# futurum

**Inspiring the** next generation

**ISSUE 19**
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## MIA LANDSEM

An ethical hacker, Mia talks about her unintended career path to fame

## NESTA

Dr Rachel Wilcock explains how data science can be a powerful tool for social good

## ORANGE CYBERDEFENSE

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# ISSUE 19
## Ethical hacking

WELCOME

With no set plan other than wanting to continue living in Oslo and look after her puppy, Mia Landsem (p. 4) left home, took on a student loan and followed her heart. Starting her career in IT support, she was also busy outside of work, channelling her own experience of digital image-based sexual abuse into online security awareness activism. Fast-forward to her current role at Orange Cyberdefense, and Mia is now an ethical hacker, paid to test an organisation's cybersecurity. An inspirational role model, Mia reminds us that having a rigid plan for success is not essential – motivation, commitment and a desire to make a difference can supplant methodical planning.

Sharing Mia's passion for cybersecurity are Orange Cyberdefense's Catherine Boddy and Zoe Grist (p. 76). As Head of the Vulnerability Operations Centre (VOC) for the UK and South Africa, Catherine believes there is no reason for tech to remain an industry dominated by men, and that women should be ambitious about the roles they want – and can – play in it. Zoe currently manages all aspects of the organisation's UK Security Operations Centre, heading up a team of technical engineers and loving her role in an industry that is evolving constantly.

While being safe online is important, so too is our ability to make the most of the incredible amount of data now available to us. Data scientists use their skills to reveal patterns in data, to identify and help solve the many challenges facing our society. Data Science Lead at Nesta, Dr Rachel Wilcock (p. 44) tells us about the job she revels in and how data science can be used for innovative social good.

These brilliant women – and the great range of researchers featured in issue 19 of Futurum – highlight the joy and satisfaction people get from careers that contribute to a healthy, happy and productive society. They also demonstrate that there are opportunities for progression everywhere, even without a set plan. Put your preconceived ideas aside for a moment and explore...


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### CONTACT

+44 117 9099150
info@futurumcareers.com
www.futurumcareers.com


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# CONTENTS

## **Research** articles




# **Research** articles



# INTERVIEWS




**COVER STORY**
**Mia Landsem**
**04**

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# MIA LANDSEM

> “You’re not dumb for owning your sexuality or trusting someone you love.”

A public speaker, author and ethical hacker for Orange Cyberdefense, **Mia Landsem** tells us about her unintended career path to fame. She also shares her experience with digital image-based sexual abuse and explains why she is helping other victims of this growing crime to fight for justice.

## What is an ethical hacker?

Basically, it’s legal hacking. When people hear the word ‘hacking’, they assume it’s illegal, but we’re paid to hack companies. We’re actually an important part of cybersecurity, for new computer systems, web applications, endpoints, or anything that involves personal information online. We test for security weaknesses – anything the bad guys will be looking for – then, we write a report and suggest system changes that need to be made.

Ethical hackers, which are also known as penetration testers or pentesters, are different to hacktivists, but I’m not a hacktivist. I don’t do illegal hacking.

© Daniel Cristino

## What do you love about your job at Orange Cyberdefense?

When I started working at Orange Cyberdefense, which launched in Norway three years ago after acquiring SecureLink, I was the third member on the ethical hacking team. Now, there are 12 of us, and we’ve grown from 30 employees to 90. It’s fun, even though it’s also a difficult job. I get to break into computer systems and manipulate people to get information – almost like a super-spy!

It might seem like a website or web application security test will be the same every time, but I always see new stuff. And when we get an exciting assignment, we have so much fun talking about it. We’re basically getting paid to do something that’s illegal in other circumstances – and it’s well paid, although that’s not what drives me.

## Why did you start a bachelor’s degree in sports science psychology and coaching?

I was on the Norwegian junior national team in Taekwondo and became a regional and double Nordic champion, winning several medals and prizes in national and international ranking tournaments. The Norwegian School of Sports Sciences had ten spaces for top athletes on its bachelor’s degree in sports science psychology and coaching, and I was one of the athletes selected. I wasn’t really aiming to become a sports coach. My big dream was to go to Oslo, where the national team is based, and aim for the Olympics. I had no thought in my head that I would ever work with IT.

## How did you get into IT?

I love gaming, as well as sport and martial arts. In 2014, I was on a TV show called Gamer, where I talked about how I wanted to use the techniques I use in martial arts to be better at gaming and vice versa. It’s been found that professional gamers have better reaction skills than professional athletes.

At the end of my second year at the Norwegian School of Sports Sciences, I hurt my knee and couldn’t walk. It was a very difficult period in my life because I needed surgery, I was on crutches for six months, and I’d gone through a really bad breakup with my then boyfriend and had to find a new place to live. It was also then that I reported a previous ex for digital image-based sexual abuse.

I also had a puppy to look after, Zelda. She’s everything to me, so, I quit school in my third year and started researching distance learning schools so that I could stay at home with her. There was an online school with a campus in Oslo that did a two-year course in network and IT security, which I chose because I didn’t have the maths qualification required to do a bachelor’s degree, and because I could switch to the campus when Zelda was old enough to be alone for several hours.

## How did you become an ethical hacker?

My original plan was to do a bachelor’s in cybersecurity or digital forensics and work for the police. In Norway, you can skip the maths requirement for a bachelor’s degree if you’re 25 or older and have work experience. I was going to be 23 when I finished my network and IT security course, so I thought I’d find an IT support role for two years and then jump onto the bachelor’s degree. But I didn’t really have a solid plan. I was really busy, travelling, doing talks about digital image-based abuse, and I was diagnosed with ADHD.

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The lockdown brought on by the COVID-19 pandemic turned out to be an opportune moment for me. I loved the isolation, and it gave me the headspace to think about what I wanted to do. At one point, I asked people in an IT security group on Facebook if they knew of any jobs I could do with two years' IT experience, and someone recommended ethical hacking.

I'd only done a four-week course in digital forensics and a four-week course in hacking, but I ended up getting interviews with a number of companies. Part of the reason I chose Orange Cyberdefense was because it supports the campaigning I do outside of work.

### Would you say that not having a life plan has worked well for you?

Lots of people ask me how I do the stuff I do and how I knew what to do to get to where I am, but I didn't know what to do. When I moved out of my mum's house, I couldn't even wash my clothes! Stuff just happened. I followed my heart. There was never any big plan. I just needed a student loan to continue living in Oslo and be with my puppy.

### Can you give some examples of the things you say to young people in your talks about internet awareness?

I talk about everything, from online security to identity theft, digital stalking, porn and image abuse. I talk about all the heavy stuff and what young people should do if something bad happens to them. I tell them to talk to professionals.

But I don't just talk to young people. I also talk to parents about how they can discuss online security with their children. Not all parents have grown up with technology in the same way as their children, so there's a lot to learn about parental controls and protecting children when they enter the digital world.

I've also done talks for the police, foster parents, childcare services and women's crisis centres. And I've produced a video for children and adults who use sign language.

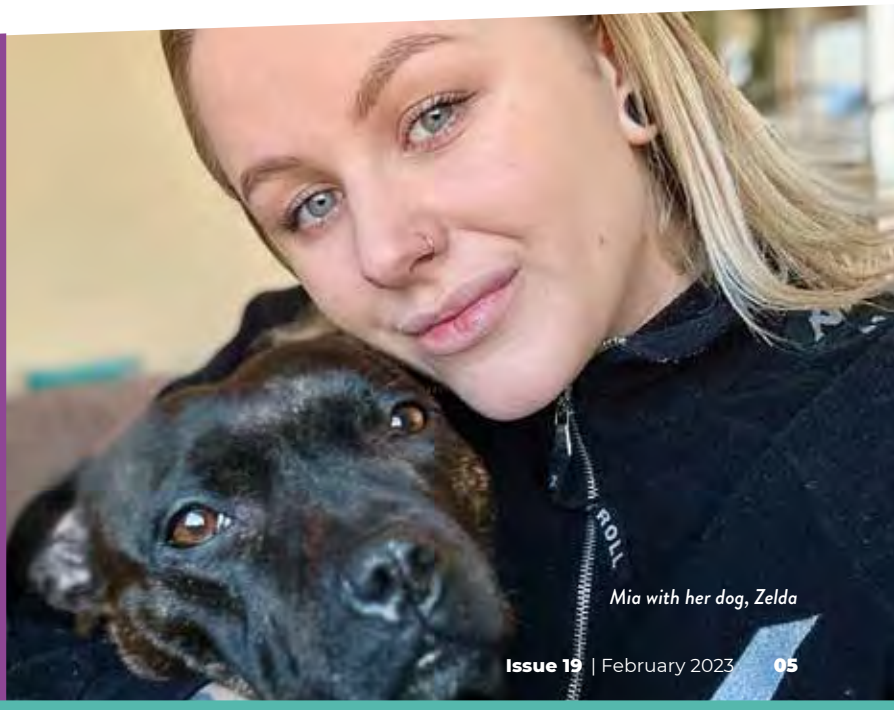
### Where does your passion for these issues come from?

If you asked my first-grade teachers, they would say I don't like unfairness. It's true. I really care about what's right and wrong. I was bullied when I was younger, and I thought it was unfair, so I always used to step in if something bad was happening to someone else. I didn't ask for help when I was having problems. I guess I've become the help I wish I'd asked for, the help I needed but didn't get.

### How did you manage to stay so strong when you had your experience with digital image-based sexual abuse?

The picture of me having sex was taken when I was 17. My boyfriend at the time shared it a couple of months before my 18th birthday, and then it turned up everywhere. It was horrible. I didn't want to live anymore. I didn't ask anyone for help, even though everyone knew about it, apart from the adults, of course.

> **"I GET TO BREAK INTO COMPUTER SYSTEMS AND MANIPULATE PEOPLE TO GET INFORMATION – ALMOST LIKE A SUPER-SPY!"**


Mia with her dog, Zelda

© Orange Cyberdefense

> **“I WAS BULLIED WHEN I WAS YOUNGER, AND I THOUGHT IT WAS UNFAIR, SO I ALWAYS USED TO STEP IN IF SOMETHING BAD WAS HAPPENING TO SOMEONE ELSE.”**

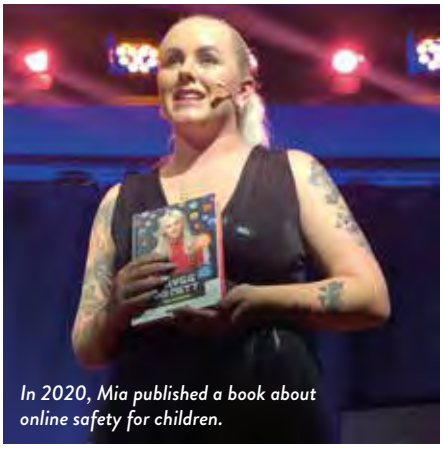
I actually have no idea how I survived. I became really anxious and depressed, but I don't really remember much from that time. I was helping people before my picture got out, so I already knew about the forums and websites where images are shared without consent. And then it happened to me. I found my own picture on one of those forums. My ex had sent it to a friend of mine who sent it to two others, and then it ended up being shared among the gaming community.

### How common is digital image-based sexual abuse?

Very common. People aren't scared to do it and it's horrible. I don't understand why they're doing it. It used to only happen to celebrities but now it's happening to everyone.

### Is it partly that teenagers do not understand the consequences of what they are doing when they share an image like this?

If this was six years ago, I'd believe that, but most teenagers in Norway know who I am and what I do. I've done 500 talks in schools. I've been on TV. We talk about this. It's in the schoolbooks now.



*In 2020, Mia published a book about online safety for children.*

> ***"WE HAVE TO SHIFT THE BLAME AWAY FROM THE VICTIM. THE PROBLEM IS ALWAYS THE ABUSER, NOT THE VICTIM."***

'I didn't know' isn't an excuse. People are hiding their IP addresses and using false accounts and names. Why would they hide that information if they didn't know what they're doing is wrong?

### How much support is there for victims of image-based abuse?

None. It's non-existent. The police might look at your case but most of the time they close it after about six months because they don't have the resources to prioritise it. It's really sad.

### What advice do you have for young people who become victims?

Talk to someone, get as much evidence as you can and file a report with the police. Even though a lot of cases get thrown out, if other people start to report abuse from the same person, then it will be taken seriously. It also gives us an indication of the number of people reporting this type of abuse.

People always think they're so dumb for letting this happen and don't want to tell anyone, or for me to tell anyone. You're not dumb for owning your sexuality and you're not dumb for trusting someone you love. The one who is dumb and to blame is the abuser.

### What can we as individuals do to help?

We have to shift the blame away from the victim. The problem is always the abuser, not the victim. Lots of people say that the victim shouldn't have allowed their photo to be taken. You can see comments like that on social media. When abusers hear comments like that, it justifies their actions – "it's their fault, not mine ".

*Mia's dog Zelda.*

I often say to parents that even if you tell your kid to not let their boyfriend or girlfriend take pictures of them naked, they're going to do it anyway. And if you're one of those parents commenting on Facebook about how people shouldn't let this happen to them, and your kids see it, you're going to be the last person they come to for help.

What you can do is explain what might happen if a picture gets taken, then they'll start thinking for themselves and might not want to take the risk. But if they do, and something happens, you want to be there to support them, not tell them they shouldn't have done it in the first place.

## **Connect** with Mia

As well as working as an ethical hacker/pentester for Orange Cyberdefense, Mia speaks publicly about the dangers of the internet and how to keep safe. In 2020, she published a book about online safety for children, and in 2021, she was shortlisted for the Cybersecurity Woman of the Year award. Mia's work on digital image-based sexual abuse has also earned her a number of awards.

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CONNECT

## **About** image-based sexual abuse

Image-based sexual abuse happens when someone shares sexually explicit images or videos of another person without their consent. Often, the aim is to cause that person distress or harm. Sometimes referred to as 'revenge porn', image-based sexual abuse is a criminal offence.

As Mia says, if you have experienced image-based sexual abuse it is important to remember that you are not to blame. Talk to people you trust and report the crime to the police.

For support and more information, visit:
www.victimsupport.org.uk/crime-info/types-crime/cyber-crime/image-based-sexual-abuse

# How can people train their brains to manage depression?

Major Depressive Disorder, also known as clinical depression, is a leading cause of disability worldwide and is estimated to affect 5% of the global adult population. At the **University of Pittsburgh** in the US, **Dr Kymberly Young** is using neurofeedback to help patients with this disorder control their brain activity and increase their positive emotions.

**Dr Kymberly Young**

Western Psychiatric Institute and Clinic, University of Pittsburgh School of Medicine, USA

PROFILE

**Field of research**
Neuropsychiatry

**Research project**
Developing rtfMRI neurofeedback for patients with major depressive disorder

**Funder**
National Institute of Mental Health (NIMH)

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TALK LIKE A ...

## NEUROPSYCHIATRIST

**Amygdala** — the region of the brain which is associated with processing emotional information

**Biofeedback** — a technique that teaches someone to control some of their body's functions, such as their heart rate

**Deep brain stimulation** — a procedure which sends electrical impulses to specific areas of the brain

**Electroconvulsive Therapy** — a procedure conducted under general anaesthetic where a seizure is generated to cause chemical changes in the brain

**Major depressive disorder** — a psychiatric illness characterised by low mood and difficulty experiencing pleasure

**Neurofeedback** — a technique which teaches individuals how to control their brain functions

**Non-invasive** — a type of medical procedure that does not require inserting any instruments through the skin or into an opening of the body

**Ketamine** — a drug, originally used as an anaesthetic for animals and then people, now used to treat depression

**Real-time** — a type of process where feedback can be given as quickly as an action is occurring

**Treatment resistant patient** — someone who has failed to benefit from at least two antidepressant medications

**Vagus nerve** — a part of the body's nervous system, playing a role in digestion and blood pressure, amongst other functions. Stimulating the vagus nerve with electrical signals stabilises the brain's electrical activity

If for two weeks or more, a person has a continuous low mood, low self-esteem or loses interest in activities they would normally enjoy, they might have major depressive disorder (MDD). Some people might struggle with depression for a few weeks or months during a particularly hard phase of life, but some may struggle with it for years.

Social support, encouragement to change lifestyle patterns, therapy and antidepressant medication are initial treatments for people with MDD, but, unfortunately, these do not work for everyone. "Only half of patients who seek standard interventions will achieve sustained remission," says Dr Kymberly Young, a neuropsychiatrist based at the University of Pittsburgh's Western Psychiatric Institute and Clinic. "The most common psychological therapy, cognitive behavioural therapy, is often not effective in severely ill patients."

If these initial treatments do not work, patients might have treatment-resistant depression. They might then try invasive treatments such as electroconvulsive therapy, vagus nerve stimulation and deep brain stimulation, or be prescribed ketamine – all of which pose significant risks to patients. "While ketamine has shown novel and promising antidepressant effects, it can also cause hallucinations, high blood pressure and confusion," says Kymberly. To devise a safer, effective, non-invasive treatment for MDD, Kymberly turned her attention to a region of the brain called the amygdala.

### What is the amgydala?

The amygdala is located deep within the middle of the brain. "Most people know that the amygdala is involved in the fight or flight response, but it does more than


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that," says Kymberly. "The amygdala is a part of the brain that responds to important information – both positive and negative – and helps guide behaviour in response to this information." People with depression have an amygdala that is over-active to negative stimuli and under-reactive to positive stimuli, and, therefore, it acts differently to the amygdala of a healthy person. "For depressed patients, this means negative things stand out while positive things are not noticed," explains Kymberly.

Kymberly realised that lots of the treatment options currently available for MDD were aimed at controlling negative thoughts, but few tried to increase positive thoughts instead. "By targeting the amygdala, our goal is to make positive memories stand out more and be more useful to individuals."

## How can Kymberly do this?

To see the activity of a specific area of the brain like the amygdala, Kymberly uses functional magnetic resonance imaging (fMRI) neurofeedback. fMRI is based on the same technology as magnetic resonance imaging (MRI) but there are crucial differences between the two. While MRI machines are scanning tools that produce images of the body and allow doctors to make sure everything is in the right place, an fMRI takes images of a brain's activity while it is performing a specific function.

More specifically, Kymberly uses a technique called rtfMRI which stands for real-time functional MRI. "This is a technique that allows data to be processed as quickly as it is acquired," says Kymberly. This means a patient getting rtfMRI can effectively 'see' their thoughts and witness the activity of their brain as it is happening.

## How does an fMRI machine detect activity?

fMRI works by measuring tiny changes in oxygen levels in the blood (blood-oxygen) in an active part of the brain. "The more active a certain brain area is, the more blood-oxygen it uses. This is an indirect measure of neural activity," says Kymberly.

Before her patients enter the fMRI scanner, Kymberly works with them to come up with a few positive memories they will need to think about while they are in the machine. Positive memories are often quite difficult for patients with MDD to come up with, especially as they might struggle with low self-esteem. For example, a depressed patient who has what should be a positive memory of their graduation day might still have a negative association with this memory if they felt they had not made the most of their education since.

Once her patients have decided upon a few positive memories, they enter the fMRI machine, and Kymberly asks them to recall these memories to themselves (they cannot speak while in the scanner as the images will be blurry). The fMRI machine measures the activity in the amygdala, which allows Kymberly and the patient to see what is happening in their brain when they are thinking about a positive emotion.

"By focusing on the important and particularly positive aspects of their memory, their amygdala response will increase," explains Kymberly. This procedure lets patients know what it feels like when their amygdala is active and engaging with positive emotions, so that they can work on making this happen more often.

"Neurofeedback allows people to see how active certain parts of their brain are in real-time with the goal of teaching them to control it," explains Kymberly. By presenting her patients with immediate feedback on their brain activity, they can be trained, over time, to learn to control that activity and increase their positive emotions.

## Why is the fMRI machine necessary?

Using the fMRI machine to engage the amygdala of a patient is essential to Kymberly's treatment. "Simply asking patients with depression to recall positive memories actually makes them more depressed," says Kymberly. "For patients with MDD, their amygdala is not active when they engage with positive stimuli, and this may be one of the reasons they experience depression. We think the key is recalling positive memories while bringing the right brain regions online for the patients to see."

> ***"NEUROFEEDBACK ALLOWS PEOPLE TO SEE HOW ACTIVE CERTAIN PARTS OF THEIR BRAIN ARE IN REAL-TIME WITH THE GOAL OF TEACHING THEM TO CONTROL IT."***

## What setbacks has Kymberly encountered?

One of the issues Kymberly has had to work against is negative feedback and disbelief from other scientists. "At my very first presentation of this research, someone came up to me and said, 'Oh this is just Peter Pan. Think happy memories and you'll fly.'"

However, Kymberly has stayed motivated and has even come to embrace this metaphor. "In Peter Pan, if you think happy thoughts and jump out the window, you will fall. It is only when you have been sprinkled with pixie dust that you are able to fly. As I said, if you just ask patients with depression to recall positive memories, they will feel worse. It is recalling positive memories while engaging the amygdala that allows people to benefit from their memories," explains Kymberly. "Amygdala neurofeedback is the pixie dust for the brain."

## Where might this research go next?

Kymberly's next steps are to conduct large scale clinical trials where she can compare neurofeedback to other available treatments such as antidepressants, psychotherapy and ketamine. "We want to show how well this intervention works relative to other treatments and determine which patients this might work best for," she says.

# ABOUT *NEUROPSYCHIATRY*

According to the American Psychiatric Association, psychiatry is "the branch of medicine focused on the diagnosis, treatment and prevention of mental, emotional and behavioural disorders". Approximately one in twenty adults in the world will struggle with depression in their lifetime, and one in five adults in the US will experience some form of mental disorder. As a result, choosing to work in psychiatry can allow you to make significant improvements to people's lives, whether by helping deliver current treatments or by paving the way to new, ground-breaking techniques.

