and physics behind the flow of liquids and gases

INFORMATION THEORY – the mathematical study of the coding of information, and how rapidly this information can be transmitted

INTERNET OF THINGS – the internet-connected network of computing devices embedded in everyday objects

MOLECULAR COMMUNICATION – using the presence, absence, or concentration of molecules to digitally encode a message

“Engineering can be thought of as the process of applying physics and mathematics to solve a problem through design and ingenuity,” says Professor Justin Coon, who heads the Information and Network Science Lab at the University of Oxford’s Department of Engineering Science. “At Oxford, we teach engineering in a holistic manner to capture the foundational principles of physics and mathematics.”

The researchers in Justin’s lab come from a variety of mathematics, physics, and engineering backgrounds. “Some have studied communication and information theory to an advanced level, while others have expertise in material physics and fluids,” he says. They are pooling their specialties to work on innovative projects, looking at novel ways of approaching communication and data. “We do what we do because we are curious, we want to learn, and we want to contribute to the body of knowledge that humans have been building for millennia,” says Justin. “Every day that we discover something new – a new theory, a novel way of approaching a problem, a clever design for a system – feels like an achievement.”

Justin’s lab is exploring electrophoretic molecular communication, graph compression, the value of information and network security. The team’s wide-ranging work shows that studies in engineering and communications can be incredibly broad and fascinating.

ELECTROPHORETIC MOLECULAR COMMUNICATION

Nanotechnology is becoming increasingly advanced, to the point where there is scope for a ‘nanonetwork’. This is where nanomachines communicate with each other. However, while we tend to use electric circuits or radio waves to fulfil this function, these methods can be impractical or unsafe at the nano level. Finding alternatives is a prime topic of research, and drawing on lessons from the natural world, where cells often use molecules to communicate, may provide a solution.

There is a growing and diverse research community investigating molecular communication – using molecules to transmit information from one point to another. “For example, biologists have made progress towards identifying properties of bacteria to propel information,” says Justin. “Engineers, on the other hand, have focused on how to encode information in chemical and biological systems, through variations in molecule concentrations.”

However, there are good reasons why we have tended to use electrical communication rather than molecular communication within the machines and infrastructure we build. “Most molecular communication systems operate very slowly through diffusion – think about tea diffusing in cold water,” says Justin. “Even when we speed the process up (such as by stirring the tea), the system remains limited by the laws of fluid dynamics.” Making such a

system responsive to rapid changes in inputs is a key challenge.

Justin's lab is working to solve this problem. "In our lab, we are working on a specific kind of molecular communication that utilises electric fields to propel information-carrying molecules to different parts of the system." Electric fields react very quickly, so by using them to induce molecular motion, it should be possible to build rapid and responsive communication systems. Justin compares these systems to a simple electrical circuit, comprising a battery, a conductive wire and a lightbulb. "In our case, the battery creates a strong electric field, and instead of a wire, we have a liquid confined in a tube," he says. "Instead of electrons, we have molecules that carry information to the lightbulb."

"We don't know exactly what impact this research will have, but we do have some ideas," says Justin. "There has been a lot of work on nano devices in recent years, which our research could potentially improve." These devices have implications for all sorts of fields, such as drug development and environmental monitoring. "Most of these devices are currently limited by fluid physics," says Justin. "We hope our research will help improve their performance, making them more usable for real-world applications."

GRAPH COMPRESSION

There is a huge amount of data in the modern world – so much, in fact, it can be difficult to know what to do with it. "Whether we like it or not, our lives are underpinned and driven by data these days," says Justin. "Most data, and most physical systems, are connected in some way, just like points on a graph are connected by links between them." Storing, processing, and communicating this data relies upon being able to represent it efficiently – which is where compression comes in. "Compression involves encoding datasets so that fewer resources – bits, in this case – are used," says Justin.

To understand how compression works, think about the first line of this carol: *Jingle bells, jingle bells, jingle all the way*. If we want to 'compress' this into fewer letters, we can represent it as A B, A B, A C D E – where A = jingle, B = bells, and so on. As long as whoever is sent the compressed version knows the code, all the data are still there.