Neuropsychiatry is a sub-discipline of psychiatry that focuses on the role of the brain in the onset and recovery from psychiatric disorders.

Many people confuse psychiatrists with psychologists, but these are quite different professions. Psychiatrists are medical professionals who can prescribe medication and deliver a range of therapies for complex mental disorders, while psychologists provide psychotherapy (therapy based on talking) and do not have to be medical doctors.

### What does Kymberly find rewarding about working in psychiatry?

"We are actually using what we've learned from decades of neuroimaging research into the causes of depression to develop a new treatment. My research has the potential to change people's lives for the better, and that is incredibly rewarding."

### What research opportunities will be open to the next generation of psychiatrists?

"The field is moving towards more personalised treatment approaches," says Kymberly. "Rather than a one-size-fits all approach to treatment, in the future we will look at the characteristics of individuals to determine what treatment will work best for them. This includes neural characteristics, or selecting a treatment based on how their individual brain functions."

## Pathway from school to *neuropsychiatry*

- To become a psychiatrist, you will need to study a degree in medicine before going on to do specialised training. In the US, this means you will do an additional four years of training in psychiatry after your medical degree.
- To work in any career in neuropsychiatry, Kymberly recommends gaining a solid background in both psychology and neuroscience. "Courses in statistics and computer programming are also very helpful," she adds.
- Get involved with research as early as you can. "Use the connections your mentors and teachers have made to connect with individuals doing work that excites you. The Society for Biological Psychiatry (**sobp.org**) is an excellent resource for those wishing to pursue a career in neuropsychiatry," says Kymberly.
- The University of Pittsburgh offers numerous research training opportunities for undergraduate students (**psychiatry.pitt.edu/educationtraining/research-training/undergraduate-graduate-student-training**). As well as this, the university's Summer Premedical Academic Enrichment Program is open to under-represented minority college undergraduates who want to pursue careers in medicine: **explorehealthcareers.org/enrichment/summer-premedical-academic-enrichment-program-spaep**

## Explore careers in *neuropsychiatry*

- The American Psychiatric Association has information on choosing a career in psychiatry and what psychiatry involves: **www.psychiatry.org/residents-medical-students/medical-students/choosing-a-career-in-psychiatry** and **www.psychiatry.org/patients-families/what-is-psychiatry**
- According to U.S. Bureau of Labour statistics, the average annual salary for a psychiatrist in the USA is $240,000. This is the highest mean wage of all mental health occupations.
- The National Institute for Mental Health (NIMH) has lots of resources and interesting articles about what is happening in the world of psychiatry: **www.nimh.nih.gov**

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# Q&A

## Meet Kymberly

### Who or what inspired you to become a scientist?

I went to college thinking I was going to be a lawyer. In my sophomore year, I took an elective called "The Pathological Brain". I fell in love with neuroscience and never looked back. I had an amazing professor at Dickinson College named Dr Anthony Rauhut. He made the brain something interesting to study and easy to understand. Dr Rauhut was incredibly supportive. He helped me fine-tune my ideas into testable hypotheses and encouraged me to pursue what fascinated me about the brain. I would likely be a lawyer today if I hadn't stumbled into his class!

In addition, my postdoctoral mentor Dr Jerzy Bodurka shaped me as a scientist. His dedication to pushing the limits of technology, and his warm and inclusive leadership style made me into the careful and compassionate scientist I am today.

### What is the biggest factor that has helped you succeed?

Other people! You can't succeed as a scientist working in isolation. There are so many things you have to be good at: neuroscience, psychology, computer programming, statistics, biology, electrophysiology, physics, creative thinking, writing and public speaking. You can't do it all! Working with people who can help you in the areas you are weakest in enables you to build a strong and successful research programme.

> "I FELL IN LOVE WITH NEUROSCIENCE AND NEVER LOOKED BACK."

### What is the worst piece of advice you have been given?

To act more like a man and not show emotions! Not only was this extremely sexist advice (given by a man), it was also impractical and harmful. Allowing people to see you as a human who reacts to successes and failures, just like any other human, strengthens relationships and promotes good collaborations. When you don't show any emotions, people become distant and afraid of you. I unlearned this advice by working with inspiring mentors who were open in showing their emotions and having honest reactions.

### What are your proudest career achievements so far?

When I was a postdoctoral scientist, I was awarded the National Institutes of Health's Pathway to Independence K99/R00 award. This is an incredibly difficult grant to get, and only the strongest applicants who the NIH believes will be successful at changing the world are awarded it. Getting my first randomised clinical trial of neurofeedback published in the *American Journal of Psychiatry* was also a very proud moment for me.

More recently, I served as the chair of the programme committee for the Real-time Functional Imaging and Neurofeedback (rtFIN) conference. I was so proud of how well that conference turned out – both in terms of scientific content and for the chance to interact with other leaders in the field.

### What are your ambitions for the future?

I really want to make amygdala neurofeedback available as a treatment option for patients with depression. Translating scientific findings into clinical practice is challenging, but I am determined to work with doctors, patients, insurance companies and communities to make this a widely available intervention for patients with MDD.

## **Kymberly's** *top tips*

1. Be passionate. One thing I didn't learn until I was a graduate student is that, in research, you fail more often than you succeed. When you get a paper or grant rejection, don't give up. Being passionate about what you do is critical. If you aren't invested in your work, it's much harder to accept these rejections and try again.

2. Be persistent. Incorporate feedback from rejections to make your project stronger.

# The human story behind human genome sequencing

In 2008, **Professor James Lupski,** from **Baylor College of Medicine,** USA, contributed to the scientific work behind the first human whole genome sequencing. Two years later, he was one of the first people to have his own genome sequenced. He is considered a pioneer of clinical genomics, a field that has revolutionised the diagnosis, understanding, clinical management and treatment of genetic conditions and diseases, including James's own.

**Professor James Lupski**

Baylor College of Medicine & Texas Children's Hospital, Houston, Texas, USA

PROFILE

**Field of research**
Clinical Genomics

**Research highlights**
James is a pioneer in the field of clinical genomics – he contributed to the first personal genome sequencing efforts and was then one of the first people to have their genome sequenced

**Funders**
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TALK LIKE A ...

## CLINICAL GENOMICIST

**Autosomal recessive inheritance** — when an individual receives two mutated versions of a gene, one from each biological parent

**Chromosome** — the structure containing DNA in a cell's nucleus

**Chronic disease** — a long-term health condition

**Diploid** — the presence of two sets of chromosomes, one supplied by each biological parent

**Haploid** — the presence of only one set of chromosomes in sex cells

**Recombination** — the process by which pieces of DNA are broken and recombined, creating new combinations of genetic information

Hidden in the nuclei of your cells, DNA molecules lie tightly coiled, harbouring the genetic secrets that make you who you are. Thanks to advancements in clinical genomics, it is now possible to unravel your DNA's code, allowing scientists to better understand and treat genetic conditions.

### What is a genome?

Every living thing has a genome, and every genome is unique. "A genome is the complete set of DNA in each cell of an organism," explains Professor James Lupski, a clinical genomicist at Baylor College of Medicine. This DNA is composed of two complementary strands that twist around each other, forming a double-helix structure, linked like steps in a ladder by pairs of molecules called bases. The size of a genome can be measured by the total number of base pairs (bp) present in an organism's DNA.

The size of a genome varies dramatically between species and is not proportional to the size of the organism. For example, horses have 2.7 billion bp in their genome, whereas tiny desert locusts have around 8.8 billion bp. One of the largest recorded genomes belongs to *Polychaos dubium*, a single-celled amoeba, which boasts an impressive 670 billion bp. In comparison, the human genome seems somewhat meagre, containing a modest 3.2 billion bp. But this genome is what sets us apart – it is what makes us human.

Our 3.2 billion bp are split into 23 chromosomes, and two complete chromosomal sets are housed within the nucleus of almost every cell in our body. The exceptions are egg and sperm cells. These sex cells are haploid, meaning they each contain only one set of chromosomes. "During sexual reproduction, both biological parents contribute one set of chromosomes to their child, providing them with a full diploid genome of 46 chromosomes and roughly 6 billion bp of DNA," explains James.

### What causes changes to the genome?

While a child inherits genetic information from both biological parents, the process of recombination during sexual reproduction causes this DNA to get mixed up. This is the main cause of our individuality and results in children having traits (e.g., hair and eye colour) that are a mixture of those of their biological parents.

Alterations to DNA are also caused by mutations. There are three main types of genetic mutation: single nucleotide variation (SNV), in which just one base pair changes; indels, in which small sections of DNA (up to 50 bp) are inserted or deleted; and copy number variants (CNV), which occur when large sections of DNA are lost or gained in the maternally or paternally inherited genome. "CNVs can involve millions of base pairs," says James. When this happens, it causes genomic


rearrangements, mutations that occur when large sections of DNA in the genome are repeated (as they are in CNVs), rearranged or deleted.

## What are the impacts of genetic mutations?

Genetic mutations are the main driver of evolution, allowing individuals to develop new traits that, if useful, are passed on through the generations. However, not all mutations are beneficial. A mutation can change a nucleotide at a given position of the human genome and involve just a single gene, or it can affect large sections of DNA involving multiple genes, such as in genomic rearrangements. Such variations can cause genetic diseases that can severely impact people's lives.

Thanks to the process of genome sequencing, scientists can now study the genomes of individual people in detail. This technique gave rise to the field of clinical genomics, where scientists and medical professionals investigate the genetic causes of diseases, to understand their biological mechanisms at the molecular level.

## What is whole genome sequencing?

Whole genome sequencing (WGS) is the technique to read an individual's entire genome. Scientists start by taking a cell sample, such as blood or skin cells, from the person. DNA is extracted from these cells and cut into short fragments roughly 100 bp long. These fragments are put into a sequencer which determines the order of their base pairings. This process produces millions of sequenced fragments that are then stitched together by a powerful computer program and compared to the haploid reference human genome (HRHG).

The HRHG is a composite genome created by scientists from the genomes of multiple individuals. It is used as the standard reference against which researchers compare genomes of people being sequenced to study their unique individual variation. This comparison allows geneticists to determine which genetic mutations are present in the person and helps them understand how mutations might affect gene function and contribute to disease. WGS allows individuals to understand how their genetics might impact their health.

## What are the challenges of personal genome sequencing?

"Ethical considerations are always at the forefront of research involving human subjects," says James. "Potential benefits must outweigh the risks, and the research participants must provide informed consent before their genome is sampled and sequenced."

From a technical perspective, sequencing all 6 billion bp in a human genome is an incredibly complex task. Moreover, analysing the data produced and comparing them to the HRHG requires monumental amounts of computing power. The databases produced by some genomic research projects contain thousands of trillions of base pairs. Analysing these 'big data' sets and drawing conclusions about the potential health consequences of an individual's genome is a daunting task. Without recent advancements in computational science and big data analyses, personal genome sequencing would not be possible.

Financially, both the experimental and computational sequencing methods are expensive. At first, this was a significant barrier to genome sequencing. However, as the technique has progressed, the cost of sequencing an individual genome has decreased, and next-generation sequencing is now possible. Additionally, the value of information produced by genome sequencing increases as we learn more about human biology and disease.

## What did the first personal genome sequence show?

In 2008, James contributed to sequencing and analysing the very first personal genome using next-generation technologies, that of Dr James Watson, co-discoverer of the Watson-Crick double-helix structure of DNA. This WGS was a major milestone in the emerging field of clinical genomics, as it established that personal genome sequencing had become a technically and financially viable process.

> **"ETHICAL CONSIDERATIONS ARE ALWAYS AT THE FOREFRONT OF RESEARCH INVOLVING HUMAN SUBJECTS."**

Sequencing Watson's genome and comparing it to the HRHG provided important insights into genomics. One significant discovery was the massive amount of variation between Watson's genome and the HRHG. This shows that, despite humans sharing a large portion of our DNA, we are all truly unique as individuals. This initial sequencing also indicated the HRHG is a robust reference tool for mapping variations in individual genomes, proving it can be relied upon for these kinds of studies.

These original findings, along with the hundreds of thousands of personal genomes sequenced since 2008, have paved the way for personal genomics to be used in clinical settings. By sequencing an individual's genome, medical professionals can diagnose genetic disorders. WGS can be important for medical management in families and can help physicians prescribe the most appropriate treatments.

## Why is clinical genomics important?

"Clinical genomics can tell individuals whether any rare diseases run in their family," explains James. It can also highlight whether a person might be more prone to common conditions such as heart disease or cancer. Understanding the gene variants that cause genetic diseases allows medical professionals to provide personalised treatments to their patients. This means that, in the future, people with genetic conditions will hopefully be able to live healthier lives, thanks to the work of clinical genomicists such as James.

# JAMES'S *GENOMIC STORY*

James played a key part in the first personal whole genome sequencing. As a clinical genomicist, his role was to interpret the variations in Watson's genome and decipher the potential medical implications. After this scientific milestone, researchers wanted to repeat the process for someone with a genetic disease, so James volunteered.

"When I saw what could be done with the Watson personal genome, the opportunity to provide insight into my own disease and a 'real life' clinical situation was readily apparent," says James, who has Charcot-Marie-Tooth disease (CMT), a disorder involving the function of the peripheral nerves. "I volunteered out of pure scientific curiosity, and because I hoped we might discover something to help families suffering with CMT."

### What is CMT?

CMT is a chronic disease that causes peripheral neuropathy, the degradation of nerve cells in the body's extremities, mainly in the hands and feet. CMT can cause foot deformities that can make walking very difficult, as well as muscle wasting, weakness, numbness and tingling in the hands and feet. "From a young age, I had difficulty in finding a pair of shoes that would fit and had trouble walking," says James.

### What did James's genome sequencing uncover?

Before sequencing his genome, James had studied CMT in his lab at Baylor College of Medicine for over twenty years. During this time, he discovered the copy number variant (CNV), known as the CMT1A duplication, responsible for the major form of the disease, as well as several other gene variations that can cause CMT. "But I had never been able to determine the cause of my disease," he says, as none of these variations could have been the cause of CMT in his family (three of his seven siblings also have CMT).

"In my family, CMT appeared to segregate as an autosomal recessive trait," explains James. This means two copies of a mutated gene must be present in an individual for the disease to develop. The causes of CMT that James and others had already discovered did not match with the characteristics of autosomal recessive inheritance.

So, James's genome was sequenced, then analysed by Claudia Gonzaga-Jauregui, one of the graduate students in his lab. She discovered he had a variation in a gene that is important for maintaining peripheral nerve cells, which was consistent with the expected characteristics of recessive inheritance. "I cannot tell you how exciting that moment was!" exclaims James. For the first time, he understood the cause of his family's disease, and his team had shown that personal genome sequencing can pinpoint the genetic causes of a disease.

This breakthrough was reported around the world and ushered in a new era in genomics. As well as being a huge personal triumph, James's team's discovery helped pave the way for personalised medicine to become a reality, potentially helping millions of people and families around the globe living with genetic diseases.

## Pathway from school to *clinical genomics*

- At school and college, biology, chemistry, maths and computer science will give you the foundations of the skills and knowledge needed by clinical genomicists.
- Some universities offer degrees in genomics. Degrees in genetics, medicine, molecular biology and biochemistry could also lead to a career in clinical genomics.
- Volunteering in research labs and finding internships is a great way to get practical, hands-on experience.

## Explore careers in *clinical genomics*

- Discover genetics with the American Society of Human Genetics (**www.ashg.org/discover-genetics**) and find out what careers are available in the field (**www.ashg.org/careers-learning/career-flowchart**)
- The American College of Medical Genetics and Genomics provides information about careers in medical genetics (**www.acmg.net/ACMG/Education/Student/Careers_in_Medical_Genetics.aspx**)

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# Q&A
## Meet James

### What were your interests when you were younger?

As a child, I always liked to take things apart, then put them back together, particularly the neighbour's lawnmower. As a teenager, I enjoyed building and riding small motorcycles, and making fireworks. I taught myself how to make gunpowder and became terribly excited with the explosive results! I was also fond of playing chess, watching football and listening to rock-and-roll music.

### How did CMT impact your teenage years?

I had ten operations during high school and the first few years of college. After each, I spent considerable time in a wheelchair or on crutches while I recovered, so I spent most of high school being home-schooled. I only had tutoring for a couple of hours a day, four days a week, leaving me with plenty of free time to explore my curiosity.

### To what extent did your personal experiences influence your interest in genetics and medicine?

A lot! Living with CMT made me fascinated by genetics and medicine. I vividly recall that the home tutor who taught me biology exposed me to DNA for the first time. I had been trying to understand genetics by thinking about the transmission of CMT with respect to my siblings and me. Now, I could explore it by studying how a real molecule influences the chemistry and biology of a living organism (in this case, me).

> **"HUMAN GENETICS IS THE STUDY OF HUMANS, BY HUMANS. IT HAS BEEN AN INCREDIBLE PRIVILEGE TO BE BOTH THE SUBJECT AND INVESTIGATOR IN CLINICAL GENOMICS RESEARCH EFFORTS."**

*James discusses the results of a western blotting experiment with trainees*

I wanted to go to medical school, so studied chemistry and biology at university. I had always been fascinated with chemistry and learnt to love laboratory studies and the practical work of benchtop empirical science.

### While studying at university, how did you benefit from helping in research laboratories?

In my opinion, this was key; the best way to learn science is by doing science. During my time at New York University, I volunteered in a lab in the medical school. The scientists there were happy to have me clean the dishware. They also taught me how to do real experiments, and I gradually took on more responsibility and fulfilled a technician's role. By my third year of university, I was working in an organic chemistry lab, which was both fascinating and fun. During the summers after my third and fourth years, I participated in an Undergraduate Research Program at Cold Spring Harbor Laboratories on Long Island, New York, where I learnt to do experiments in molecular biology and recombinant DNA research.

### What are your most memorable career moments?

A major highlight was when my lab identified the mutation responsible for CMT – the CMT1A duplication. Also, identifying the gene that causes CMT in my family, through sequencing my own genome, was a huge moment. Human genetics is the study of humans, by humans. It has been an incredible privilege to be both the subject and investigator in clinical genomics research efforts.

## **James's** *top tips*

**1.** Follow your interests, aspirations and dreams!
**2.** Always keep learning.
**3.** Don't be afraid to explore, and enjoy the process.

# How can marine invertebrates help prevent organ transplant rejection?

A major challenge surrounding organ transplants is the body's recognition of the new organ as 'other', which often leads to a dramatic immune response and rejection of the organ. To address this issue, **Dr Fadi Lakkis** of the **University of Pittsburgh** in the US is examining the mechanisms behind this response, using some interesting little invertebrates with their own unique traits to test his theories.

**Dr Fadi Lakkis**

Biomedical Science Tower,
University of Pittsburgh, USA

PROFILE

**Field of research**
Immunology

**Research project**
Studying marine invertebrates and mammals to learn about the genetic and molecular mechanisms behind allorecognition

**Funder**
US National Institutes of Health (NIH)

TALK LIKE AN ...

## IMMUNOLOGIST

**Adaptive immune system** — the part of the immune system that recognises and attacks specific pathogens

**Allorecognition** — the ability of an organism to distinguish its own tissues from those of other organisms

**Cnidarian** — a wide-ranging group of aquatic invertebrates

**Innate immune system** — the part of the immune system that involves non-specific responses to foreign objects

**Invertebrate** — any animal lacking a backbone, comprising 95% of all animal species

When we think of incredible medical achievements that have the potential to make a significant impact on an individual's quality of life, organ transplants are surely near the top of the list. From a person deciding to donate their organs, to a bereaved family making the decision to donate a loved one's organs, transplants represent scientific endeavour and human altruism working in beautiful unison. However, as you would expect of such an incredible medical intervention, the mechanisms behind organ transplants are complex and still pose many unanswered questions.

"The science of organ transplantation is, in many ways, a great success story," says Dr Fadi Lakkis. "However, while patients might do well in the short term, often the body rejects the organ some years later." This is a serious issue, especially for young patients, since it creates a critical need to find replacement organs which are usually in short supply. Understanding why these organs are rejected is essential to preventing this need and, ultimately, to saving lives. Dr Fadi Lakkis is a Distinguished Professor of Surgery at the University of Pittsburgh and specialises in researching why and how transplanted organs are rejected.

In almost all cases, the body's ability to reject foreign material is an extremely useful trait that helps protect us from injury and infection. The human immune system has evolved over millions of years to become extremely good at identifying and addressing anything in the body that should not be there. This is called immune recognition – the distinction between self and non-self. This applies to anything foreign, including material from other members of your species, such as organ transplants, – in which case, it is known as allorecognition.

### The hidden immune system

The science behind allorecognition is far from fully understood and involves a 'secret' branch of the immune system. "An immune system can be divided into two parts," says Fadi. "People are most familiar with the adaptive immune system, made of T cells and B cells which produce antibodies and attack specific pathogens. The other part, the innate immune system, is a bit more hidden."

The innate immune system is more primitive and much more ancient than our adaptive immune system but is also more generalised. "The white blood cells in the innate immune system tend to respond to anything foreign by causing inflammation," says Fadi. "It is this system that triggers organ rejection." But an important question remains – what exactly are these cells sensing that leads to this rejection? If we can

*Hydractinia colony growing over the edge of a slide in the laboratory (© Matt Nicotra, PhD)*

understand what they sense, then we might be able to find clever ways of stopping them sensing this for transplanted organs.

## Lessons from an unlikely source

Allorecognition is found across nature. A tenet of evolution is the preservation and inheritance of genetic material, so rejecting anything that could endanger this genetic material is generally sensible. However, there are cases where this does not fully apply, which present an opportunity to understand the genetics behind allorecognition itself.

Cnidarians are a unique group of marine animals that branched off from our own evolutionary tree about 600 million years ago, before the evolution of backbones or central nervous systems. The group includes animals such as jellyfish, sea anemones, corals and a less known genus called *Hydractinia*, which are the stars of Fadi's research.

"In the wild, *Hydractinia* live in shallow waters, in crowded environments where 'real estate' is in high demand," says Fadi. "*Hydractinia* don't move from place to place but fix to a surface and produce more cells to grow outwards and, ultimately, produce offspring." Inspired by the work of two evolutionary biologists, Leo Buss and Matt Nicotra, Fadi became interested in what happens when two of these animals grow until they are touching one another. The sense of 'self' is more vague in these animals as they have the ability to fuse and swap stem cells, so can find themselves harbouring another organism's genetic material. "The only way for these organisms to protect their space is by rejecting others, via their version of the innate immune system," says Fadi. "However, they can also 'join forces', fusing and sharing stem cells, so we were interested in how they decide whether to reject or accept."

The answer lay in how closely related the two animals were – in other words, how much of their genetic material they shared. Fusing can bring advantages, as bigger animals can produce more offspring and produce them sooner. However, it can also be dangerous, as the stem cells of either animal may overwhelm the other and stop their genes being passed on.

> **"THE SCIENCE OF ORGAN TRANSPLANTATION IS, IN MANY WAYS, A GREAT SUCCESS STORY."**

"Nature found a compromise," says Fadi. "The animal senses how closely related the other organism is, and if they're closely related, they are happy to fuse." This fusing is worth the genetic risk because, even if the animal becomes overwhelmed, most of its genes will still be passed on when the other animal produces offspring. "However, if they are not closely related, they will reject the other organism," says Fadi. "It is both protecting its territory and protecting its genes."

## Relevance to humans

Fadi and his colleague Matt Nicotra grew *Hydractinia* on glass slides in the lab, noting which combinations chose to fuse or reject and their relatedness. Then, Matt investigated the genetics of the animals to see what controlled this decision. Matt identified a whole family of genes responsible for recognition of self or non-self. "*Hydractinia* are far removed from us, so their genes don't bear much relation to ours," says Fadi. "However, the downstream mechanisms – the way the molecules produced by the genes function – may be similar." This forms a future area of research: studying the molecules produced when these genes are expressed, how they recognise self or non-self, and how they communicate this recognition to the cell.

On to humans, Fadi explains that pregnancy presents a unique example of when the boundaries between self and non-self become blurred, and what this means for allorecognition. Even though a foetus shares half its genes with its mother, the mother and child are still genetically different, yet are inextricably linked via the placenta and umbilical cord. "There is a conflict between two genetic materials," says Fadi. "We think that allorecognition plays a role in stopping the foetus's genetic material 'invading' the mother. At the same time, the foetus 'tricks' the mother's immune system, to some degree, to stop it attacking the foetus itself." Understanding what these tricks are could lend insight into how we could 'trick' patients' bodies into accepting donated organs.

With a growing understanding of the innate immune system, the next step is to study how it works in animals more like us. "Mice are mammals like us humans," says Fadi. "In mice, we found the cells of the innate immune system have receptors that recognise transplanted tissue as non-self." These findings have caused a lot of excitement and stimulated new research. "We're now trying to see if we can use antibodies to block these receptors, which could make transplant organs better accepted," says Fadi.

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# ABOUT *IMMUNOLOGY*

Immunology involves the study of the body's immune system. It is a very important branch of medicine and biology, given how essential the immune system is to how we respond to disease and the serious consequences if the immune system goes wrong. Dr Fadi Lakkis explains more about his field.

"Immunology touches almost all aspects of human life. As well as my own specialism of organ transplantation, it is also important to understand infectious disease and cancers, and develop vaccines and treatments. For instance, we're finding ways to prompt the immune system to reject tumours.

"Immunology helps us understand autoimmune diseases, where the body rejects its own tissues. This includes lupus and rheumatoid arthritis. We're also finding more and more links between the immune system and neurodegenerative diseases such as Alzheimer's and the possibility that it is a malfunction of the innate immune system that leads to the death of brain cells.

"The beauty of immunology is that it doesn't involve just a single tool. It involves learning a whole set of tools and is now being further enriched by the rise of new fields such as computational immunogenomics. A lot of our lab work these days involves analysis of very large sets of genes or seeing which genes are being transcribed. This is a lot more efficient than experiments on individual cells.

"Understanding computer science and mathematics is becoming increasingly important to immunology. When you have gigantic datasets, you have to know what to do with them. Processing and visualising them accurately and effectively is essential and requires a knowledge of programming and statistics."

## Pathway from school to *immunology*

- Fadi says studying biology at school and post-16 is essential. He also highlights the growing importance of computer science within his field. Other subjects such as mathematics and chemistry can also be useful.
- At university, specific degrees in immunology are available at a number of institutions. Other degrees that can lead to a career in immunology include medicine, biology, molecular biology and genetics.

## Explore careers in *immunology*

- The Society for Science runs a wealth of impactful science competitions and outreach programmes for high school students: **www.societyforscience.org**
- The University of Pittsburgh, where Fadi works, holds a number of summer camps and other research opportunities for high school students: **www.howscienceworks.pitt.edu/high-school-students/research-opportunities**
- The American Association of Immunologists has a summer research programme for high school teachers that promotes excellence in science education: **www.aai.org/Education/Summer-Teachers**
- Careers in immunology can involve work in the lab, with patients or both. Immunology jobs can be well-paid – according to CareerExplorer, the average salary for an immunologist in the US is around $200,000: **www.careerexplorer.com/careers/immunologist/salary**

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***"FOR ME, THE BEST EUREKA MOMENTS ARE WHEN YOU DISCOVER THAT YOUR HYPOTHESIS IS WRONG! THAT LEADS YOU TO A MORE TRUTHFUL PATH."***

## Meet *Fadi*

**"I remember being inspired by books, such as the *Children's Encyclopaedia Britannica*,** and educational magazines I borrowed from my brother. I like physical books – a solid object that doesn't involve other distractions, like online sources do. Teachers were my other main inspiration. All it takes is one teacher who gives you support or positive feedback to get you hooked.

**"Many scientists forget that when we have a hypothesis, our experiments should try and refute it, rather than prove it.** For me, the best eureka moments are when you discover that your hypothesis is wrong! That leads you to a more truthful path.

**"I've been fortunate to have two very different mentors.** One had a very rigorous approach, which helped me learn discipline in my work. The other was very hands-off, which allowed me to make my own mistakes and be creative.

**"I'm an immigrant.** As an immigrant, you have to prove yourself repeatedly before you can meet your goals. This can be frustrating, but the way to overcome it is to be optimistic and not resent the situation. It's an increasingly common experience; here in the US, a large proportion of people working in science are immigrants. Fortunately, our merit-based system means that even with initial disadvantages, it's possible to gain the recognition you deserve.

**"I'm most proud of the young people who I've helped train.** Many have gone on to have their own research labs and do very well. More specifically, I'm proud of my work into understanding the innate immune system and the big advances we've uncovered. I'm proud to have worked on this fundamental question and progressed our collective understanding, even if just by a few inches."

### **Fadi's** *top tip*

Find your own projects, such as participating in science fairs. As well as building your own scientific knowledge, this will provide experience of hands-on science and develop your ability to communicate and present your findings effectively.

*A Hydractinia colony rejecting another*

# Investigating the root of inflammatory diseases

Inflammation is an essential part of our immune system, but when it goes wrong, it can lead to serious diseases such as lupus and psoriasis. **Professor Hans Haecker** and his team at the **University of Utah** in the US are investigating the molecular components of cells that drive our inflammatory response, and screening for molecules that may help treat chronic inflammatory diseases.

**Professor Hans Haecker**

Professor of Microbiology and Immunology, University of Utah, USA

PROFILE

**Fields of research**
Microbiology, Immunology

**Research projects**
Investigating the mechanisms behind innate immunity and inflammation, and consequent drug development

**Funders**
National Institutes of Health (NIH), University of Utah

## DISCIPLINES

**Haematology** — the branch of medicine involving the study and treatment of blood

**Immunology** — the branch of medicine and biology that studies the immune system

**Medicinal chemistry** — the branch of medicine that involves developing molecules for medicines

**Microbiology** — the branch of science that studies microorganisms

**Pharmacology** — the branch of medicine involving the study of drugs

TALK LIKE A ...

## MICROBIOLOGIST AND IMMUNOLOGIST

**Autoimmune disease** — when the body's immune system attacks the body's own cells by mistake

**Immune system** — all the parts of the body (including white blood cells and the lymphatic system) that help it fight infections and other diseases

**Inflammation** — when the body's white blood cells produce chemicals that stimulate aspects of the immune system, with physical symptoms including redness and swelling

**Intracellular** — located or occurring within a cell or cells

**In vitro** — a term for experiments that take place outside of a living organism

**In vivo** — a term for experiments that take place inside of a living organism

**Lupus** — a chronic inflammatory disease with symptoms including joint pain, skin rashes and organ damage, in particular kidney injury

**Phenotypic screening** — a drug discovery strategy to identify molecules that affect a cell's characteristics

**Progenitor cells** — stem cell descendants with the limited ability to self-renew, proliferate and give rise to more specialised cells

**Psoriasis** — an inflammatory disease that causes patches of thick, red skin and silvery scales

**Signalling cascade** — a series of chemical reactions within a cell caused by a certain stimulus

**Toll-like receptors (TLRs)** — a class of membrane-spanning proteins important to our innate immune system

Inflammation occurs when our cells recognise a pathogen or other foreign molecules. It is a process that ultimately alerts other parts of the immune system to kick into action. "If strong enough, inflammation is what we can feel and, possibly, even see, typically as redness, swelling, heat and pain," says Professor Hans Haecker. The Haecker Lab at the University of Utah focuses on uncovering the molecular mechanisms behind inflammation and using this knowledge to inform the development of new drugs.

While a certain level of inflammation is normal and useful when encountering a threat to the body, it can lead to problems, too, if it occurs at a large magnitude. "If pathogens enter a person's bloodstream and promote inflammation in the entire


body, the person can become very sick and even die," says Hans. "Understanding what drives this response and how we can control it is, therefore, critically important."

## Toll-like receptor signalling

Our bodies have various intelligent ways of identifying pathogens. The most well-known are antibodies, but there are also more generalised receptors that act as the first line of defence against pathogens before the highly specific antibodies get involved. "Toll-like receptors (TLRs) are molecules on the surface of cells which recognise certain components of pathogens," says Hans. "They are transmembrane receptors, which means part of them is on the outside of the cell, to interact with pathogens, and part on the inside, to trigger a response from the cell."

In humans, there are ten different TLRs that recognise different types of pathogen components. "For example, TLR4 recognises lipopolysaccharides (LPS), which are found on many bacteria," says Hans. "Another type, TLR9, recognises a special form of DNA found in viruses." Between them, the TLRs can likely recognise just about any pathogen that exists. Once recognition occurs, the TLR activates a signalling cascade within the cell which ultimately triggers the immune cell response - including the first stage of inflammation.

## TLRs and chronic inflammatory diseases

Autoimmune diseases occur when the body's immune system malfunctions. The inflammation pathway is no exception, and diseases such as lupus and psoriasis happen when the body's inflammatory response triggers attacks on healthy cells. "For both lupus and psoriasis, there is evidence that the amount of a molecule that forms part of the TLR intracellular signalling cascade, known as ABIN1, is slightly reduced in some patients," says Hans. "While the precise molecular mechanisms remain unclear, it appears that ABIN1 is essential to tame inflammation, so lower amounts lead to a less controlled inflammatory response."

Hans' lab has performed in vivo experiments using mice to test the effects of reduced ABIN1 in more detail. "We've found that mice that lack ABIN1 develop lupus- and psoriasis-like diseases," he says. The team has paired its findings with in vitro experiments that try to uncover the cellular and molecular mechanisms in play. "We can investigate which immune cell types are involved and how we might be able to manipulate them," says Hans. "This understanding may inform the development of new treatment options."

While these findings are promising, Hans is quick to add that these diseases are far more complex than an issue with a single molecule. "In lupus, there are dozens of genetic features that suggest a role of specific molecules in the disease process," he says. "However, it's important to note that genetic information alone is typically not that informative, but rather hints at which mechanisms might be involved." For instance, it was such genetic information that suggested the ABIN1 molecule was involved, which led to the experiments where mice were engineered to lack the gene that codes ABIN1, and the effects of this were then monitored.

## Drug screening

Drug screening involves the identification of molecules that might have potential as future medicines. "Large numbers of compounds, collectively called a compound 'library', are tested to see if any of them have a desired effect," says Hans. "We use a phenotypic screening approach, which uses living cells and observes their interactions with these compounds." This approach involves looking for the activation of a certain gene that can be measured, such as those activated by the stimulation of TLRs. "If a compound in your library blocks TLR-driven gene activation, you have a hit," says Hans.

However, like so much of science, it is not quite that simple. Because the TLR-triggered signalling cascade involves so many different molecules, a screening 'hit' does not give you much information on which particular molecule has been affected to break the chain reaction. "To address this, we developed a unique screening platform that breaks the TLR signalling cascade into segments, which we screen consecutively," says Hans. "This allows us to identify more closely which molecule the compound has affected, simplifying the tedious follow-up work dramatically."

## Interdisciplinary working

Hans' lab focuses on microbiology and immunology, but the team incorporates expertise from a range of other disciplines. "For example, we are exploring TLR signalling pathways by purifying known components to identify novel molecules," he says. "This involves an understanding of biochemistry to perform these methods." The team also needs knowledge on how blood functions and the cells within it - such as immune cells - are produced, which relies on a field called haematology.

While a lot of this know-how comes from within the team, there is a limit. "It would be impossible to have all the expertise required for such large projects combined in one lab," says Hans. "For instance, for drug development we collaborate with experts in medicinal chemistry and pharmacology, whose contributions are essential."

Such interdisciplinary working has driven the many successes of the Haecker Lab to date. "We have identified molecules important for cells to detect pathogen DNA, and discovered that this process takes place in little capsules the cell develops to sample molecules from its surroundings," explains Hans. "We've also established a new cell system that allows us to indefinitely keep and multiply 'progenitor' immune cells, which can be transferred into mice where they develop into any immune cell type." These findings and more are substantially adding to the ever-growing knowledge bank of immunology.

# **ABOUT** *MICROBIOLOGY AND IMMUNOLOGY*

**Professor Hans Haecker explains more about his discipline and what enthuses him.**

**"Microbiology and immunology overlap and complement each other.** They are both related to the most important function of the immune system, which is to protect us from pathogenic microbes. While immunology focuses on the host, microbiology focuses on the pathogen. An immunologist may study an immune process (such as TLR function) while a microbiologist may investigate how pathogens trick or overcome our immune systems. Of course, to understand the big picture, it is necessary to consider both together.

**"Every day, I get to work with colleagues who are excited by what they do.** It is very rewarding in the long term to see the impacts that such collective enthusiasm can have. The field of innate immunology and inflammation has been revolutionised over the last 25 years, not least due to our increased understanding of pathogen receptors such as TLRs. While some of these findings have been translated into medical practice, such as in vaccination strategies, there is much more to be explored.

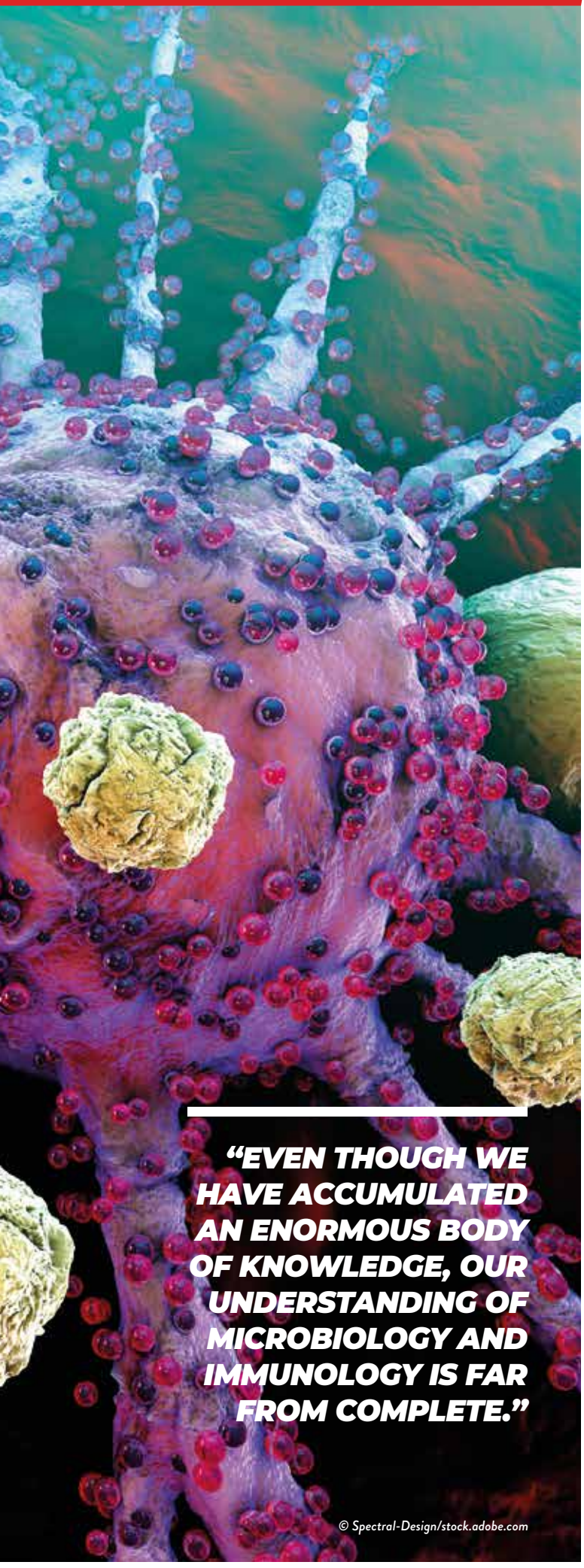
**"Even though we have accumulated an enormous body of knowledge, our understanding of microbiology and immunology is far from complete.** Additionally, some newer areas of research, in particular computational biology and approaches driven by artificial intelligence, are becoming more important. Combining new expertise in these areas with expertise in 'old' areas has huge potential for the upcoming generation."

## **Pathway from school to** *microbiology and immunology*

- Hans recommends studying science subjects such as biology and chemistry at school and post-16. A-level mathematics is often highly desired for university courses, while other science subjects may also be useful.
- At university, genetics and biochemistry remain key. More novel fields, such as computational approaches to analysing large datasets, and integration of AI-driven approaches, are likely to be increasingly important and desirable.

## **Explore careers in** *microbiology and immunology*

- Both the American Association of Immunologists (AAI) (**www.aai.org/**) and the American Society for Microbiology (ASM) (**asm.org/**) have a range of resources related to outreach, latest scientific findings and career opportunities.
- The University of Utah offers a STEM ambassador programme that provides outreach and insight into science-related careers through camps, lectures, school visits, teacher information and other resources. **stemap.org/university-of-utah-resources/**
- According to CareerExplorer, the average annual salary for an immunologist (full professor) in the US is around $200k.



***"EVEN THOUGH WE HAVE ACCUMULATED AN ENORMOUS BODY OF KNOWLEDGE, OUR UNDERSTANDING OF MICROBIOLOGY AND IMMUNOLOGY IS FAR FROM COMPLETE."***



## Meet *Hans*

**I have always loved sports, which typically comes with various injuries!** I think this sparked my first career aspiration, which was to become a medical doctor, specifically an orthopaedic surgeon.

**I first encountered basic research while in medical school.** After finishing med school, I felt that having a more robust understanding in science would help me improve my work as a physician. After my PhD and postdoctoral training, prospects in research appeared more promising, so I stayed. However, I've remained focused on how to translate research into medicinal practice.

**Obtaining funding is always a challenge for academic research,** not only for lab equipment and supplies, but also for salaries for your team, including students, postdocs and technicians. NIH provides the lion's share of research funding in the US, including our own, but we've also received funding from specific foundations such as the Lupus Research Alliance and National Psoriasis Foundation.

**It's a privilege to run a lab working on something I find fascinating and believe has real impact.** To work towards the end goal to make a real-world difference, through the highs and lows with a dedicated team, is a joy. And the excitement of finding something new never gets old!

**I co-founded a company called Nanospot.ai, which focuses on point-of-care diagnostics.** These are tests to identify diseases that can be performed at any site, such as with the patient at their home or in a doctor's office, as opposed to other tests that have to be shipped to reference labs. We developed a test for SARS-CoV2 antibodies, which provides information about the level of immunity a patient has against COVID-19, and combines an 'old-fashioned' diagnostic method with AI interpretation. I hope to expand our company further to make diagnostic testing more broadly available and more efficient.

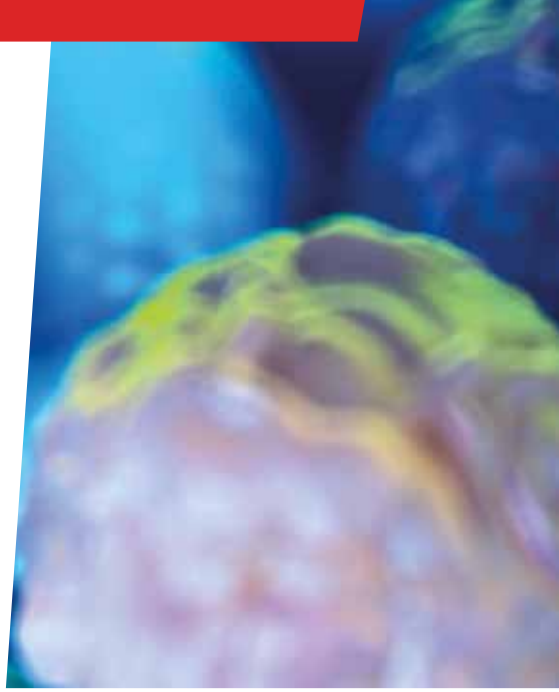
**It's not so common for researchers to set up their own companies.** It's important that the idea behind the endeavour has true commercial potential. You also need the right environment and possibly other co-founders based in industry. If this all comes together, it's exciting to be part of a start-up and push towards a common goal. A career in research does not have to be restricted to academia.