However, this is an extremely straightforward example. "The complexity of the problem is exciting," says Justin. "For instance, if you draw 25 dots on a piece of paper to represent the points in a graph, and then attempt to connect them using every possible combination of links, the number of graphs you could construct is larger than the number of atoms in the known universe." It is possible to use mathematical rules to reduce this complexity to something manageable for basic smartphones or laptops. Justin's team is working on developing a tool for the visual representation of graph compression algorithms. They aim to make such tools more user-friendly for the real world.

VALUE OF INFORMATION

With so much data in the modern world, there needs to be a prioritisation system in place. "We are working on formalising the value of information in networks of sensor devices," says Justin. "This work is based on the field of information theory, which was pioneered by Claude Shannon in the 1940s and forms the basis of all digital communication systems today."

Justin's team uses Shannon's theory alongside properties of probability and statistics to attach a value to data. "Shannon defined a notion of information that is based on how likely an event is to occur," says Justin. For instance, tossing a coin is equally likely to result in heads or tails – this binary 50/50 result forms one 'bit' of information. However, if the coin is weighted towards heads, then an observer who knows this could predict that a heads result is more likely, even



PROFESSOR JUSTIN COON

Head, Information and Network Science Lab, Department of Engineering Science, University of Oxford, UK

FIELD OF RESEARCH

Engineering Science

RESEARCH PROJECT

The Information and Network Science (INS) Lab conducts research on a wide variety of information and communication theories and technologies at many different scales and for a broad array of applications.

eng.ox.ac.uk/information-and-network-science-lab

FUNDERS

Engineering and Physical Sciences Research Council (EPSRC), grant number EP/T02612X/1 (ProTo-Net); John Fell Fund (grant no. 0006235)

without doing the experiment. This means there is less than one bit of information present – the result will 'probably be heads'. A little information is lost here (the possibility of getting tails) but in this model that is deemed less important than the data saved.

Justin illustrates how this valuation plays out in the real world. "Sensors are deployed to measure pollution levels, temperature, traffic and so on," he says. "The information generated at these sensors is communicated to computers where the data is processed, but not all the information is high-value." Justin's team is working on developing ways to quantify which data should be communicated, and when it should take place to avoid outdated data. "This will help computers process and react to information as efficiently as possible, thus improving our

quality of life and perhaps even saving lives,” he says.

NETWORK SECURITY

Tanmayee Deshpabhu is a PhD student in Justin’s lab, whose research investigates how to provide security for future communication networks. “Many future networks will be distributed, which means that, rather than messages and data going through a central hub, devices will instead speak directly with one another,” she says. Distributed networks form the foundation of the ‘Internet of Things’, which involves devices in many aspects of our lives communicating with each other – washing machines and fridges connecting to our smartphones, traffic lights connecting to CCTV cameras, medical databases connecting

to AI diagnosis software, energy sources communicating with the power grid, and so on.

However, the lack of a central hub that can oversee these interactions means that this interconnectedness could be exploited maliciously, putting people at risk. “Recently, I worked on identifying the vulnerable points of direct and unregulated communications in a distributed network,” says Tanmayee. “Understanding the security risks means that our future systems can be designed to avoid them.” She is utilising machine learning to build classification tools, which use information about past attacks to identify patterns that can predict and prevent future attacks. This should allow the individual components of the Internet of

Things to independently carry out their own risk assessments.

One major issue is that attacks are always evolving, becoming more advanced as the technology designed to resist them becomes more sophisticated. “The goal of my research is to work towards a distributed security framework that can stay one step ahead of these attacks,” says Tanmayee. “This is a vital stepping stone to making our everyday lives more connected and instant. For example, we could use these networks to coordinate emergency response vehicles, or dynamically combine renewable energy resources for a stable power network.”

MEET JUSTIN AND TANMAYEE



HEAD OF THE
INFORMATION AND
NETWORK SCIENCE
LAB, DEPARTMENT OF
ENGINEERING SCIENCE,
UNIVERSITY OF OXFORD

PROFESSOR JUSTIN COON

WHAT DID YOU WANT TO BE WHEN YOU WERE YOUNGER?

Many things! My aspirations ranged from becoming a rock ‘n’ roll guitarist to a surgeon.

WHAT INSPIRED YOU TO STUDY ELECTRICAL ENGINEERING?

When I was around 17, I realised that I found mathematics to be beautiful, interesting, and fun to learn. I wanted to study something at university that would lead to a mathematics-heavy career, and electrical engineering presented an opportunity to apply physics and mathematics in an unfamiliar context. I figured that if I was going to spend four years studying a course, I’d like to learn something new!