### **Hans'** *top tips*

1. Be curious and open to new information, and choose your own way based on what you find exciting and matches your talents.
2. Be disciplined and don't be discouraged if things don't work out right away.
3. Don't be afraid to ask for help. Most people are happy to support you!

# What happens when our blood production system fails?

A healthy adult produces billions of new blood cells every single day. Yet for some people, the process that generates these cells does not function properly, potentially resulting in blood cancer. At the **Albert Einstein College of Medicine** in New York, USA, **Dr Kristina Ames** has been investigating why blood production problems occur and has discovered a potential treatment that could restore the function of blood production cells.



**Kristina Ames, Ph.D.**

Cell Biology Department, Stem Cell Institute,
Albert Einstein College of Medicine, New York, USA

PROFILE

**Field of research**
Cell Biology

**Research project**
Investigating the role of the PI3K/AKT signalling pathway in the production of blood cells

**Funders**
US National Institutes of Health (NIH),
National Cancer Institute (NCI),
National Heart, Lung and Blood Institute (NHLBI)

*Special acknowledgement to Dr Kira Gritsman for her continuous mentorship and support during this project and beyond.*

## TALK LIKE A ... CELL BIOLOGIST

**Acute myeloid leukaemia (AML)** — a form of blood cancer

**AKT** — a protein that regulates a wide variety of cellular functions including cell growth, division and survival

**Autophagosomes** — the vesicles used in autophagy

**Autophagy** — the process of cellular recycling and cleaning of unnecessary cellular components, such as non-functional organelles and proteins

**Blast** — an abnormal immature white blood cell that multiplies uncontrollably, filling up the bone marrow and preventing the production of other blood cells

**Differentiation** — the ability of a cell to become a cell of a different type

**Haematopoiesis** — the production of blood cells

**Haematopoietic stem cells (HSCs)** — cells found in bone marrow from which all blood cells are produced

**Isoforms** — functionally similar proteins with similar but not identical sequences of amino acids, encoded by different genes or by the same gene of different RNA transcripts

**Mouse model** — a genetically engineered lab mouse used to study human disease

**Myelodysplastic syndrome (MDS)** — a form of blood cancer

**Phosphoinositide 3 kinase (PI3K)** — the family of signal transducer enzymes involved in cellular functions, such as cell growth, proliferation, differentiation, motility, survival and intracellular trafficking

**PI3K/AKT** — a signalling pathway that regulates a wide variety of cellular functions including cell survival and growth (where PI3K enzymes and AKT protein are the main regulators)

**Progenitor cells** — cells produced from HSCs that have not fully differentiated into mature blood cells

Have you ever considered what the blood pumping around your body contains? It is a complex mixture of living cells that each have their own important role to play. Red blood cells carry gases around the body, delivering oxygen to every cell and removing carbon dioxide. Platelets cause your blood to clot when you cut yourself, so that the bleeding stops. Granulocytes help the body fight bacterial infections, while macrophages digest microorganisms and remove dead cells. B cells produce antibodies that attack invading viruses, and T cells destroy infected cells in the body.

An adult human body contains approximately 4.5-5.7 litres of blood, which makes up about 10% of the body's weight. But how does the body create the trillions of cells needed to maintain this volume of blood? And what happens when this process goes wrong?

## How are blood cells produced?

"The process of blood cell production is called haematopoiesis," says Dr Kristina Ames, a cell biologist at the Albert Einstein College of Medicine. "In a healthy adult, approximately $10^{11}$-$10^{12}$ new blood cells are produced every day!" This monumental daily creation of new blood (including approximately 2 million new red blood cells every second) is essential for maintaining a healthy blood system.

Haematopoiesis occurs from haematopoietic stem cells (HSCs) which exist in the marrow within your bones. These HSCs can self-renew, meaning they can generate more of themselves, so the supply never runs out. HSCs can also differentiate, meaning they can turn into progenitor cells, which then turn into all the other types of blood cell, such as macrophages, platelets and T cells. Once the blood cells produced by HSCs are mature, they move out of the bone marrow and into the blood system, where they circulate around the body in the bloodstream, fulfilling their required role.


## What happens when haematopoiesis goes wrong?

To generate new blood cells correctly, there must be a balance between HSC self-renewal and differentiation. If this balance is disturbed and the differentiation process is abnormal, improperly undifferentiated blood cells will remain in their altered immature form, known as 'blasts', which can lead to cancer.

Myelodysplastic syndrome (MDS) is a type of cancer that occurs when HSCs do not differentiate into mature blood cells, resulting in an increased number of stem cells and the presence of blasts in the bloodstream. If too many blasts are formed, MDS can develop into acute myeloid leukaemia (AML). About 20,000 people are diagnosed with MDS every year in the US, and up to 40% of MDS patients progress to AML. Most patients diagnosed with AML will die within two years.

"The causes of MDS and its progression into AML are poorly understood, so research into the initiation of these diseases is needed to inform better treatment options for patients," says Kristina.

## What signals control haematopoiesis?

To maintain proper haematopoiesis, molecules in the body, such as growth factors, send signals to HSCs in the bone marrow to inform them about conditions in the body and whether they need to produce new blood cells. "One of the most important signalling pathways that conveys resource availability is the phosphoinositide 3-kinase (PI3K)/AKT pathway," says Kristina. "The PI3K enzymes receive signals from the growth factors that activate the AKT pathway, which in turn relays information about resource availability for the multiple downstream effectors that regulate vital cell processes, such as metabolism, glucose balance, cell proliferation and cell death." The specific PI3K/AKT signalling pathway is therefore essential for regulating the cellular processes.

## What is Kristina investigating?

"Our lab is specifically interested in the role of the PI3K/AKT signalling pathway in haematopoiesis," says Kristina. The PI3K/AKT signalling pathway is activated during several types of cancer, so blocking this pathway is a therapeutic technique for cancer treatment. PI3K inhibitors are commonly used to treat cancer patients, but the role of PI3K in regulating HSC function is still poorly understood. If Kristina can determine this, it could lead to improved blood cancer treatments.

The PI3K pathway regulates the cellular processes for multiple tissues in an organism, but Kristina only wants to study its influence on HSCs and progenitor cells. To do that, she had to create a novel mouse model that allows her to investigate the effects of PI3K in the haematopoietic tissue she is interested in. "We made a unique Triple Knock Out (TKO) model that allows us to delete the three redundant isoforms of PI3K in an adult mouse haematopoietic system without affecting the development of the mouse," Kristina explains. "Thus, we can access the role of the PI3Ks in adult haematopoiesis."

## What has Kristina discovered?

Kristina used TKO mouse model to investigate whether these mice had normal blood production. She discovered that when the three isoforms of PI3K were removed from a mouse, it led to a significant decrease in the populations of all types of blood cells. This is a condition known as pancytopenia and suggests that the HSCs in the TKO mouse models were defective.

To test if this was the case, Kristina performed bone marrow transplants on the TKO mice. "Usually, bone marrow has a small population of HSCs that is very efficient in self-renewal and differentiation," explains Kristina. "But in our TKO mice models, we found that despite a decrease in the total number of blood cells, there was an increase in the number of HSCs. However, this high count of HSCs did not result in a high number of progenitor cells, suggesting a differentiation problem in TKO HSCs."

Kristina then examined the bone marrow cells in TKO mice. "The bone marrow cells of TKO mice showed signs of abnormal differentiation, which are very similar to those seen in patients with MDS," she says. "We found that TKO mice share multiple features with patients who were diagnosed with MDS, including increased self-renewal of stem cells, decreased differentiation and the presence of blasts." Some TKO mice even began to progress to a more serious condition, in the same way some patients with MDS progress to AML.

To determine the mechanism that causes the changes in HSCs and progenitor cells when PI3K isoforms are lost, Kristina took advantage of next-generation sequencing techniques. She discovered that in TKO mice, HSCs are unable to regulate the process of autophagy, in which cells recycle unnecessary organelles and clean themselves. In autophagy, vesicles known as autophagosomes degrade and recycle non-functional organelles and proteins for further cellular use, thereby keeping the cell clean and healthy. However, mice without PI3K isoforms displayed decreased expression of several autophagy genes, leading to a compromised recycling process within the cell and an accumulation of autophagosomes with undegraded cellular debris. "Intriguingly, we also found an accumulation of autophagosomes in human pre-MDS stem cells," says Kristina.

## How will Kristina's research help people with cancer?

Kristina's research has shown that a lack of PI3K signalling disrupts autophagy in HSCs, and that this causes defective differentiation. From these discoveries, she hypothesised that if autophagy could be activated with drugs, it would improve differentiation of HSCs in bone marrow. "And that is exactly what we found!" she says. "Treatment of stem cells that have compromised PI3K signalling with autophagy-inducing drugs improved cellular recycling and, as a result, improved the differentiation of HSCs." Kristina concludes that impaired autophagy is a key mechanism for disrupted HSC differentiation in patients with MDS, and that autophagy-inducing drugs could help to restore HSC function. Kristina's mouse model research is, therefore, essential for understanding the causes of and testing treatments for blood cancers, which will result in improved outcomes for people with MDS and AML blood cancers.

# ABOUT *CELL BIOLOGY*

Cell biology is the branch of biology that studies organisms at the cellular level. Cells are the functional unit of life and, traditionally, cell biologists focused on studying individual cells or genes to understand their function. However, scientists know that cells and the molecules within them do not act in isolation, so it is important to study cells within the wider context of the whole organism. "I enjoy asking big questions from the perspective of the whole organism," says Kristina. "This allows me to see the consequences of cell modifications in the whole organism, not just in individual cells. Every small change we introduce at the cellular level can lead to great consequences at the organismal level."

### What do cell biologists do?

Cell biologists spend a lot of time in the lab conducting experiments. "We use signal-based methods where scientists control cells and their functions by making changes to the expression of specific target genes. We monitor these introduced changes using various techniques, such as microscopy, flow cytometry, protein blotting and multiple molecular assays, that, together, allow us to understand protein interactions and gene function," says Kristina. "The field is rapidly developing, so nowadays we can combine these techniques with big dataset processing and next-generation sequencing." These new approaches have broadened cellular and molecular biology research. Kristina explains, "These advances give the exciting opportunity to combine 'wet lab' (lab-based experiments) and 'dry-lab' (computer-based analyses) approaches that have the potential to result in more precise experimental design and subsequent studies."

As a cell biologist, you may find yourself growing cell cultures, working with microscopes, sequencing DNA, examining the cellular structures and functions of organelles and proteins, or investigating cellular mechanisms.

How could you advance our knowledge of cells and contribute to this exciting field?

## Pathway from school to *cell biology*

- At school and post-16, study biology alongside other science and maths classes. "All science classes will be beneficial for working in a cell biology lab," says Kristina.
- Kristina also recommends learning computer science and coding, as these skills are becoming very useful for cell biologists.
- Some universities offer degrees specifically in cell biology. Otherwise, degrees in biology, molecular biology or biochemistry could lead to a career in cell biology.
- "What I like about science is that it's not rigid," says Kristina. "You can take classes in the subjects that appeal to you and go in the direction that interests you. If you like something, go for it!"

## Explore careers in *cell biology*

- Many cell biologists, such as Kristina, apply their skills in the medical field, enabling their research to improve human health. While other cell biologists focus on plant or animal cell research, to improve the health of plants and animals.
- Kristina recommends looking for opportunities to participate in summer research programmes and internships to gain experience of working in a cell biology lab.
- The Albert Einstein College of Medicine has a summer research programme for high school students: **www.einsteinmed.edu/education/phd/summer-hs-research-program.aspx**
- Kristina helped establish BEYOND ALBERT (Bronx Einstein Youth Oncology Network Dedicated to Academic Learning, Biomedical Education and Research Training), a summer programme that allows high school students in the Bronx to undertake lab-based biology research projects: **cancer.montefioreeinstein.org/education/research/high-school-program**
- Zippia provides information about careers in cell biology, including the skills and qualifications you need and the salary you can expect: **www.zippia.com/cell-biologist-jobs**

# Meet Kristina

**I have always been interested in how things work** and want to understand the details of everything around me. Early on, I discovered there are different ways to learn. You can get information from someone else, by reading or listening, or you can figure out the information for yourself. It was an amazing experience when I realised I could learn and discover by doing, but it's even more exciting when I get my turn to tell the story! I became a scientist so I can find new things and tell other people about them.

**The eureka moments are what make science so fascinating and rewarding.** But science has also taught me to be patient. A lot of the time, everything moves very slowly. Answers are missing or findings don't fit into the bigger picture. At that point, you need to trust the process. Keep adding the little pieces to your puzzle and, eventually, everything will connect. Savour the victory when it does!

**I ask three questions along every step of my research:** What? How? And why? WHAT is the exact question I am interested in at this moment? HOW will I answer it? WHY it is important? And WHAT other doors will these answers open? These questions guide me in science and in all aspects of my life.

> ***THE EUREKA MOMENTS ARE WHAT MAKE SCIENCE SO FASCINATING AND REWARDING.***

**The worst advice I was ever given was to multitask and balance things.** I am the worst multitasker, I can't balance and trying to follow this advice was very unproductive for me. Instead, I realised I am a 'juggler'. I choose three tasks that need doing and focus on one at a time, rotating between each of them several times until they are finished. I don't start anything new until one of the tasks is finished, because I become overwhelmed if I have to juggle more than three balls at once.

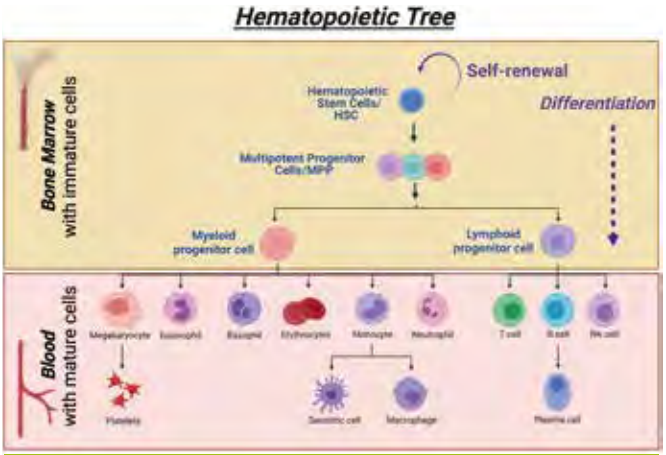
**Any obstacle can be viewed from multiple perspectives.** When you hit an obstacle, pause and look at it from a different perspective. You will often find the solution that is right in front of you!

**I am enthusiastic about raising the next generation of biomedical professionals** and am proud to have launched two educational programmes from the Montefiore Einstein Cancer Centre (cancer.montefioreeinstein.org/education). In BEYOND ALBERT, high school students explore research methodologies, learn about experimental design and conduct their own research project. In the Einstein Discover Research programme, master's students from the nearby Lehman College complete their thesis research at Montefiore Einstein Cancer Center, allowing them to become fully immersed in a research environment. I really enjoy bringing together science and education as I develop and define the vision, goals and strategies for research education programmes.

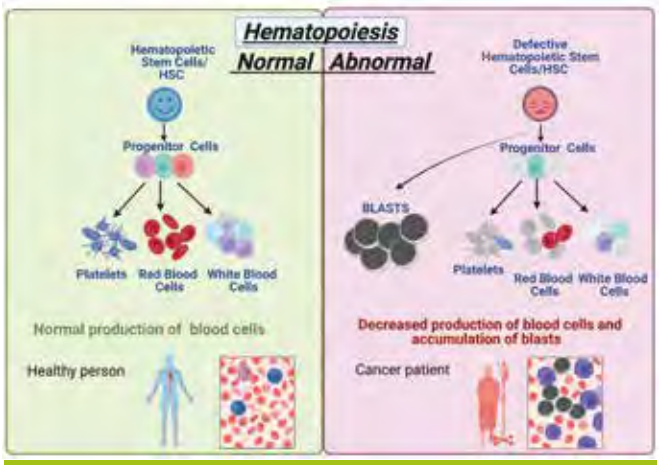
**I love walking to decompress from daily stress.** If I need to switch off for longer, I prefer to spend time in nature – I enjoy hiking and scuba diving. My favourite vacations are when I can dive with purpose and contribute to the citizen science of the Galapagos Whale Shark Project (www.galapagoswhaleshark.org).

## Kristina's *top tips*

1. Always stay curious and keep asking questions.
2. Believe you can find your way to your destination by simply taking one little step at a time.
3. Keep moving. Take breaks when you need to, but never stop.




*Schematics of the blood production process, hematopoietic tree. Created with BioRender.com*




*Normal vs abnormal blood production. Created with BioRender.com*

# What can fruit flies tell us about virtual reality exercise?

Fruit flies can be 'tricked' into getting fit without exercising. This discovery by **Dr Robert J. Wessells** at **Wayne State University**, in the US, has left him asking if we could do the same in humans.

**Dr Robert J. Wessells**

Associate Professor,
School of Medicine, Wayne State University, USA

PROFILE

**Field of research**
Physiology

**Research project**
Investigating the links between exercise and the brain through experiments with fruit flies

**Funders**
US National Institutes of Health (NIH): National Institute on Ageing (NIA), National Institute of Neurological Disorders and Stroke (NINDS)

TALK LIKE A ...

## PHYSIOLOGIST

**Genome** — the complete set of genes in an organism

**Reproductive rate** — the number of offspring a species produces per unit of time

**RNA splicing** — a method for editing genes

**Model organism** — an organism used in medical or scientific research

**Neuron** — a type of cell found in the brain and nerves that sends and receives signals

**Virtual reality (VR)** — a computer-generated simulation of an environment that users can interact with

Regular exercise is like a miracle drug. Not only does it ward off the world's most deadly diseases, including heart disease, cancer, Alzheimer's and diabetes, but it also slows down the effects of ageing. Imagine you have an illness or injury that makes it impossible to exercise. Losing access to the 'miracle drug' and its benefits will only make things worse. But could there be a way to bypass the system and keep fit without actually moving?

Dr Robert J. (RJ) Wessells, a physiologist at Wayne State University, recently discovered how to bypass exercise in tiny fruit flies. By stimulating a certain part of their brains, RJ bred flies that could run just as far as those who had undergone a rigorous training regime. If the link between the brain and exercise is also strong in humans, RJ suggests that we could use virtual reality (VR) to 'trick' our bodies into getting fit.

### How do you exercise a fruit fly?

The fruit fly *Drosophila* is a star in biomedical research. Thanks to its high reproductive rate, short life cycle, relatively simple genome and a bit of luck, *Drosophila* has featured in thousands of experiments and five Nobel prizes over the last century. Although this model organism is just a few millimetres long, it shares around 60% of its genes with humans, meaning it can help us to understand our own biology and develop new medical treatments.

To explore how *Drosophila* responds to exercise, RJ built the Power Tower – a climbing gym for flies named after a theme park ride. The Power Tower ride hoists people to the top of a 91 m tower before dropping them straight back down again. In RJ's version, the flies are raised and dropped by a few centimetres, but instead of being strapped in, the flies are inside small tubes.

When they are dropped, the flies fall to the bottom of the tube but instinctively start running up the sides as fast as they can. The Power Tower drops them every 15 seconds, meaning they are knocked back down soon after reaching the top, or even before they reach it. Some flies – the control group – are kept in tubes with the lid pushed right down so that they cannot climb up the sides. After a three-week training routine, RJ can test the speed and endurance of the exercised flies compared to the control group.

### Why did female flies not get fitter?

The first results from the Power Tower were curious: male flies got much fitter through the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exercise, but females did not benefit. To find out why, RJ used the fact that *Drosophila* cells can be switched between male and female through changing expression of a female-specific RNA splicing gene that drives female-specific gene expression. By changing the sex of different parts of the flies, he investigated exactly what was causing the male flies to get fitter.

It turned out that the difference was down to a particular set of neurons. When the sex of just these neurons was switched, female flies could increase their fitness through exercise, while male flies lost this ability. RJ had pinpointed the cells that were providing the benefits of exercise, but what is more, he knew how: these neurons were releasing a chemical called octopamine.

## What difference does octopamine make?

The next step for RJ and his lab team was to double check their finding by feeding female flies octopamine. Sure enough, the chemical allowed the females to get fitter from exercise in just the same way as males, but there was also an unexpected result.

"What surprised us was that octopamine caused improvements to speed and endurance even in flies that never actually performed the exercise!" explains RJ. Furthermore, flies that had both octopamine and exercise did not get any fitter than those that had one or the other. This was a strong suggestion that the benefits of exercise were being delivered through octopamine itself.

Finally, the researchers showed that the benefits could be delivered in a more natural way from the flies' brains. They did this by artificially activating the neurons that release octopamine for the same amount of time that they would have spent exercising on the Power Tower. The flies with the activated neurons got the same boost to fitness as those that did the exercise programme.

> **"STARTING WITH A SIMPLE RESEARCH PROJECT ABOUT EXERCISE IN FRUIT FLIES, WE WERE LED TO A DISCOVERY THAT COULD HAVE A REAL IMPACT ON HUMAN HEALTH AROUND THE WORLD."**

## What does this mean for humans?

In RJ's experiments, it was as if thinking about exercise was as good as exercising itself, suggesting a strong connection between sensory input to the brain and exercise. The challenge now is to find a safe way of 'tricking' the brain into an exercise response in animals or people who are not exercising. "This is exciting as it could potentially help a lot of people who are getting health problems from not being able to exercise," says RJ. He has already started testing if virtual exercise using virtual reality (VR) could be used as a treatment.