HOW WAS YOUR TIME WORKING OUTSIDE OF ACADEMIA?

I worked for Toshiba Research Europe Ltd for just under nine years. I started as a research engineer,

developing new communication techniques for use in Wi-Fi and cellular networks. I published and patented my work, and one of my inventions was even adopted into 4G networks. As I became more experienced, I led a group of researchers doing similar things. I really enjoyed working with people and experiencing different cultures during my period with Toshiba.

WHAT IS IT LIKE TO LEAD YOUR OWN LAB?

Keeping on top of the latest developments in the field is tough, especially since I also spend time teaching undergraduate students. However, there are many benefits, since learning new things and speaking to interested students about the topics I am passionate about is always enjoyable.

WHAT DO YOU DO TO RELAX?

I still play guitar – mostly classical these days – and also enjoy gardening, joinery, playing squash, walking in the countryside, and spending time with my family.

JUSTIN’S TOP TIPS

01 Seek ways to learn about the subject at a high level. For example, local chapters of the Institute of Electrical and Electronics Engineers (www.ieee.org), the Institution of Engineering and Technology (www.theiet.org), and the Institute of Mathematics and its Applications (ima.org.uk) often organise public lectures, publish literature, and run courses.

02 Speak to people that work in the field. And, of course, study mathematics and physics!



PHD STUDENT,
INFORMATION AND
NETWORK SCIENCE LAB,
UNIVERSITY OF OXFORD

TANMAYEE DESHPRABHU

WHAT INSPIRED YOU TO WORK WITH DISTRIBUTED NETWORKS?

When I was younger, the idea of the fully automated homes in Dexter's Laboratory or Wallace & Gromit fascinated me. With the advent of 6G for Internet of Things applications, these fantasy ideas might be closer to reality than we think!

HOW DID YOU COME TO WORK AT THE INFORMATION AND NETWORK SCIENCE LAB?

My undergraduate degree was in electrical and electronic engineering, followed by a master's in communication engineering. After my final exams, I saw a listing on a graduate opportunities page about the lab, and once I read about their work, I found it aligned really well with my interests. I never saw myself applying for a PhD unless it was in a field I am passionate about.

WHERE DO YOU SEE YOUR CAREER HEADING?

I have learned many new skills during my PhD that I hope will be applicable for a range of careers, so I'm still exploring my options. The field of communication engineering is hugely diverse in its opportunities, and I would be especially thrilled to work with something related to space research.

HAS WORKING IN A MALE-DOMINATED FIELD EVER POSED AN ISSUE FOR YOU?

Being the gender minority in a group is something

that you get used to over time. The wider community of women in STEM is welcoming and supportive, so it's important to seek out those groups and societies that highlight this community, such as Oxford's Women in Engineering Network. The only time it has felt like an issue is when awards or titles have been unnecessarily hinged on my gender – 'Best girl in engineering', for example. Fortunately, this sort of culture seems to have improved over the past few years, and it's encouraging to see that the ratio of female students in engineering tends to increase with every new cohort. I hope that trend continues.

WHAT OTHER ENGINEERING-RELATED ACTIVITIES DO YOU TAKE PART IN?

I am a member of Oxford University Racing's marketing and sponsorship team. Car racing is really cool, especially from an engineering perspective. We are working on building an electric race car for an international competition, and there's a huge sense of teamwork and collaboration – within the team and with other teams across the world. Being on the marketing team helps me to connect my engineering background with my graphic design hobby by producing creative content that engages the public. As part of this, I recently set up a collaboration with a local charity called University Education, which supports students from non-selective state schools in applying for top universities.

TANMAYEE'S TOP TIPS

- Ask questions and reach out to people for guidance, even when it feels like you should already know the answer.
- Don't be afraid to apply for opportunities, even if they seem out of reach.
- Get involved in societies and student organisations, both related to your work and your hobbies. These are fun ways to network and build lateral skills.

BOOSTING CYBERSECURITY FOR THE FUTURE

DR THEODORE (TED) ALLEN IS A MATHEMATICIAN AND COMPUTER SCIENTIST BASED AT THE OHIO STATE UNIVERSITY IN THE USA. HE IS DEVELOPING A FRAMEWORK FOR CYBERSECURITY AND COMPUTER INSPECTIONS TO ENSURE THERE ARE NO BUGS IN COMPUTERS AND THAT ANY POTENTIAL VULNERABILITIES ARE IDENTIFIED

TALK LIKE A COMPUTER SCIENTIST

BUG – an error in a computer software/program

CURVE FITTING – using a mathematical function to construct a curve that fits a series of data points

CYBER-ATTACK – an attempt to damage a computer system or network

CYBERSECURITY – the protection of computer systems

HACK – to gain access to a computer system without permission (as part of a cyber-attack)

OPEN-SOURCE – information that is freely available for anyone to access and use

SEMI-AUTOMATIC PRIORITISATION SYSTEM – a computer system that can prioritise potential vulnerabilities with minimal human input

INTERNET OF THINGS – the billions of physical devices around the world that are connected to the internet

VULNERABILITY – a weakness on a computing system that has the potential to cause a problem. Some may only cause minor inconvenience, while a super-critical vulnerability may cause serious damage

With ongoing developments in computers, software and technology, as well as the rise of the Internet of Things, it is hardly surprising that cybersecurity is becoming increasingly important. Indeed, there are people around the world who work tirelessly to infiltrate computer systems in order to steal information.

Dr Theodore (Ted) Allen is a mathematician and computer scientist based in the Integrated Systems Engineering Department and the Industrial & Systems Engineering Program at The Ohio State University. Fortunately, researchers

like Ted, are working to protect our computers from cyber-attacks by developing frameworks for cybersecurity and computer inspections. Such frameworks ensure there are no bugs in computers and that any potential vulnerabilities can be identified and addressed before the security of any given system is compromised.

QUALITY ASSURANCE AND INSPECTION Computers and computing services must conform to what people expect and need. To ensure this is the case, computers constantly conduct auto-inspections, which are always

running in the background of any computer system. These inspections will look for parts of software that are not conforming to the expected standards and alert the user to them.

However, assuring quality at the same time as conforming to expectations is extremely expensive. Inspecting every attribute on a computing system would be impossible. Instead, mathematical approaches have been developed so that only a few attributes need to be inspected and educated guesses can be made about the rest.



DR THEODORE ALLEN

Associate Professor of Integrated Systems Engineering and Computer Science and Engineering, The Ohio State University, USA

FIELDS OF RESEARCH

Integrated Systems Engineering, Artificial Intelligence

RESEARCH PROJECT

Developing a framework for cybersecurity and computer inspections to ensure there are no bugs in computers and that any potential vulnerabilities are identified

FUNDER

National Science Foundation (NSF)

SMART INSPECTION METHODS

Ted's work is primarily concerned with developing smart inspection methods that achieve desired outcomes without costing too much or being too time-consuming. These methods can then be adapted to cybersecurity. As it is too expensive to inspect whether 100% of items on a computer conform to expected standards, and it is too risky to inspect 0%, as vulnerabilities will not be detected, Ted uses a smart inspection strategy called 'single acceptance sampling'. He only inspects a small proportion of the total attributes on a computer, rather than testing them all. If only a small number (below a set threshold) of inspected attributes fail the tests, it is assumed that all attributes on the computer are acceptable. However, if too many of the tested items do not conform to standard, then the computer does not pass the inspection, and every attribute must be individually tested.

"To test the usefulness of our methods, we try to get organisations to use our approaches and then estimate practical benefits like cost savings and intrusions avoided," explains Ted. "We can also simulate the processes to see if they will work in realistic virtual worlds."

PROBABILISTIC MODELLING

The number of devices connected to the internet is expected to double within the next four years and will soon reach 10 billion. "Each of these 10 billion devices could have up to 1,000 vulnerabilities," explains Ted. The devices can be in various states of compromise and if each vulnerability requires a unique test, regularly inspecting all these devices for vulnerabilities, even approximately, is an immense challenge. Worse, a device may have a vulnerability that no

one knows how to detect. "An innovative idea in simulation that we are experimenting with is using curve fitting, or 'modelling', to predict which vulnerabilities are on devices based on cleverly picked samples using a variety of inspection methods," says Ted. "We call this 'multiple-fidelity' acceptance sampling because each type of inspection has a different level of trustworthiness, or fidelity."

One great property of the cybersecurity domain is the immense amount of data available, such as session log data and user authentication data. "When you look at the data, it often feels immense and random. Yet, when you fit curves and use statistical techniques, you can begin to see what is going on," explains Ted, highlighting how mathematical skills are essential in the field of computing.