If you have ever used VR, you might think this sounds far-fetched. Surely anyone would know they were wearing a headset and not really going for a run? However, think about what happens when you go to see a scary film at the cinema: your body's natural fear responses, such as a quicker pulse and sweat, appear even though you know it is just a film. In the same way, RJ hopes that virtual exercise could trigger the responses that keep you fit and healthy when you exercise.

RJ feels his work shows the importance of pursuing a wide range of scientific research. He explains, "It taught me that even questions with no obvious relevance to humans sometimes generate unexpected results that end up changing medicine. Starting with a simple research project about exercise in fruit flies, we were led to a discovery that could have a real impact on human health around the world."


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# ABOUT *PHYSIOLOGY*

If life is a complex machine, physiologists are the mechanics trying to understand how it is built and how it works. They are driven by a curiosity for the details. For example, it was not enough for RJ to see that octopamine could increase the fitness of fruit flies; he kept doing more experiments to confirm if this was really the chemical released during exercise. From the scale of cells and molecules up to whole organisms and ecosystems, physiology aims to stitch together a complete picture of plant, animal and human bodies, ultimately leading to new medical and veterinary treatments.

### What is challenging about experiments in physiology?

To focus on a single biological process, physiologists need to try and control all the variables that might affect it when they do experiments. For example, in RJ's work with *Drosophila*, he made sure all the flies experienced the repeated dropping of the Power Tower, whether they were exercising or not. Furthermore, he strictly controlled their temperature, diet and even the amount of exercise the flies' parents had.

### What will the next generation of physiologists explore?

"A major area of opportunity will be using small genetic model animals," says RJ. Including worms, mice, rats and zebrafish among others, these model animals have already led to huge advances in our understanding of development and genetic diseases. It was only recently, however, that physiologists started using them to explore things such as ageing, exercise and metabolism.

The greatest mysteries of physiology lie in the brain, but recent technology is transforming our ability to investigate this organ. Magnetic resonance imaging (MRI) provides 3D images of brain activity, and scientists are now able to stimulate specific neurons and measure the response.

## Pathway from school to *physiology*

- At school and post-16, start by studying maths and science subjects and getting involved with any other STEM opportunities that come your way.
- You can go straight from (post-16) school/college to an undergraduate degree in physiology. To work in research, you will eventually need to do a PhD.
- Other routes into physiology can start with broader degrees such as biology, biomedical science and even other physical sciences or computer science.

## Explore careers in *physiology*

- Watch a video introducing the field by The Physiological Society: **www.physoc.org/explore-physiology/what-is-physiology**
- What can Greenland sharks teach us about living a long life? How does your body know when to take another breath? Explore a blog by the American Physiological Society and learn about the range of research taking place in the field: **www.physiology.org/career/teaching-learning-resources/student-resources/what-is-physiology**
- Physiologists work in healthcare, teaching, sport and industry, as well as research. Meet some of them here: **www.physoc.org/careers**

# Q&A

## Meet RJ

### Who or what inspired you to become a scientist?

I was originally inspired by books and TV shows about animals. I was constantly reading about animals and their adaptations used to survive in environments around the globe. I studied zoology with the goal of studying animal behaviour. I was fascinated by genetics and decided to learn more about how animal behaviours were controlled at the molecular level.

### What led you to pursue physiology?

After a PhD in genetics, I became interested in physiology while studying a mutation that affected heart performance. I had to learn about cardiac physiology and figure out ways to measure it in flies. This started me on a new path, thinking about organ physiology and using a combination of genetics and cell biology.

The biggest eureka moment in my career came when my team realised we could do controlled exercise training with fruit flies. We saw a world of opportunity, and how we could someday provide the benefits of exercise to people who can't exercise for any reason. My colleagues in the lab are still working every day to build on that eureka moment!

## **RJ's** *top tips*

1. Don't give up. There are always setbacks along the way, but if you keep working hard, you can make it to a career in science.
2. Make good use of mentors – people you know from early on who can give you advice and write reference letters for you.
3. To discuss career paths or do some volunteering, don't be afraid to contact local scientists at universities or in industry.



# Meet Jodi

**Jodi Protasiewicz**
Student on the Maximizing Access to Research Careers (MARC) programme, School of Medicine, Wayne State University, USA

**Field of research**
Biological Sciences

**Funders**
National Institutes of Health (NIH), National Institute on Ageing (NIA)

**Science was always my favourite subject throughout middle and high school,** and I knew that I wanted to involve myself more in science when I started college. Participating in the pre-MARC and now the MARC programme has been a great opportunity for me to get involved, as it has allowed me to join a lab and conduct my own research.

**During the school year, I work in my research lab during free time or in between classes.** I work full-time in the lab during the summer and have very flexible hours.

**The programme has challenged me with learning hands-on skills used in the lab.** In my lab, these skills include working with fruit flies as a model organism, interpreting data and making measurements of various things.

**I am so happy to be part of the MARC community!** It means that I am part of an amazing and supportive group of people, while also preparing me for graduate school. Highlights include presenting my research at conferences and being able to connect with other students who are also passionate about STEM.

**In the future, I plan on attending graduate school to earn my PhD.** I wish to stay in research afterwards, with my dream career being a position at NASA where I can conduct work in astrobiology.

## **Jodi's** *top tips*

Actively seek out opportunities, build a network, find a good balance between your research and college classes, and don't be afraid to challenge yourself!

# Meet Maryam

**Maryam Safdar**
MD/PhD Student and Research Assistant
School of Medicine, Wayne State University, USA

**Field of research**
Physiology

**Research project**
Investigating relationships between endurance exercise and sleep

**Funder**
US National Institutes of Health (NIH)

**Discoveries in biomedical research make up the basis of medical advancement,** so I have always had an interest in how those discoveries are made. I took a biology course in high school and was introduced to the concept of super bugs, and that is when my interest in scientific research became something beyond intrigue.

**Becoming a doctor** – treating disease and working with patients – has been a dream of mine for a long time. I did my undergraduate thesis work in Dr Wessell's lab and he introduced me to the Wayne State University School of Medicine MD/PhD dual degree programme. This programme allowed me to continue to pursue research, while also getting the education I need to become a doctor.

**I was ecstatic when I heard back about my acceptance onto the MD/PhD programme.** During the two years of my medical education, I did a few rotations, including one with Dr Wessell. I returned to his lab to continue my education in physiology and to learn about what goes into scientific research.

**Making exercise more accessible to those who really need it is one of my main motivators.** My project investigates the relationship between endurance exercise and circadian rhythm (sleep) disturbances. I generate the data through experiments and organise it into presentations. However, it is also a lot about learning about the field and how to conduct research. Part of my responsibility as a scientist is to share my findings with others by presenting at conferences and writing research articles.

## **Maryam's** *top tip*

The best way to assess whether you are fit for your dream career is to try it out! Don't hesitate to search out opportunities, and put yourself out there to get experience in shadowing or volunteer work.

# How to build a game-changing malaria vaccine

For millennia, malaria has plagued human civilisation, killing billions over the course of history. Finding ways to combat this complex and clever disease remains a significant challenge. However, recent research by **Professor Richard Bucala** and his team at **Yale School of Medicine** in the US have found a way to develop a potentially super-effective vaccine – by turning the disease's most devious tactics against it.

**Professor Richard (Rick) Bucala**

Professor of Medicine, Pathology and Epidemiology & Public Health, Yale School of Medicine, USA

PROFILE

**Research project**
Developing an effective scalable saRNA vaccine against malaria that targets parasite MIF

**Fields of research**
Immunology, Autoimmunity, Infectious Diseases, Vaccine and Drug Development

**Funders**
National Institutes of Health (NIH), Mathers Foundation, Open Philanthropy

## TALK LIKE A ... MALARIA RESEARCHER

**Antibody** — a protein of the immune system that recognises a specific antigen

**Antigen** — a substance that induces an immune response in the body, in particular the production of antibodies

**Biochip** — in the context of this article, a portable biosensor able to analyse particular qualities of a sample of a substance

**Cytokine** — a type of protein produced by cells that modifies the immune response

**Immune response** — the response of the immune system to a harmful or foreign substance such as a pathogen

**Immunological memory** — the immune system's ability to 'remember' past pathogens, so it can respond more rapidly and effectively when it encounters them again

**Inflammatory response** — a response of the immune system that aims to mitigate the impact of harmful substances

**Malaria** — a disease caused by a mosquito-borne parasite that invades the body's red blood cells

**MIF (macrophage migration inhibitory factor)** — an important cytokine that participates in inflammatory and immune responses

**RNA (ribonucleic acid)** — a nucleic acid, principally used in organisms to carry information from DNA. **mRNA** (messenger RNA) is a type of RNA found within cells that carries information from DNA in the nucleus to the cytoplasm, where it is used to make proteins. **saRNA** is an artificial form of RNA that contains genes that cause the saRNA molecule to be duplicated once inside cells

**Parasite** — an organism that lives in or on a different host organism and receives sustenance at the expense of the host

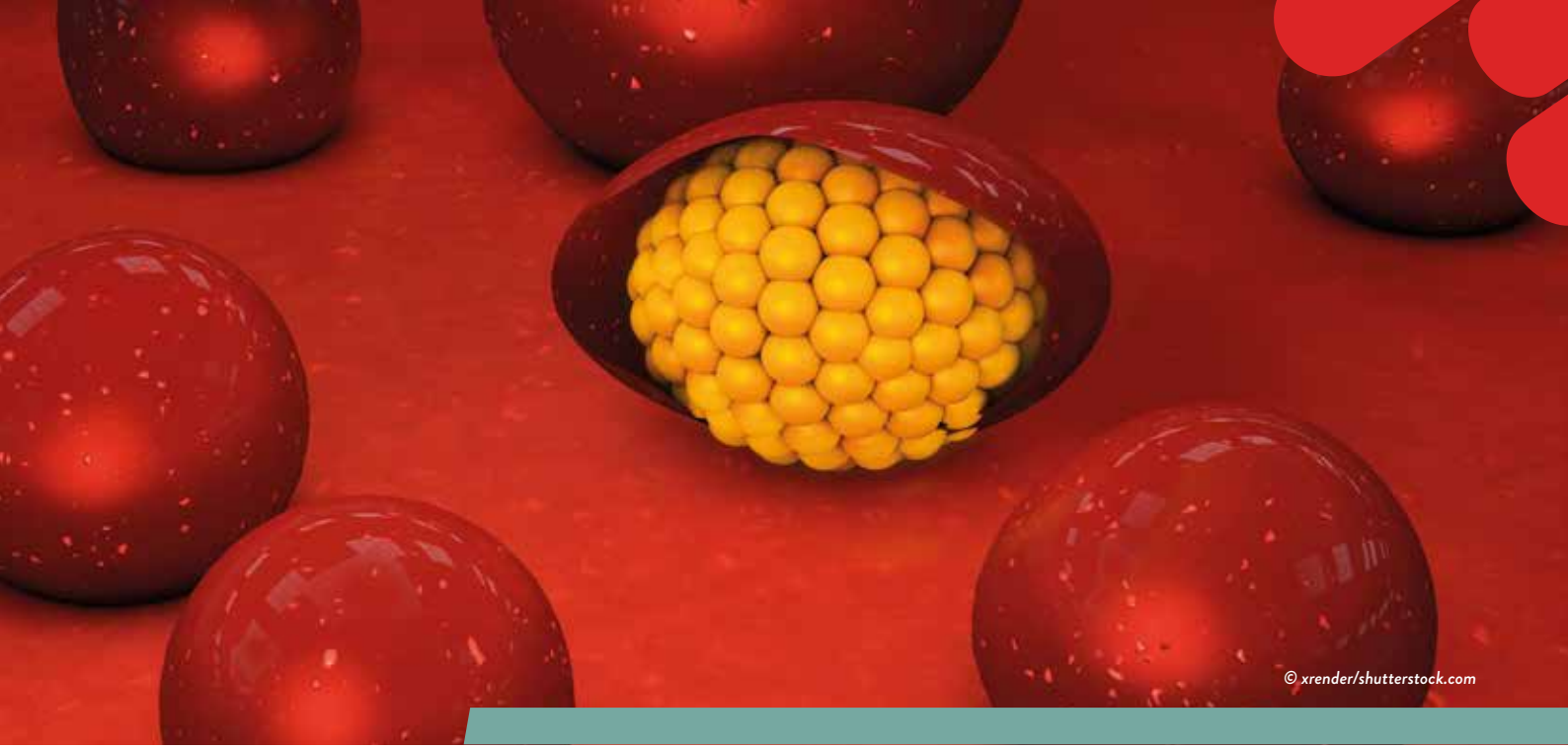
**RNA (ribonucleic acid)** — a nucleic acid, principally used in organisms to carry information from DNA

Malaria is one of the world's most deadly diseases, and despite gigantic investment in finding solutions, the unique nature of the disease continues to throw up obstacles. "It's estimated that malaria has caused 50% of all human deaths since the Stone Age," says Professor Richard (Rick) Bucala. "Even with today's anti-malarial drugs and mosquito control strategies, malaria remains the world's second leading cause of death by infectious disease." Rick is a professor of medicine at the USA's Yale School of Medicine and is busy unpicking malaria's unique mechanisms to discover how to defeat it.

The development of malaria vaccines has not been straightforward. "The first malaria vaccine was approved for human use in 2015, although it provided protection for no more than half of individuals and its effectiveness waned significantly over time," explains Rick. "In the latest clinical studies, a more recent vaccine has been shown to provide almost 80% protection." Both vaccines work by teaching the body to identify a particular outer surface protein of the malaria parasite, but this protein varies between strains and is likely to mutate as malaria develops resistance to the vaccine. "There are significant costs involved in producing this protein-based vaccine, let alone the many variants that will need to be created, so it's unclear what its global impact could be," says Rick.

### Our immune system

To understand why it is so difficult to develop a malaria vaccine, we must first understand two important parts of our immune system, and the malaria parasite's method for exploiting them. The first is the body's ability to remember past pathogens and identify when the same pathogen is trying to invade the body again, allowing a rapid immune response before the pathogen has time to become established. It is this 'immunological memory' that forms the foundation of all vaccines, which typically involve providing the body with a pathogen identifier that the immune system remembers for future occasions.




The second involves some of the first molecules of an immune response, which get to work when a pathogen is identified. "Cytokines are the hormones of our immune system and regulate the strength and direction of our inflammatory and immune responses to an invading pathogen," says Rick. "One such cytokine, MIF (macrophage migration inhibitory factor), is one of the very first immune mediators to be released and acts broadly to ensure strong inflammatory responses." As it turns out, MIF is at the heart of the malaria puzzle – but not in the way that might be expected.

## The MIF Mystery

Malaria escapes immunological memory, making it a real challenge for the body to develop an effective immune response to re-infection. It is for this reason that the disease has existed for so long, as human populations do not develop immunological resistance to it. It also explains why developing vaccines has been such a challenge. "It has long been known that individuals infected with malaria do not mount protective immune responses and always remain susceptible to re-infection," says Rick. "Moreover, current candidate vaccines for malaria don't elicit an effective immunological memory response."

The mechanisms by which malaria avoided immunological memory remained a mystery for many decades. The plot thickened when, in the early 2000s, research found that malaria parasites have their own gene for the cytokine MIF, meaning they produce a version of MIF themselves when infecting a host. "Given MIF's important role in the immune system, the finding that these parasites produce their own inflammatory cytokine was extremely puzzling," says Rick. "A talented student in my lab, Tiffany Sun, decided to investigate this puzzle for her PhD thesis." Tiffany studied a strain of malaria engineered with the MIF gene removed and used it to infect mice. These mice had a much more effective immune response and immunological memory than mice infected with a malaria strain that had its MIF gene.

> **"WE ARE TARGETING THE PRECISE MECHANISM THE PARASITE USES TO EVADE THE DEVELOPMENT OF A PROTECTIVE IMMUNE RESPONSE."**

These results indicated that the malaria's MIF gene must be behind the suppression of the body's immunological memory. "Further experiments showed that the strong inflammatory response caused by the parasite MIF gene led to the death of the particular immune cells responsible for memory development," says Rick. "The parasite is essentially exploiting the body's own inflammatory response through the use of MIF."

## A vaccine Holy Grail?

Rick's lab was excited by these results, as it potentially indicated a chink in the malaria parasite's armour. In 2011, Rick and his team got to work developing a vaccine, not based on proteins as with traditional vaccines, but rather using newly developed techniques based on RNA. RNA is a nucleic acid, like DNA, and is used within cells as the 'code' to produce proteins. Typical vaccines involve the injection of antigens – proteins present on pathogens that are identified by specific antibodies. Instead, RNA vaccines involve the injection of antigen-coding RNA into a body's cells to stimulate them to produce these antigens themselves, essentially kickstarting immunological memory without exposure to the disease itself. Most RNA vaccines of this type use the most 'standard' form of RNA, known as messenger RNA (mRNA). "mRNA technologies have received a lot of attention because of the success of the COVID-19 vaccines, which were the first mRNA-based vaccines to be developed," explains Rick.

Rick's lab is using an engineered RNA type called self-amplifying RNA (saRNA). "saRNA contains genes that allow the RNA to replicate once it reaches the inside of cells," says Rick. "This means much less RNA is needed for vaccination compared to mRNA vaccines, significantly reducing the cost of production." This is an important feature for a malaria vaccine, given it is most prevalent in less developed nations where resources are scarce.

The choice of antigen is critical to an effective vaccine, and it is at this point that the lab's work on parasite MIF comes in. The antigen Rick and his team are stimulating the body to produce and learn to recognise is none other than parasite MIF. "We are targeting the precise mechanism the parasite uses to evade the development of a protective immune response," says Rick. "Our studies with animal models show that once this mechanism is neutralised, the infected host mounts a fully protective and long-lasting immune response that both eliminates the parasite and prevents re-infection."

The vaccine Rick and his team are developing also has one extra important asset compared to other malaria vaccines: longevity. "Because parasite MIF must be able to mimic our own MIF to stimulate our immune system, it can't mutate to evade detection like other antigens can," says Rick. "While other candidate malaria vaccines use structural antigens which can vary between malaria strains and mutate over time, the parasite MIF antigen is highly conserved – meaning the development of malaria strains resistant to our vaccine would be exceedingly unlikely if not impossible." If this vaccine can be approved for human use and scaled up, it might just provide the global battle against malaria with the silver bullet that has been sought for so long.

# ABOUT *MALARIA RESEARCH*

**Combatting malaria is one of humanity's most significant challenges, with huge potential to save lives and prevent suffering. Rick explains more about his own research and the wider battle against malaria.**

"The global problem of malaria is one of humanity's greatest unmet medical needs. It kills around 600,000 people annually, mostly children, and has a huge societal and economic cost to many countries, too. This makes research into malaria important and potentially incredibly impactful.

"Perhaps the most frustrating aspect of this work is that malaria is preventable. It is a tragedy that it occurs in those countries with the fewest resources to prevent or manage its societal cost. Resistance to antibiotic treatment is developing and prevention strategies such as mosquito nets (that can, for example, go around beds to prevent malaria-carrying mosquitoes getting in) are only partially effective. Having an effective, low-cost vaccine would be a vital new tool towards controlling and even eliminating malaria.

"My lab is multidisciplinary, and this is important for research into malaria vaccines. My own graduate training was in biochemistry and immunology. Knowledge of protein biochemistry is essential for the design of vaccine antigens, and knowledge of molecular biology and RNA is necessary for producing the constituents of RNA vaccines. Having experience with immunology and infectious disease models in mice also is essential.

"Some years ago, my lab developed a biochip that allows the direct visual detection of a person's MIF alleles (different versions of a gene). Curiously, alleles that lead to low expression of MIF are especially common in sub-Saharan African populations, where malaria is prevalent. We reasoned that because lethal malaria results from excessive inflammation, which MIF helps to drive, it makes sense that low-expression MIF alleles are found in populations historically exposed to malaria. It suggests infected individuals have less excessive inflammation and so are more likely to survive. Our biochips helped us demonstrate this, showing that children with low-expression MIF alleles, who were infected with malaria, were less likely to have severe manifestations of the disease.

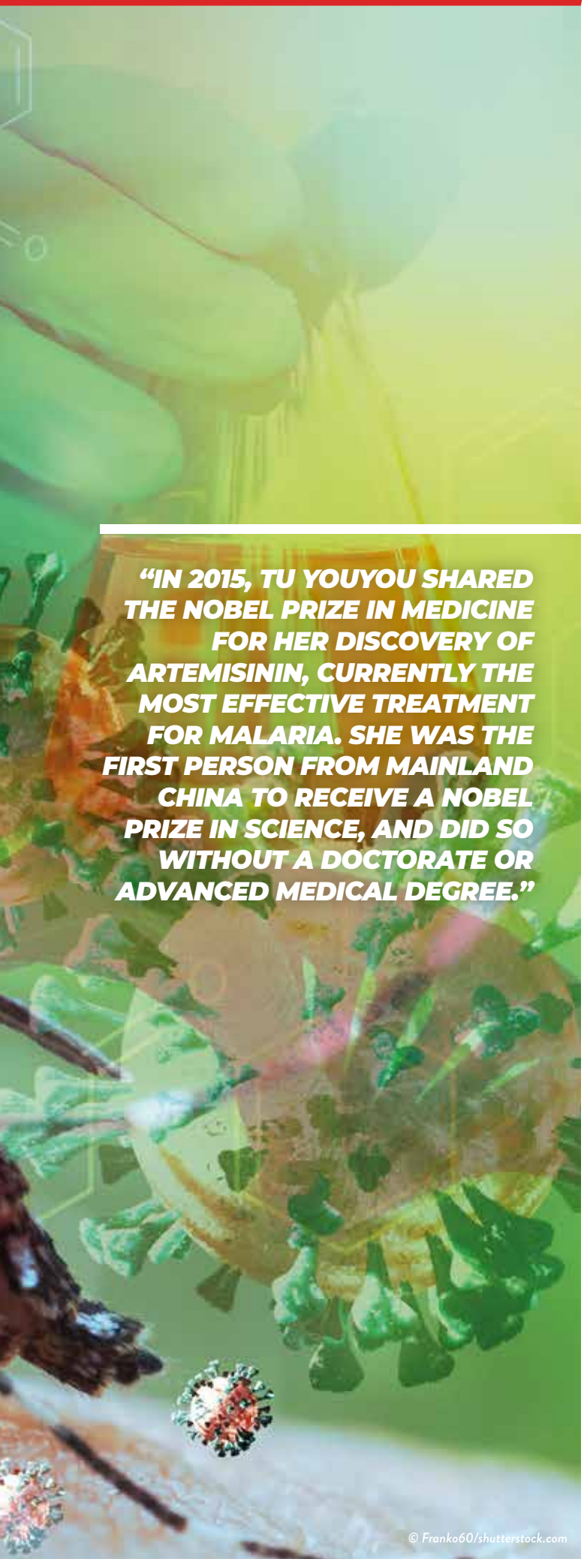
"The importance of malaria research has been recognised for over a century. In 1902, a British physician named Sir Ronald Ross received the Nobel Prize in Medicine for demonstrating the mosquito transmission of malaria parasites. In 2015, Tu Youyou shared the Nobel Prize in Medicine for her discovery of artemisinin, currently the most effective treatment for malaria. She is the first person from mainland China to receive a Nobel Prize in science, and did so without a doctorate or advanced medical degree."