PROTECTING COMPUTERS WHILE SAVING MONEY

One of the key focuses of Ted's work is developing a semi-automatic prioritisation system to deal with cyber threats. Some of these involve sophisticated learning models, such as reinforcement learning, in which computer programs adaptively improve by inspecting and fixing bugs in certain situations. These modelling efforts can sometimes provide helpful insights, including how to save money and even lives. "Five years ago, our models indicated that it was possible to save a lot of money in cybersecurity. This has now happened in many places," says Ted. "People implemented restrictions on who can install software, which we predicted would help. These restrictions did indeed help save money."

Ted and the team have also developed software

that 'scrapes' data from many open-source databases, including Twitter. Open-Source Intelligence (OSINT) involves collecting and analysing open-source data. This is a valuable method of generating information about computer vulnerabilities, allowing Ted to learn from data available on the internet. "Our automatic OSINT creates models to predict which vulnerabilities are super-critical and will be attacked by hackers. Combining this information with local inspection data, we can create alerts that certain devices desperately need to be turned on, scanned and patched, or hidden from the internet," explains Ted.

WHAT NEXT?

So far, Ted and his team have discovered the importance of super-critical vulnerabilities and have developed a special modelling system to detect them. "We are trying to combine this system with economic modelling methods to save money at our university," says Ted. "There are clearly some worries about taking risks and so getting management onboard is a challenge. Yet, we are getting better and better and our case for enacting these changes is getting stronger." Hopefully, the cybersecurity systems that Ted is designing will help to save money while also protecting computers from cyber threats.

ABOUT CYBERSECURITY

Cybersecurity has become something of a buzzword in recent times. The unfortunate truth is that many of us do not pay much attention to cybersecurity until it is too late and our devices or accounts have been hacked. While losing access to our social media accounts can be extremely upsetting, for some organisations, being hacked can lead to the loss of extremely valuable intellectual property or can result in private data being exposed.

HOW CAN WE PROTECT OUR COMPUTERS?

There are many important steps to consider, but the good news is that most of them are simple and straightforward. Ted recommends the following:

- Use strong passwords that are long and very hard to guess
- Use two-factor authentication (which is a password plus a call or message to your phone

to confirm it is you logging on)

- Avoid downloading files or clicking on links from disreputable or unknown sources
- Where possible, avoid email attachments and use drop boxes like Google Drive
- Do not give personal information to those requesting it on the internet unless you initiate the process and, even then, be careful
- Consider using antivirus and endpoint security

WHAT DOES TED ENJOY MOST ABOUT HIS JOB?

Mathematics can help almost any type of person in almost any type of job and given that Ted is massively interested in maths, his job is perfect for him in many ways! “On one day, I might help a manufacturer make more products with lower cost, then help a pipeline inspection company avoid oil spills, then help election

officials reduce voting queues, and then support improved battlespace communications using drone swarms,” explains Ted. “Mathematics can be overwhelming, yes, but it is also beautiful. You can see patterns in our world and feel a type of deep connection with people and things.”

WHAT SKILLS ARE NEEDED BY THOSE WORKING IN CYBERSECURITY?

Ted works in cybersecurity analytics, but this is just one of many areas of study in the field. “The truth is that some of the biggest contributors in cybersecurity study management, others study political science, and some are even psychologists,” says Ted. “Of course, hardcore computer science, operations research and artificial intelligence are critical. Yet, policy and procedures and leadership are arguably even more critical.” Ultimately, Ted says that those interested in pursuing a career in the field really just need a thirst for learning and compassion – inspiration and wisdom can come from anywhere!

EXPLORE A CAREER IN CYBERSECURITY

- Ted recommends building computing skills by taking courses through providers such as Coursera (www.coursera.org) or the Ohio Cyber Range (www.ohiocyberrangeinstitute.org).
- Explore organisations such as the International Information Systems Security Association (www.issa.org) or the Chartered Institute of Information Security (www.ciisec.org) to learn what those working in cybersecurity are doing.
- Prospects provides a job profile for a cybersecurity analyst: www.prospects.ac.uk/job-profiles/cyber-security-analyst
- According to www.talent.com, the starting salary for those working in cybersecurity is \$87,500, which will increase with experience.