## Pathway from school to *malaria research*

As Rick says, interdisciplinarity is essential for effective malaria research, which means the topic can be approached from a wide variety of educational backgrounds. To study biochemistry or immunology, like Rick did, universities typically want to see high school and college qualifications like biology, chemistry and mathematics. Depending on the course, other useful subjects can include further sciences, like physics and psychology, geography and the arts.

## Explore careers in *malaria research*

- Rick says that the Yale School of Medicine has programmes to sponsor high school students in laboratories, with participation of Yale faculty scientists: **medicine.yale.edu/edu**
- There are opportunities available at many scientific institutions for high school students to get involved with research. For instance, the National Institute of Allergy and Infectious Diseases (NIAID) runs a summer internship programme for high school students at its laboratories in Maryland and Montana, in the US, with opportunities to conduct research into infectious diseases. Find out more: **www.niaid.nih.gov/about/summer-internship-program#HS-SIP**
- Jobs within medicine research vary widely in both scope and salary. According to **salary.com**, the average salary for a medical research scientist in the USA is around $93,000.



***"IN 2015, TU YOUYOU SHARED THE NOBEL PRIZE IN MEDICINE FOR HER DISCOVERY OF ARTEMISININ, CURRENTLY THE MOST EFFECTIVE TREATMENT FOR MALARIA. SHE WAS THE FIRST PERSON FROM MAINLAND CHINA TO RECEIVE A NOBEL PRIZE IN SCIENCE, AND DID SO WITHOUT A DOCTORATE OR ADVANCED MEDICAL DEGREE."***



# **Meet** Rick

**When I was younger, I was inspired by the elegance and beauty of molecular structures and their capacity to explain how biology works.** Later, I was motivated by the stories of scientists who designed and created new molecules to treat disease and improve health. I was especially inspired by the career of Louis Pasteur, who made key scientific insights by investigating the practical needs of his time, including the germ theory of disease, fermentation, vaccination and the chemistry of isomerisation.

**My greatest ambition in medicine is to find new ways to treat disease.** I felt that a career in medical research, rather than becoming a health practitioner, was the best way to achieve this goal.

**Initially, I embarked on the study of medicine because I thought it would make me a better scientist.** Once I began to take care of patients, however, I saw how much physicians can help patients through the simple power of knowledge and reasoning. I also began to appreciate the complexity of medicine, and how so many factors, including social and humanistic factors, have to be considered to arrive at the best treatments and, ultimately, the best research questions.

**I have trained over 60 scientists during my career.** Trainees often bring a fresh and, I would say, fervent approach to scientific questions, using their individual perspectives and educational backgrounds to provide unexpected insights, which often leads to novel and creative solutions. It's always stimulating to work with younger investigators and see them go on to tackle new areas of research with confidence and independence.

## **Rick's** *top tip*

The public health importance of combatting malaria is an enduring source of inspiration. Because the problem is so multifaceted, involving epidemiology, mosquito ecology, parasite biology, immunology and genetics, the opportunity to contribute, collaborate and learn across disciplines can be incredibly rewarding. Ask yourself how you could contribute – be inspired!

*Rick with former MD PhD student Rita Das en route to Mach Mission Hospital, in Zambia. Dr Das is currently with Moderna, Inc., one of the companies behind the COVID mRNA vaccine.*

# Could a healthy diet combat multiple sclerosis?

**Associate Professor Lucinda Black**, from **Curtin University**, Australia, has been exploring the links between diet and multiple sclerosis (MS).

**Associate Professor Lucinda Black**

Associate Professor, School of Population Health, Faculty of Health Sciences, Curtin University, Australia

PROFILE

**Field of research**
Nutritional Epidemiology

**Research project**
Exploring the role of diet in multiple sclerosis (MS)

**Funders**
MS Western Australia (MSWA), MS Australia

## TALK LIKE A ... NUTRITIONAL EPIDEMIOLOGIST

**Calorie** — the units used to describe the amount of energy in food

**Case-control study** — a study that compares two groups of people: one group with the disease and a similar group of people who do not have the disease

**Cognitive decline** — a gradual loss of mental abilities

**Diet** — the types of food and beverage that a person habitually consumes

**Epidemiology** — the study of the frequency, pattern and causes of health problems in populations

**Fatigue** — extreme tiredness

**Gut microbiome** — the trillions of microorganisms that live inside our digestive system

**Legumes** — the family of plants that includes foods such as soy, peas, beans and lentils

**Nutrition science** — the study of nutrients in food, how the body uses them, and the relationship between diet, health, and disease.

**Vegan diet** — a diet that excludes animal products

What should we eat? It might sound like a simple question, but everyone seems to have a different answer. Is it five fruit and vegetables a day we should be counting, or calories consumed? Hinduism tells us not to eat beef, Judaism says it is pork we should avoid, and environmentalists suggest going vegan – yet the supermarket is full of steak and bacon. Almost every conceivable diet, from cutting out carbohydrates to only eating fruit, has its supporters.

Part of the confusion comes down to the complexity of nutrition science. Thanks to a maze of other factors, from genetics and gut microbiome to exercise and psychology, it is fiendishly difficult to draw a straight line between diet and health. However, this does not stop committed researchers like Associate Professor Lucinda Black and her team from taking on the challenge. As a nutritional epidemiologist at Curtin University, Australia, Lucinda is working hard to help people with multiple sclerosis (MS), and those at high risk of developing MS, base their diets on good evidence.

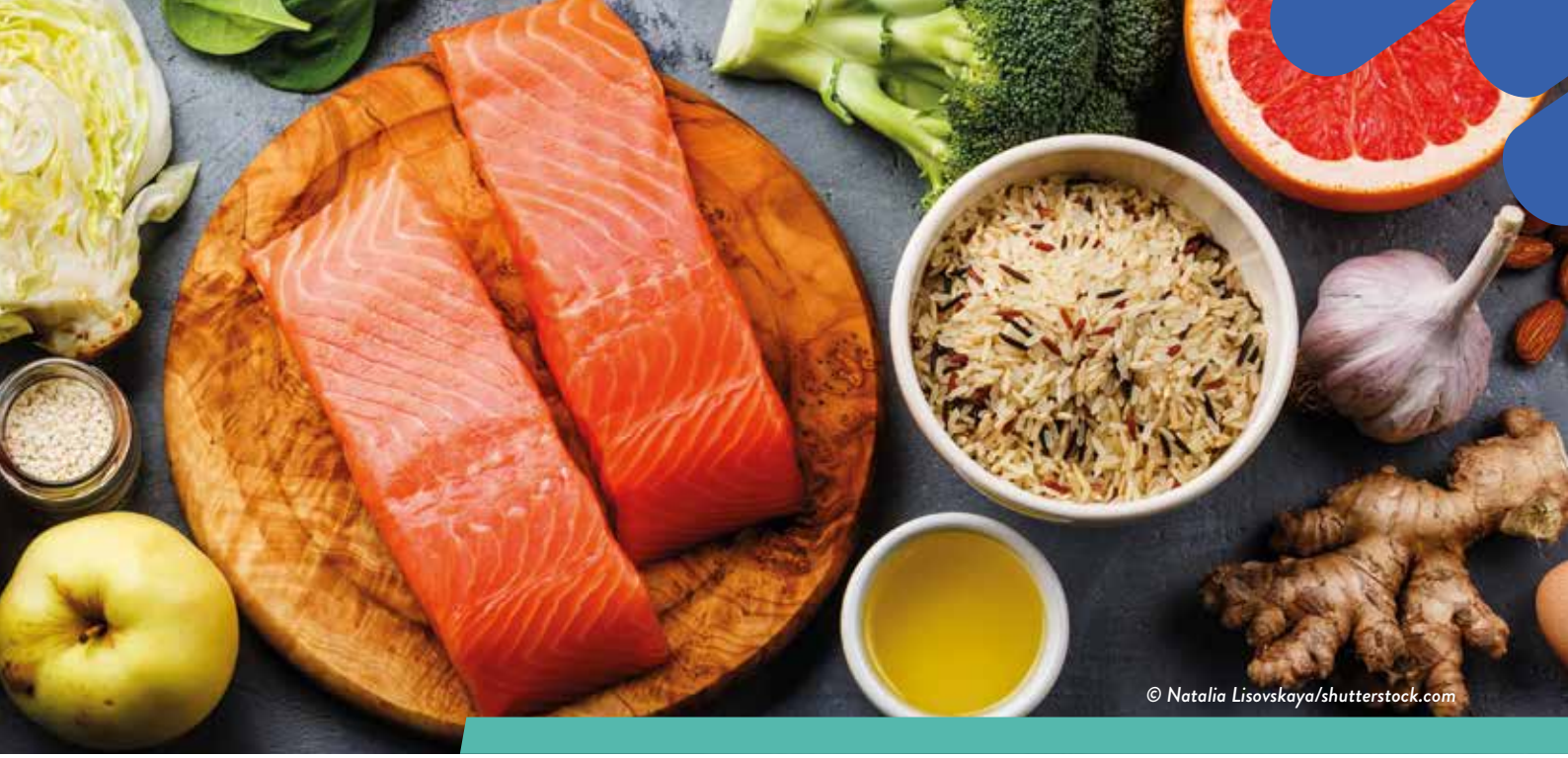
### What is multiple sclerosis?

MS affects the central nervous system, which is made up of the brain and spinal cord. When you want to move a muscle, your brain sends an electrical signal through the nerve cells telling the muscle what to do. Similarly, signals are sent to the brain from around the body to tell it about movement and function, and senses such as vision, hearing, touch, taste and smell. Nerves have a protective sheath called the myelin, which helps to ensure messages are sent quickly and efficiently. It is the myelin that gets damaged when a person has MS. This means parts of the nervous system start misbehaving or breaking down: signs and symptoms can include fatigue, numbness, weakness, vision impairment and cognitive decline.

MS is a lifelong condition, and no cure has been found yet. It can become severe: for example, some people lose their ability to walk or have difficulty swallowing. However, scientists around the world are working hard to find a cure, and modern treatments allow many people to live comfortably with the disease.

### How can researchers study the links between diet and MS?

Research can help us understand how diet contributes to people getting MS and, after a diagnosis of MS, how diet might affect the severity of the disease. Researchers often use case-control studies to understand disease risk. They recruit people with a disease (cases) and healthy people (controls) who are similar to those who have the disease, such as matching people on whether they are male or female, how old they are and where they live. Lucinda is using data from studies from around the world that have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recorded information from people with MS, and healthy control groups, to see if people who ate or avoided certain foods were more likely to get MS. The same studies might follow people with MS over many years, even decades. If people with MS who ate or avoided certain foods had less severe symptoms over time, then this could suggest that diet was helping to combat the disease. This kind of study can provide clues about what diets or foods might be worth testing in a randomised controlled trial.

A randomised controlled trial provides a stronger level of evidence than asking people what they eat over time. Lots of people take part, and they are randomly allocated into two groups: one group follows the specified diet and the other group does not. The health of everybody in the trial is measured at the beginning and the end of the study, and the data are analysed afterwards. If people in the group who followed the diet were statistically healthier at the end than people who did not follow the diet, then this is good evidence that the diet made a difference.

## Could healthy eating help prevent MS?

Healthy eating is important for everyone. For people at high risk of MS, such as those with a close family member who has MS, a healthy diet may help prevent onset of the disease. Using data from an Australian case-control study, Lucinda analysed the diets of 698 people, 252 of whom were 'case' participants who had damaged myelin – a common sign of MS. The other 446 people (the healthy 'control' group) were chosen to match the case participants according to age, sex and where they lived. She found a link between diet and the risk of getting MS: a healthier dietary pattern (high in poultry, fish, eggs, vegetables and legumes) was linked to a lower risk of getting MS.

Using the same set of participants, Lucinda investigated people's fish consumption in more detail. She found that higher fish consumption was linked to lower risk of getting MS, particularly consumption of oily fish, such as salmon, mackerel, tuna and sardines, which are "high in vitamin D and omega-3 fatty acids, both of which may be beneficial in relation to MS".

In another study, this time from the US, Dr Alison Daly analysed dietary intake in childhood and adolescence recalled by 505 adults with MS and 556 matched controls. The participants were asked to remember the foods they ate when they were growing up. Higher consumption of fruit, yoghurt and legumes during childhood and/or adolescence was linked to lower risk of developing MS as an adult.

Having identified some foods that may be important for the risk of getting MS, Lucinda is now looking at links between these foods and how quickly the disease progresses in people who already have MS – could certain foods or nutrients help reduce the severity of MS?

## Could healthy eating help people with MS?

There is a lot of confusing information about the best diet for people with MS. "People with MS often look for advice on the internet," Lucinda says. "But searching online for 'diet to cure MS' gives over 25 million results, including some that recommend going vegan, and others that recommend lots of meat!" In reality, there is not yet enough scientific evidence to be sure what the best diet is for people with MS. For people with MS, though, a healthy diet can be a tool to combat symptoms and common problems like fatigue and obesity.


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> ***"PEOPLE WITH MS OFTEN LOOK FOR ADVICE ON THE INTERNET, BUT SEARCHING ONLINE FOR 'DIET TO CURE MS' GIVES OVER 25 MILLION RESULTS, INCLUDING SOME THAT RECOMMEND GOING VEGAN, AND OTHERS THAT RECOMMEND LOTS OF MEAT!"***

Dr Rebecca Russell interviewed people with MS to uncover their thoughts about diet. She asked people with MS if they had changed their diet after they were diagnosed, whether they thought that food affected their symptoms, and what dietary advice they had received. "They told us that they didn't get much, if any, advice about diet from health professionals," says Rebecca "They were confused about where to get credible advice."

Lucinda and her team aim to generate strong scientific evidence and create dedicated resources that help people with MS make informed decisions about their diet. They are developing a nutrition education programme specifically for people with MS, giving participants a chance to hear from experts and share their experiences with each other.

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# ABOUT *NUTRITIONAL EPIDEMIOLOGY*

Can we prevent and manage diseases by choosing what we eat? This is the overarching question that nutritional epidemiology tries to answer. Researchers like Lucinda hunt for patterns that might link diet and disease, perform statistical analyses, and set up trials to test their hypotheses. Their ultimate goal is to provide evidence to support dietary recommendations that will protect us from illness or help relieve our symptoms when we do get ill.

### What are the challenges in nutritional epidemiology?

Think about what you ate yesterday. Can you remember exactly what you ate and drank, and how much of it you consumed? Could you recall how often you ate certain foods in the last year?

According to Lucinda, getting accurate information about what people eat is the most challenging part of nutritional epidemiology. Some people might not remember what they ate, and it is nearly impossible to keep track of every food and drink you consume. In addition, the very act of taking part in a study and recording your diet could change your behaviour: if you had to write down everything you ate next week, would you think twice before choosing an unhealthy snack, or would you 'forget' to tell the researcher?

Furthermore, nutritional epidemiologists cannot perform highly controlled laboratory experiments like in chemistry or physics. This means there are lots of other factors that may confuse the results. To try and control for these factors (which could be anything from smoking habits to hours spent outside or time spent watching TV), researchers need to include as many people in their studies as they can and collect a lot of information in addition to dietary intake.

### What diseases do nutritional epidemiologists study?

Nutritional epidemiologists can study any disease. Some try to determine if certain foods cause cancer, while others are interested in heart disease or viruses such as SARS-CoV-2, the virus which causes COVID-19. Lucinda, meanwhile, has found her niche in MS.

"It is a pleasure to work in the field of diet and MS," she says. "People with MS are so interested in nutrition and motivated to make healthy changes. It is a privilege to be doing something I love and know that the findings are helping people with MS."

## Pathway from school to *nutrition science*

- In general, a good background for studying nutrition science will include taking biology/human biology, chemistry and maths at school.
- Many universities offer undergraduate or postgraduate degrees in nutrition science, food science and dietetics.
- Research is one of many pathways for a nutrition scientist. If you are interested in being a researcher in nutrition, you will typically need to do a PhD in nutrition or food science.

## Explore careers in *nutrition science*

- Nutritional epidemiology is just one aspect of nutrition science. Others include dietetics, sports nutrition, public health nutrition, food science, food sustainability and animal nutrition.
- Outside of universities, nutrition scientists may join companies that develop and manufacture food products, provide nutritional counselling to groups or individuals to improve health and well-being, or join organisations or government departments that promote healthy eating.
- Food scientists are involved in new food product development, quality assurance, food regulation, research and development.
- Dietitians provide guidance about how to manage diets and nutrition for people with health conditions. They often work in hospitals making sure patients are getting sufficient nutrients to manage their disease.
- Many countries have a nutrition society, including Australia (www.nsa.asn.au) and the UK (www.nutritionsociety.org). Contact your national society to see if they have volunteering opportunities and sign up to receive their newsletter.

# Q&A
## Meet Lucinda

### What were your interests when you were younger?
I had a chemistry set and I kept a lab book to record my experiments. I recorded successes and failures with growing crystals, producing fizzy and colourful chemical reactions, and writing secret messages in invisible ink.

### What inspired you to become a nutritional epidemiologist?
As a young adult, I faced challenges with my health. With the help of a nutritionist, I changed my diet substantially and I saw the power of nutrition to transform health and well-being.

I soon became passionate about nutrition and decided to study nutrition to help others. Initially, my research focused on the effects of vitamin D. However, after speaking at an MS conference about vitamin D, a person with MS came up to me and said, "What I really want to know is, what should I eat?" When I tried to find an answer in the scientific literature, I discovered a major knowledge gap, so I set about trying to answer that question.

### What are your proudest career achievements so far?
My proudest achievements are seeing my students succeed in research. I know that I have been instrumental in helping them achieve their goals, and it's very rewarding to see their careers develop. I also enjoy involving people with MS in our research – when they tell us we are making a difference, I know we are on the right track.

### As a nutritional epidemiologist, do you enjoy cooking and eating?
I enjoy cooking and eating even more since studying nutrition. I enjoy knowing that what I'm eating is providing my body with the best nutrition possible. I can look at my meal and know pretty much exactly what it's providing me!

Luckily, my tastes have changed from preferring junk food to preferring healthy food. I still enjoy small treats most days, like a homemade chocolate mousse made with rich dark chocolate.

### What do you enjoy doing in your spare time?
Pilates and ballroom dancing keep me fit and healthy, and they are a great way to get moving after a day at my desk in academia.

### **Lucinda's** *top tips*

1. It's helpful to have a long-term goal in mind. At the same time, enjoy the journey and be flexible, because the path may not be linear and the goal may change.
2. Choosing to follow what you are good at and what you enjoy means that work is likely to be fun. Monday morning can be as exciting as Friday afternoon if you follow your passion.
3. Remember that setbacks are also opportunities – something that seems like a setback at the time might lead to an unexpected and positive outcome later.

# **Meet** *the team*

**Associate Professor Andrea Begley**
Advanced Accredited Practising Dietitian

Andrea is guiding the development of nutrition resources for people with MS

**Dr Alison Daly**
Public Health Statistician

Alison conducts statistical analysis for the team's research projects

**Dr Eleanor Dunlop**
Accredited Practising Dietitian

Ellie is investigating the links between diet and MS onset in children using data from a Canadian study

**Dr Rebecca Russell**
Associate Nutritionist

Rebecca leads the community involvement activities and is developing a nutrition education programme to help people with MS make healthy dietary choices

**Dr Minh Pham**
Epidemiologist

Minh is investigating the links between ultra-processed foods and MS disease progression using data from an Australian study

**Xiaochen (Grace) Qu**
PhD student

Grace is investigating the links between fish and meat consumption and MS disease progression using data from an Australian study

# Can mathematics keep our food safe to eat?

Keeping germs out of our food is a constant battle, but mathematical modelling can help us trace contamination and stop the spread. **Professor Renata Ivanek**, an epidemiologist at **Cornell University**, USA, has been helping keep food production facilities running safely and our food free from bacteria.

**Professor Renata Ivanek**

Department of Population Medicine and Diagnostic Sciences, Cornell University College of Veterinary Medicine, USA

PROFILE

**Field of research**
Epidemiological Modelling

**Research project**
Creating mathematical models to investigate epidemiology in the food industry

**Funders**
US Department of Agriculture (USDA), US National Science Foundation (NSF), Center for Produce Safety (CPS), Cornell Institute for Digital Agriculture (CIDA), The AI Institute for Sustainable Food Systems (AIFS), Frozen Food Foundation

TALK LIKE AN ...

## EPIDEMIOLOGIST

**Algorithm** — a set of strict, logical rules that can be followed by a computer

**Epidemiology** — the study of diseases and how they spread in a population

**Food contamination** — the presence of harmful chemicals or microorganisms in food

**Mathematical model** — a description of a system in terms of mathematical equations

**Pathogen** — a bacterium, virus or other microorganism that can cause disease

When you get sick, do you ever wonder where you got the illness from? If you have a stomach bug, do you consider if any of the food you ate the day before was past its best-before date? If you catch a cold, do you think about who could have passed it to you? Bacteria and viruses causing diseases are an invisible enemy – as the pathogens are so tiny, it is hard to know for sure where you get them from.

Now imagine wearing a pair of magic glasses that lets you see bacteria. You could walk into your kitchen and see bacteria like in an advert for an antibacterial cleaning product – every contaminated piece of food and surface would glow! Professor Renata Ivanek, an epidemiologist at Cornell University, has not invented magic glasses, but she has been working on a mathematical equivalent. Her research is keeping our food safe to eat by modelling the spread of a bacteria called *Listeria*.

### How does *Listeria* get into our food?

*Listeria* refers to a group of bacteria. Not all of them are dangerous, but one species in particular (*L. monocytogenes*) is a pathogen that causes an infectious disease called listeriosis. People with listeriosis get a high temperature and feel achy or sick. Most get better after a few days, but it can sometimes be life-threatening or lead to miscarriages.

When there is an outbreak of listeriosis, epidemiologists try to determine where it began. The most common way to get infected is by eating food that has not been cooked properly or has been kept chilled for a long time. This includes cold meats and fish, pre-prepared fruits, sandwiches, salads and soft cheeses. By establishing who has gotten ill and what they ate, the contamination can usually be traced back to a specific food production facility.

*L. monocytogenes* finds its way into food production facilities because it is present everywhere – it is commonly found both in the country and in urban environments. A small slip in hygiene is therefore all it takes, and once *Listeria* is in the food facility, it is able to spread even inside fridges.

### Can we keep our food safe from *L. monocytogenes*?

Food facilities test regularly for contamination by taking swab samples of various surfaces in the facility. They look for any bacteria in the *Listeria* group, as this will highlight places in the facility that have good conditions for dangerous *L. monocytogenes* to grow. However, there is no way to test every single surface in a factory every day, so *L. monocytogenes* sometimes slips through the net. This is where Renata's modelling work comes in.

With her team, Renata has created a tool called Environmental monitoring with an Agent-Based Model of Listeria, or EnABLe.


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It is a mathematical model that simulates the spread of *Listeria* in food production facilities. "In a nutshell, EnABLe recreates the unique food facility environment, equipment and practices, and serves as a digital twin of the facility," explains Renata.

In EnABLe, the biology of *Listeria* is represented by equations. For example, an equation might state how quickly the bacteria replicate depending on temperature, moisture and nutrient availability. These equations are applied to a virtual copy of the food production facility. This 'digital twin' is like a computer-game version of the facility that includes the building and all of its equipment and workers. These simulated people and objects are the 'agents' that interact with each other to make up the agent-based model.

## What can a model tell us about contamination?

Imagine, as an example, a chopping board. If a worker with *Listeria* on their hand uses the board to chop an apple, cross-contamination could occur. The bacteria might start to replicate if the board is wet and could contaminate any other food that touches the board until it is cleaned. By this time, *Listeria* could have spread all around the food facility, but where?

EnABLe keeps a tally of the bacteria present on every agent in the model every hour, so in this example, it would know exactly which surfaces need to be disinfected. In practice, companies can run the model to explore where in the facility *Listeria* contamination is most likely, and which control strategies would be most effective for reducing the risk of an outbreak. Furthermore, if *Listeria* is detected in the facility through routine swabbing of surfaces, the model can be used to figure out where the contamination likely came from.

## How does worker health influence food production?

During the COVID-19 pandemic, we avoided being close to other people indoors, but this was often impossible for workers inside food production facilities. As a result, the virus could spread rapidly in these facilities, risking not only the health of the employees but also the security of food supply chains. Thankfully, Renata was able to help. Under the guidance of food industry leaders and the US Centers for Disease Control and Prevention, Renata and her team created a new model called Food Industry COVID-19 Control (or FInd Cov Control).

> **"IN A NUTSHELL, EnABLe RECREATES THE UNIQUE FOOD FACILITY ENVIRONMENT, EQUIPMENT, AND PRACTICES, AND SERVES AS A DIGITAL TWIN OF THE FACILITY"**

Like any other mathematical model, FInd Cov Control works by programming in a set of inputs, and it then generates a set of outputs. The inputs to FInd Cov Control include the number of employees, their age, infection status and vaccination history, as well as details about the food production facility, such as worker hierarchy and shift schedule and the types of COVID-19 control strategies in place (e.g., testing or physical distancing). The output is a prediction of when workers will get ill and how this will affect food production. Using these predictions, companies can determine the best way to protect their workforce and keep their production line open.

## What is the best way to control COVID-19 in the food industry?

"The analysis with FInd Cov Control is ongoing," says Renata, "but there are several valuable insights we already have about COVID-19 control in the food industry." The model has found that intensive testing for the virus is very effective, but also costly. Cutting costs by slightly reducing the amount of testing, however, is a bad idea. If the testing rate is high enough to send lots of people home because they test positive, but not high enough to eradicate the outbreak, then there is likely to be both a shortage of workers and the infection will continue to spread, causing more potentially life-threatening illnesses. "Cost-effectiveness is not just a function of cost and worker availability, but also the protection of public health," says Renata.

Another effective approach, according to the model, is to enforce intensive physical distancing and hygiene measures. In practice, though, this approach is unpopular and difficult to maintain. In the long term, Renata suggests "the most cost-effective approach is maintaining a vaccinated workforce to prepare for a new outbreak".

In the future, Renata's models could be used for other diseases or workplaces. "The model can be adapted by changing the parameters of the employee population, restructuring the work module or incorporating the epidemiology of a new infection in the disease module," she says. Her research can therefore help all industries to protect their workers while maintaining production.


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# ABOUT *EPIDEMIOLOGICAL MODELLING*

Where do diseases come from, who is at risk from them, and how do they spread? These are some of the underlying questions that epidemiology tries to answer. To do this, researchers not only zoom in to the microscopic scale of pathogens to understand their biology, but also zoom out to analyse the patterns of disease in communities and populations around the world.

### Why is computer modelling so important in epidemiology?

Epidemiologists aim to predict the spread of diseases through a population, but this is a complex problem. Even if an infection's spread follows a simple rule, the numbers can quickly get out of hand. Imagine a disease where every infected person passes it on to two other people each day. It starts with one case, the next day there are two new cases, and the day after that there are already four new cases. At this exponential rate of spread, after three weeks there would be over 2 million cases! To get more realistic predictions for the spread of diseases, epidemiologists consider how long a person remains infectious, how sick they get, how many people they come into contact with, and how easily transmissible the disease is.

Keeping track of this complexity by hand would be impossible, so epidemiologists build large-scale computer models. Epidemiological computer modelling requires collaboration: some researchers will be experts on how certain infections behave, while others will use their mathematics and coding skills to turn this knowledge into algorithms. Finally, research teams can experiment with their models to find out the best ways to slow the spread of a disease and help healthcare systems prepare for outbreaks.

### Who is working in Renata's research lab?

Renata's research team includes people with a wide range of backgrounds. At the moment, her lab members come from Chile, China, Croatia, Turkey, the US and Zambia. They are at a range of stages in their education or career – some are high school students, some are university undergraduate students, some are graduate students, and others are postdoctoral researchers. They also come from different disciplinary backgrounds, and so bring expertise in veterinary medicine, food science, public health, mathematics and statistics to the group. "This diversity is important because our different experiences contribute to the lab mission in unique ways," says Renata. "Our diversity helps us to identify and solve meaningful problems. We are different, but what we all have in common is an interest in mathematics, food and health."

## Pathway from school to *epidemiological modelling*

- As an interdisciplinary field, there are a number of routes into epidemiological modelling. "In my research, people typically fall into one of three groups," says Renata:

1. Those who studied mathematics, statistics or computing, but have little knowledge of health or food
2. Those who studied epidemiology, public health, medicine or food safety, but have no computer coding skills
3. Those who, like me, know just enough about mathematics, food and health that they can effectively collaborate with people in groups one and two.

- "It doesn't matter which subjects you start with, people with knowledge of any related field are valuable in our research," says Renata. "Follow your interests and curiosity to find your path to epidemiological modelling."

- If you are most interested in how diseases work, then consider degrees in human or veterinary medicine, biomedical science, public health or epidemiology.

- If you love the idea of modelling, you may prefer to study mathematics, statistics or computer science, and then apply these skills to epidemiological challenges.

## Explore careers in *epidemiological modelling*

- Public Health Degrees provides information about how to become an epidemiologist and the areas of epidemiology you could specialise in: **www.publichealthdegrees.org/careers/epidemiologist**

- There are a number of paths you could follow to work in the food safety profession: **foodsafetycareerguide.com/2018/08/17/how-to-get-started-in-food-safety**

- The Centers for Disease Control and Prevention has information about what epidemiologists do and epidemiology-related lesson plans and classroom resources: **www.cdc.gov/careerpaths/k12teacherroadmap/epidemiology.html**

- Coding skills are important for epidemiologists. Use online courses such as Code Academy (**www.codecademy.com**) or Free Data Camp (**www.freecodecamp.org**) to teach yourself. Then, when you are ready to explore infectious disease modelling, visit MIDAS (**www.midasnetwork.us**) to find modelling projects to work on.

# Q&A
## Meet Renata

### How did you end up becoming an epidemiological modeller?

When I was younger, I loved animals so I wanted to become a vet because I had the naïve idea that I could heal and save all creatures. I also developed a love of solving math problems at an early age thanks to my excellent first math teacher.

I studied veterinary medicine at university, where I discovered the epidemiology of infectious diseases. But I was blindfolded by my goal of becoming a vet, so I didn't pursue epidemiology at the time. Later, during my master's degree in veterinary epidemiology, I realised how big a role math plays in epidemiology and that I could combine my interests in math and health in a single discipline.

My PhD united these interests, and I became an epidemiological modeller. Food is essential to health, so it was natural to focus my epidemiological knowledge and modelling skills on problems at the health-food interface.

### How did you learn computer modelling?

I learned computer modelling simply by doing it. In research, I often find myself at the very edge of my comfort zone, where solving a problem requires something I don't yet know. Being at the edge was how I started incorporating computing into my research, one small step at a time and learning along the way.

While I studied epidemiology then learned computing on the job, you could approach epidemiological modelling in the opposite direction and train in computer modelling then apply your skills in epidemiology. I think that either direction has its challenges. I also think that irrespective of the direction, having strong skills in one discipline before learning another is helpful, because it gives you confidence that you are doing something right.

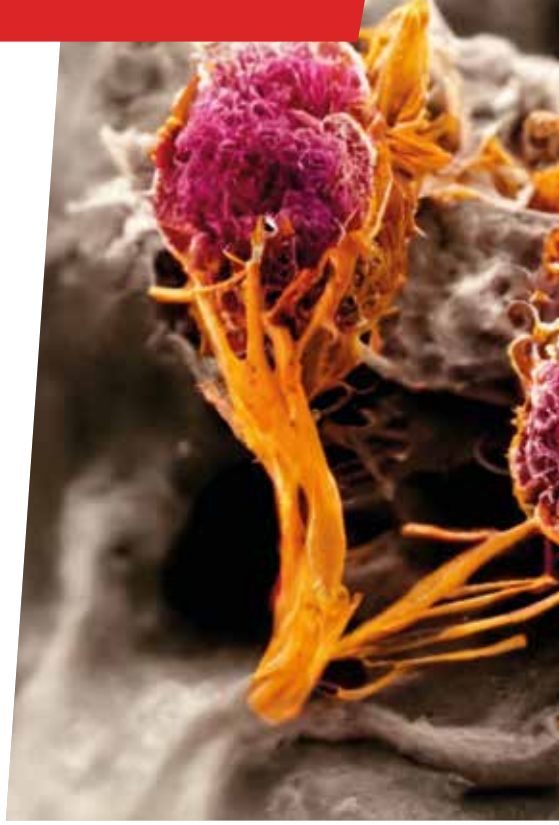
### What motivates you at work?

I am very curious and love learning new things. I also enjoy working with students who are curious, creative and have the drive for research. In my research lab, we are addressing real problems faced by society, and we strive to make a difference by developing new and sustainable approaches for improving the health of human and animal populations, and optimising food production systems.

### **Renata's** *top tips*

1. Don't be afraid of dreaming big and working for it!
2. You may not always land where you had hoped. But success is more likely if you have a vision of where you want to land.
3. Remember that failure may open a new door for you that you never even considered before.

# Synthetic biology: the power of modified microbes



Microbes are the world's most brilliant chemists, able to turn simple sugars and other compounds into a vast array of complex chemicals. Nowadays, scientists like **Professor Ian Paulsen** and his team at the **ARC Centre of Excellence in Synthetic Biology** in Australia are uncovering not just how these processes work, but how to modify them to get microbes to produce chemicals that no natural microbe makes. This ability opens up a virtually infinite array of possibilities that have the potential to save our environment and millions of lives.

**Professor Ian Paulsen**

Director, ARC Centre of Excellence in Synthetic Biology, School of Natural Sciences, Macquarie University, Sydney, Australia

PROFILE

**Field of research**
Synthetic Biology

**Research project**
Researching and developing synthetic microbes for sustainable production of industrial biochemicals, fuels and plastics

**Funders**
Australian Research Council (ARC), NSW State Government

TALK LIKE A ...

## SYNTHETIC BIOLOGIST

**Metabolic pathway** — a linked series of chemical reactions happening within a cell, typically led by proteins

**Microbe/microorganism** — a microscopic organism, such as bacteria or yeast

**Synthetic biology** — brings together multiple disciplines to design useful things from the building blocks of life, using genes to make new microbes with new abilities

What have microbes done for us? Microbes regulate the climate, help us digest the food we eat, and decompose our waste. They also brew our beer, make our bread rise, and ferment our cheese. In fact, despite their negative connotations with disease and infection, the majority of microbes are either beneficial or at least harmless to us. Yet, despite these many and varied uses, researchers believe they remain a mostly untapped resource for humanity.

Professor Ian Paulsen is the Director of the ARC Centre of Excellence in Synthetic Biology, a research centre that spans nine universities across Australia. "The general idea of synthetic biology is that we can engineer microbes to do things that naturally occurring microbes don't do," he says. "This might be producing high-value substances like biofuels, fertilisers or plastic precursors." Ian's team has a vision of building a 'bio-based economy' in Australia, focusing on ways to improve agriculture and waste processing through the creation of unique microbes.

### How to engineer a microbe

Synthetic biology makes use of the rapidly progressing science of genetic engineering, which involves changing an organism's genes so that it will express different proteins. Proteins are the 'machinery' that drive the creation and conversion of molecules within cells. "If we want to make a certain product, we'll try and work out what metabolic pathway could lead to it, and then find genes from different organisms that can be combined to make that pathway," explains Ian. "We then insert those genes into our microbe of choice and see what happens."

Genes are complex things and there is a lot of trial-and-error involved to get these pathways working, but Ian's team has made impressive progress already. "Each time we make changes, we test what is and isn't successful, and use that data to help improve designs until we can successfully engineer microbes to produce the desired product," he says.

### No more cow burps

Ian is dedicated to ensuring that the work of his team has viable real-world applications. One significant example of this comes from a start-up company, Number 8 bio (www.number8.bio), set up by some of his team members, which focuses on reducing cows' methane emissions. Like all animals, cows have communities of microbes living within their digestive system, which help with digestion but produce methane as a by-product. This is an issue because methane is a potent greenhouse gas, and cattle methane emissions are a significant contributor to climate change.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To address this, the researchers at Number 8 bio are engineering yeast strains that can be fed to cattle to supplement their digestive microbes and prevent the emission of methane. "This has strong environmental benefits and also benefits farmers because methane contains carbon that could otherwise be used by the cows to grow," explains Ian. "For the same amount of feed, a cow will gain 20-30% more body weight – a real saving for farmers."

## The microbial village

Ian believes that the next step for synthetic biology lies in mimicking, in an industrial setting, how microbes interact in the natural world. "Currently, virtually all synthetic biology used in industry involves a single engineered microbial species," he says. "In the real world, microbes live in complex communities where they are constantly competing and collaborating with one another." Ian's team is trying to engineer synthetic microbes that function together in a community with each microbe specialised for a particular task. For instance, engineering one microbe to use carbon dioxide as a feedstock and synthesise and secrete a sugar that a different microbe can be then use as a feedstock for growth. The carbon energy from that sugar can be used to build an industrial biochemical that the first microbe would not be able to produce.

> "THE GENERAL IDEA OF SYNTHETIC BIOLOGY IS THAT WE CAN ENGINEER MICROBES TO DO THINGS THAT NATURALLY OCCURRING MICROBES DON'T DO. THIS MIGHT BE PRODUCING HIGH-VALUE SUBSTANCES LIKE BIOFUELS, FERTILISERS OR PLASTIC PRECURSORS."

## Changing the world?

Modifying the genetic structure of organisms is no trivial task, and Ian is conscious of ensuring that ethical and societal considerations are taken into account. Synthetic biology has a range of potential impacts on society, both positive and negative. For instance, engineering a microbe to make a compound that we currently source from plants grown on agricultural land has the potential benefit of producing the compound without losing valuable land, water and fertiliser. On the other hand, being able to produce the compound synthetically might threaten the livelihood of a farmer in a developing country.

"Our team includes social science and humanities researchers who look at the policies and implications of synthetic biology," says Ian. "They have expertise in important areas such as bioethics and technology law."

Ian's team is especially interested in complying with the Nagoya Protocol, a treaty involving many nations that sets out rules for the fair sharing of benefits arising from the use of genetic resources. Many medicines, for instance, are created using substances originally sourced from tropical species, so the communities that safeguard these species should also benefit from their use. "The protocol aims to protect the rights of Indigenous peoples and developing countries from which biological material is taken and profited from," says Ian. "We are aiming to set a global standard for complying with the protocol when it comes to synthetic biology, by integrating humanities considerations within our development process from an early stage."


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# ABOUT *SYNTHETIC BIOLOGY*

**Synthetic biology is a new but rapidly progressing field, and there is a lot of demand for people with relevant expertise.**

Because of synthetic biology's industrial applications, there is demand not only for researchers, but also those who have the skills to turn research outcomes into viable and scalable businesses. "We are training both the entrepreneurs who will form new companies, as well as the workforce that will staff and run these companies," says Ian. "By the time a high school student reading this goes to university, there will be a full industry waiting for them, seeking researchers, technicians, administrators, business developers, and many more skilled workers."

Only two years since its inception, the ARC Centre has already seen major successes. "The Centre has already led to the formation of three start-up companies that have raised $60 million in venture capital between them," says Ian. Samsara Eco (**www.samsaraeco.com**), one of these companies, is using engineered enzymes to break down common plastics into constituent components that can be used to create brand new plastics. "You can use this process to infinitely recycle drinks bottles, for instance," says Ian. "That means no more fossil fuels are needed for plastic production."

The Centre has its sights set on a variety of future opportunities, focusing on those that can significantly better society. "For example, we're engineering an entirely new yeast chromosome with genes from different organisms that would enable yeast to produce oils for human consumption," says Ian. "This would mean that oils such as palm oil, which results in massive deforestation of tropical rainforests, could instead be made in a more environmentally sustainable manner by yeast fermentation – analogous to how we currently make beer and wine."

## **Pathway from school to** *synthetic biologist*

Biomolecular science forms the knowledge foundation of synthetic biology. Sasha recommends taking biology and chemistry at college/post-16, as well as learning computational skills. At university, courses or modules in molecular biology or biochemistry will be beneficial.

## **Explore careers in** *synthetic biology*

- More information about synthetic biology and associated careers can be found at **www.coesb.com.au**
- Macquarie University has an award winning Professional and Community Engagement (PACE) programme, which provides undergraduate students with industry-valued practical experience in running experiments and working with experienced lab researchers. Learn more: **students.mq.edu.au/careers/pace**
- Synthetic Biology Australasia is a community of scientists sharing knowledge and experience in synthetic biology. Its website also points towards opportunities for students: **www.synbioaustralasia.org/for-students**
- Synthetic biology is a rapidly emerging field and demand for experts and practitioners is growing. As a reference point, Payscale says the average molecular biologist salary in Australia is around AU$100,000.

# **Meet** *some of the team*

## Dr Sasha Tetu

**Fields of research:**
Microbiology, Molecular Biology

**Funders:**
Australian Research Council (ARC), Horticulture Innovation

**I have always cared about the environment and been curious about what organisms are found where and why.** Microbes often get bad publicity, but this is starting to change and there are so many helpful, weird and wacky microbes out there that we are just beginning to learn about.