TED'S TOP TIPS

- 01** My accomplishments have been modest considering how lucky I have been with my parents, education and citizenship. Yet, what accomplishments that I have come mainly from trying hard. I highly recommend everyone puts effort in. You really do get out what you put in.
- 02** Curiosity has long been my strength and I am happiest and at my best when I am learning or explaining things that I understand well. If people are curious and interested in finding answers, a large part of the work is already done.
- 03** Learning mathematics takes time to understand for everyone, but related subjects will also help you learn. For example, if you study physics, you will learn differential equations and probability theory for free!

PATHWAY FROM SCHOOL TO CYBERSECURITY

- At school, study computing or information technology to learn computing and coding skills. It will also be very useful to study maths.
- Many universities offer degrees in computer science or informatics, where you will be able to take modules in cybersecurity. A degree in maths will also enable you to enter the field of cybersecurity.
- If you are interested in pursuing a career in cybersecurity, Ted highlights that you can get certification in cybersecurity, regardless of your degree subject. “Cybersecurity relates to digital pollution,” says Ted. “Like regular pollution, we all have a stake and can all contribute.”



HOW DID TED BECOME A COMPUTER SCIENTIST?

WHAT WERE YOUR INTERESTS WHEN YOU WERE YOUNGER? HAVE YOU ALWAYS BEEN INTERESTED IN COMPUTERS?

No! When I was in high school, computers were only just entering schools. I first thought they were for non-athletes or ‘computer jocks’. I thought I was an athlete and I was too unwise to see how important computers would become. Oops!

WHO OR WHAT INSPIRED YOU TO BECOME A COMPUTER SCIENTIST?

I draw immense inspiration from the great Sir Ronald Fisher, who invented a lot of what we now call ‘statistical science’. His contributions helped the world increase food production six-fold. By varying many aspects of production at one time, and with careful curve fitting, nature reveals itself efficiently. In my mind, Fisher was more important than any US president (except, possibly, Washington and Lincoln). We owe a lot of our prosperity to the techniques in mathematics that he invented.

WHERE ELSE HAVE YOU APPLIED MATHEMATICS TO SOLVE REAL-WORLD PROBLEMS?

Through my own experiences working with companies, I have seen many magical benefits

from applying mathematics and computer science. For example, I am part of a team that is saving the delivery company DHL \$160M by improving the routing of their delivery vehicles. We are saving thousands of kilotons of CO₂ every year by reducing driving. A lot of the time, applications of mathematics and computer science are about overcoming our own biases and seeing clearly with the help of computers and models. If we do not see a need to use computers, that is often our own blindness.

AS WELL AS CYBERSECURITY, WHAT ARE YOUR OTHER RESEARCH INTERESTS?

Like many operations researchers and computer scientists, I am interested in designing methods to help people design things. This level of indirection seems weird. Yet, it is true that the process of making decisions is surprisingly important. With this in mind, we are developing innovative approaches to predict the future (Optimal Classification Trees), to schedule jobs in manufacturing (genetic algorithms with active evaluation), to monitor robots and manufacturing cells (special control charts), design the routes for trucks (red-black ant colony searchers), and to allocate resources

such as voting machines (generalised ‘indifference zone’ binary searches). Mathematicians seek out the most important problems and we try to help solve them.

WHAT DO YOU ENJOY DOING IN YOUR FREE TIME?

I love spending time with my family, including playing games. I like cycling and listening to podcasts and audiobooks. I am huge fan of Ezra Klein and Fareed Zacharia. Also, I play Magic the Gathering online and sometimes in person. It is expensive and addictive, but I like it!



Ted cycling with his family

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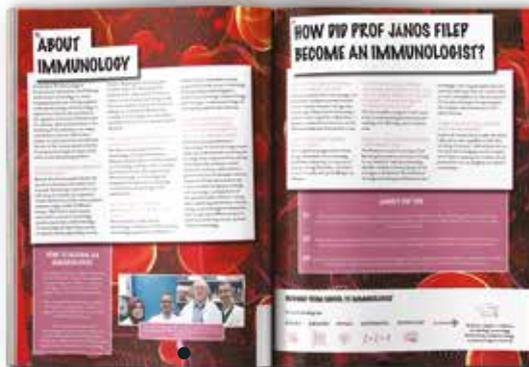


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For example, János wasn't massively interested in biology when he was younger. He is now an immunologist!

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