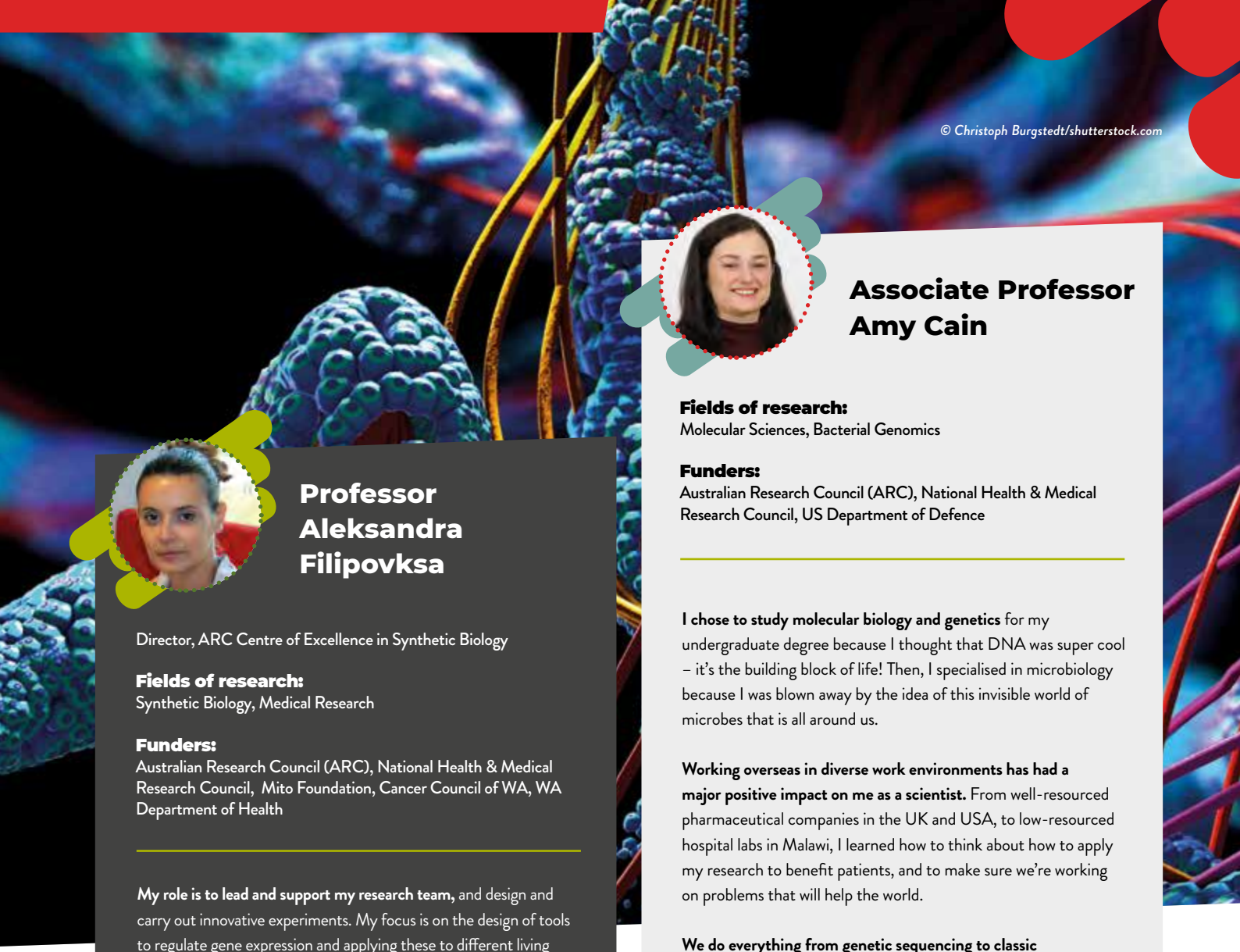
**I did a basic science degree, covering plant and animal biology, ecology and molecular biology.** Since my undergraduate days, the advances in this field have continued to speed up, with DNA sequencing and synthesis technologies meaning we can now answer all kinds of fundamental and important biology questions.

**My research focuses on plastics in the ocean.** We researched the impact of the chemicals that leach out from these plastics on photosynthetic marine plankton and found that almost all of these organisms are negatively affected by exposure to these chemicals. However, other groups of bacteria could tolerate exposure and, in some cases, even grow better – maybe using these chemicals within their metabolism. This suggests there are likely to be 'winners and losers' among marine microbes in areas of ocean with a lot of plastic pollution.

**I have worked with so many amazing people over my career.** It is great to have a job where you are learning new and interesting things all the time, and I also enjoy having a mix of lab and computer work.

## **Sasha's** *top tip*

Think about what you are most passionate about contributing to. There are so many questions out there to answer and plenty of different ways for biomolecular research to contribute positively to human, animal, plant and environmental health. What will you find rewarding?







## Professor Aleksandra Filipovksa

Director, ARC Centre of Excellence in Synthetic Biology

**Fields of research:**
Synthetic Biology, Medical Research

**Funders:**
Australian Research Council (ARC), National Health & Medical Research Council, Mito Foundation, Cancer Council of WA, WA Department of Health

**My role is to lead and support my research team,** and design and carry out innovative experiments. My focus is on the design of tools to regulate gene expression and applying these to different living systems to improve their functions and energy metabolism.

**Scientific research is full of serendipitous moments that have led to unexpected discoveries and revealed new aspects of cell function.** There are times when research can be very slow, but patience and perseverance inevitably lead to exciting new discoveries. I am motivated by the ability to make new discoveries that no one else has made previously.

**I am proud of finding out how specific genes work** and designing new methods to study their function. In the future, I want to design new and exciting features of cell function that provide hope for cures for devastating and incurable diseases.

**Science is the most rewarding career,** filled with travel, exchanging ideas, meeting like-minded people, and pushing the boundaries of imagination. Synthetic biology is a field that is rapidly expanding to provide new hope for many of today's challenges including improved health, green energy and climate change. It is well worth investing in and pursuing.

### **Aleksandra's** *top tip*

Everyone should take their own path. Your personal journey will make your contributions to scientific discoveries unique and distinctive.



## Associate Professor Amy Cain

**Fields of research:**
Molecular Sciences, Bacterial Genomics

**Funders:**
Australian Research Council (ARC), National Health & Medical Research Council, US Department of Defence

**I chose to study molecular biology and genetics** for my undergraduate degree because I thought that DNA was super cool – it's the building block of life! Then, I specialised in microbiology because I was blown away by the idea of this invisible world of microbes that is all around us.

**Working overseas in diverse work environments has had a major positive impact on me as a scientist.** From well-resourced pharmaceutical companies in the UK and USA, to low-resourced hospital labs in Malawi, I learned how to think about how to apply my research to benefit patients, and to make sure we're working on problems that will help the world.

**We do everything from genetic sequencing to classic microbiology, to bioinformatics.** This means we can take a hypothesis, such as a potential new antibiotic, from the basic discovery stages up to testing on an animal model, from which it can be translated into drugs for human use.

**We apply synthetic biology approaches to plastic degradation.** We are finding genes that code for enzymes that allow microbes to break down plastics and inserting them into synthetic microbes. This has allowed us to produce a bacterial 'hyperdegrader' that breaks down plastic rapidly.

**I would like to build a start-up company of my own in the near future.** It would tackle the mounting problem of plastic waste using our synthetic biology findings, scaling our synthetic microbes to tackle anything from individual household plastic waste through to breaking down landfill.

### **Amy's** *top tips*

Get all the experience you can. For instance, volunteer in labs by emailing the group leaders from research papers you think are cool. Have confidence that you can do whatever you set your mind to, work with good and positive people, and set yourself ambitious goals to change the world!

# Can data science help us achieve a stronger start and brighter future for children?

**Dr Rachel Wilcock**, Data Science Lead at **Nesta**, explains how data science can be a powerful tool for social good

Data scientists use scientific methods and computer algorithms to extract knowledge and information from large datasets. This is useful in a huge range of applications, from monitoring global finances to improving medical imaging techniques. Thanks to data science algorithms, when you use a search engine, such as Google, to look for anything online, the most relevant results appear first. And have you noticed that after searching for something online, your social media accounts are then full of adverts for that very same thing? This is because data science algorithms track your online activity to discover your likes and interests.

The ability to uncover information hidden within data is extremely useful. Data scientists use their skills to reveal the patterns in data, which can then be used to identify and help solve the many challenges facing our society. We spoke to Dr Rachel Wilcock, Data Science Lead at Nesta, to discover what a career in data science for social good involves.

## What is data science?

Data science is a multidisciplinary field which uses a range of methods, from descriptive statistics to machine learning, to gain insights from datasets. This involves everything from scraping websites to create new datasets, to communicating findings by producing interactive visualisations of the data.

## How does Nesta use data science for social good?

Nesta is an innovation foundation for social good. We focus on three missions, each with its own goal: 'A Healthy Life' aims to increase the number of healthy years lived in the UK, while narrowing health inequalities; 'A Fairer Start' aims to narrow the outcome gap between children growing up in disadvantage and the national average; and 'A Sustainable Future' aims to reduce household emissions by 30% from 2019 levels by 2030.

We use data science for social good by using innovative data sources, methods and visualisations to solve problems and find new insights to social issues. To do this, the data analytics team contains people with a range of skills, from data scientists and data engineers to those specialised in data discovery and data visualisation.

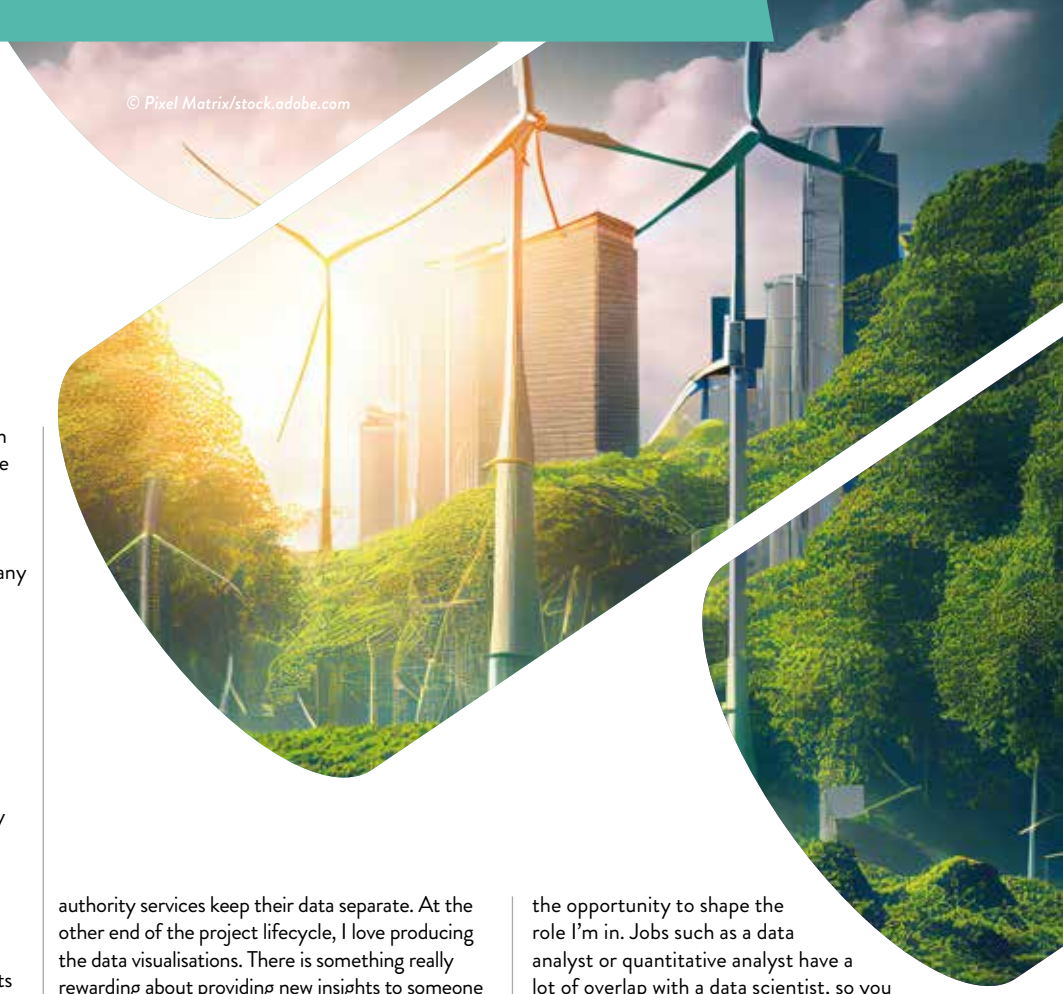

## What does your role at Nesta involve?

My job is really varied. I lead a small team of data scientists and quantitative analysts and I am the lead data scientist in Nesta's Fairer Start mission. This involves managing the workload of projects, suggesting potential avenues for new research, finding ways to tackle social challenges with data science methods and establishing which outputs will be most useful for our stakeholders.

In one project, as part of the A Fairer Start Local partnership, we worked with the City of York Council to help them make data-driven decisions related to the uptake of health checks for two-year-old children. I was involved throughout the entire project lifecycle, from helping to devise the research questions, to cleaning and pre-processing their data, to developing the final product. This was a prototype dashboard that allows the council to see the uptake of health checks across the city, and how it varies between different demographics.

## How do the skills you learnt during your PhD help you now as a data scientist?

I did a PhD in volcano seismicity, during which I developed a new algorithm to separate volcanic earthquakes from tectonic earthquakes in areas where they often co-exist. I now apply the techniques and methods I used to analyse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earthquake data to analyse childhood data from local authorities across England. My earthquake algorithm and all my PhD data analyses were conducted in Python, which I taught myself how to use through online courses. As well as knowledge of Python programming, I learnt many transferrable data skills in my PhD: cleaning and pre-processing data, ensuring algorithms are efficient, creating data visualisations to communicate my results...

### What do you most enjoy about being a data scientist?

I love the variety of projects I work on and the real-world impact I have. For example, the City of York Council is now using the dashboard we created to develop new methods to encourage parents to bring their two-year-old for their health check.

From a data science perspective, I enjoy all aspects of the role – even the data cleaning! I especially like the creativity of trying to come up with new ways to solve a problem. This is often a real challenge when studying early childhood data, as different local authority services keep their data separate. At the other end of the project lifecycle, I love producing the data visualisations. There is something really rewarding about providing new insights to someone and presenting their data in a way that helps them understand their own work more.


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### What advice can you give young people interested in a career in data science?

Even if you've only used coding languages a little bit, you're off to a good start. There are lots of online courses that can supplement your coding and programming skills, so you don't need to have a university degree explicitly related to data science. A lot of the skill in data science is thinking about how you could tackle problems and what research questions you need to ask of the data.

For me, where I worked was more important than just doing data science, and Nesta have given me the opportunity to shape the role I'm in. Jobs such as a data analyst or quantitative analyst have a lot of overlap with a data scientist, so you could start in these roles and then transfer to data science. It may be that you become a data analyst at a company you're interested in, and as you develop your skills you could then move towards a role more focused on data science.

## **Find** out more

- **www.nesta.org.uk**
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> **"A LOT OF THE SKILL IN DATA SCIENCE IS THINKING ABOUT HOW YOU COULD TACKLE PROBLEMS AND WHAT RESEARCH QUESTIONS YOU NEED TO ASK OF THE DATA."**


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# Modelling mines: how can a new 3D modelling platform make mining more sustainable and be part of the solution to climate change?

Despite public perceptions, mining is set to play a vital role in the planet's transition to a sustainable future. Many low-carbon technologies, such as electric cars and solar panels, rely on metals that need to be dug out of the ground. **Dr Laurent Ailleres**, from **Monash University** in Australia, and his team are developing a 3D modelling platform that will help mines become more efficient and reduce their environmental and climate impacts.

**Dr Laurent Ailleres**

School of Earth, Atmosphere and Environment, Monash University, Australia

PROFILE

**Field of research**
Geoscience, Computer Science, Mathematical Geology

**Research project**
Developing software that creates accurate 3D models of mine sites to improve their efficiency and sustainability

**Funders**
Australian Research Council (ARC); federal, state and territorial geological surveys in Australia, exploration and mining industries

**Collaborators**
National (Australia, Canada, UK and USA) and Australian state and territory geological surveys, University of Western Australia, Université de Lorraine and d'Orléans in France, RWTH Aachen in Germany, the CSIRO and AuScope.

TALK LIKE A ...

## GEOSCIENTIST

**Orebody** — a connected mass of ore (naturally occurring metals or valuable minerals)

**Barren rock** — rock that does not contain any useful metals or minerals

**Stratigraphy** — the layering present within a mass of rock

**Lithology** — the rock type defined by mineral content and textures

What do you think of when you hear the word "mining"? Do you think of black and white photos of tired looking men covered head to toe in dirt? Of pickaxes and minecarts or coal and dead canaries? Chances are, you do not think of the clean and green low-carbon tech of solar panels and electric vehicles (EVs). But the reality is, mining is as important today as it ever has been, and it will play an essential role in transitioning to a more sustainable future for our planet.

Metals such as lithium, cobalt, copper and nickel are vital components of many low-carbon technologies. All these metals are used in the manufacturing of batteries for EVs – for example, copper is essential to conduct the electric power to electric engines. Many governments around the world are putting a lot of faith in EVs to help them reach their climate targets. Both Australia and the UK, for example, are aiming to be carbon net-zero by 2050. In Australia, the Beyond Zero Emissions' Electric Vehicles Report says a complete shift to EVs is feasible well before 2050. In the UK, the Climate Change Committee has recommended that all 49 million vehicles in the country should be replaced with EVs. With such ambitions, the demand for mining is likely to skyrocket over the coming years.

The problem, however, is that mining has traditionally had a detrimental effect on the environment. Mines consume a lot of energy and water when they are drilling and crushing rocks, which they do to extract metals and minerals. They also produce a lot of waste in the form of barren rock and contaminated slimes that can leech into the surrounding environment and pollute waterways, farmland and natural habitats. The water and energy used by a mine, along with the waste produced, is part of its mining footprint.

The challenge is to reduce the amount of energy and water needed and waste produced during the mining process, whilst simultaneously increasing the output of important metals. Dr Laurent Ailleres, from Monash University, has led the development of an ingenious new modelling tool, called Loop, that could help the mining industry rise to the challenge.

### What is Loop?

Loop is an open-source (freely available) modelling software that can be used to create detailed 3D models of geological features that exist underground. For example, an orebody is a mass of rock within a mine that contains valuable metals. Loop enables mine engineers and geologists to model and map the characteristics of an orebody accurately. These characteristics might include the


types of ore that are present, as well as their density and distribution, along with the structure and condition of the surrounding rock.

"These parameters have huge influences on how to extract and process the ores," explains Laurent. If an orebody is modelled accurately, the whole process of discovery, extraction and processing the ore can be optimised. This would result in less drilling and a more efficient processing phase, which would, in turn, reduce the amount of water and energy needed, and the amount of waste produced.

## How does Loop work?

Loop software makes use of geological maps that have been constructed from field data. These data are collected from surveys of the surface geology and drill holes, which allow geologists to build a picture of the subsurface rock. Drill holes can extend deep into the rock. However, their diameter is often just 5-10 cm. They produce samples that reveal how an orebody is layered (its stratigraphy) and other aspects of its lithology and physical characteristics.

Loop software combines these data to make predictions about the lithology and stratigraphy of an orebody. Once this is done, Loop can simulate other properties within the orebody using various geostatistical methods.

It is important to remember, however, that Loop relies on predictions and simulations to produce its models. "The results are highly uncertain, and it is essential that this uncertainty is characterised throughout the entire workflow," explains Laurent. This ensures that all possible predictions have been considered.

The current method of building models relies on subjective interpretation of the field data, and this varies from one geologist to the next. Loop software builds models based on objective field data, ensuring the models it creates are as realistic as possible while fitting the data.

> **"WHAT HAS MORE VALUE IN THE LONG TERM – DRINKABLE WATER OR METALS FROM THE MINE? IS THERE A SOLUTION THAT WOULD ENABLE BOTH TO CO-EXIST? THESE ARE QUESTIONS THAT LOOP MODELS CAN HELP ANSWER."**

## What are the benefits of this automation?

As well as removing the subjective aspect, Loop software can create models much faster than current methods. This means that testing different predictions and scenarios can be done rapidly, and better characterisation of the orebodies can be achieved.

Some of the parameters needed to create 3D models can be difficult, or even impossible, to measure in the field. Loop gives geologists the ability to build multiple models that use different values for these parameters, allowing them to explore all the possibilities in greater detail. "This is essential for understanding and quantifying uncertainty and mitigating risks," says Laurent. By considering the uncertainty of a model, mine and exploration geologists can decide whether to move ahead with a project or whether they need to collect more data. Having sufficient data is essential for minimising risks, as using inaccurate models to make decisions could potentially backfire.

## How can Loop models help reduce risk?

Having accurate 3D models of a mine gives geologists and mine engineers a more detailed picture of how it will interact with its surrounding environment. For example, mines located near important waterways can cause severe environmental damage. Rainwater and drainage can wash pollutants from a mine into nearby rivers and reservoirs, causing harm to the local wildlife and even putting human health at risk.

"What has more value in the long term – drinkable water or metals from the mine?" asks Laurent. "Is there a solution that would enable both to co-exist?" These are the kind of questions that Loop models can help answer. The models could also be used to monitor other polluting activities, such as agriculture, and advise on how best to minimise their negative impacts.

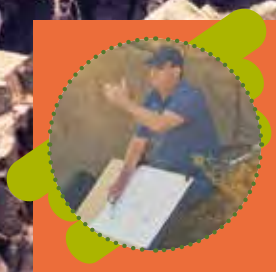
## Why are community values important to Loop?

The team behind the Loop project is made up mainly of researchers and developers. For the project to be successful, a thriving and diverse community needs to be built. "Our community is growing," says Laurent. "Users will provide feedback on what works well and what requires improvements." In this way, Loop will be able to adapt and evolve to best suit the needs of the mining industry.

Laurent hopes that as more people start using Loop software, its benefits will become evident to a wider audience. As it is open-source, it is accessible to a wide range of users. He explains, "We need champions in the community to demonstrate how Loop is actually reducing the mining footprint and improving subsurface resources management."

## What's next for Loop?

The team's current focus is on making the software easier to use and more accessible so that other groups can build their own models and answer their own questions. "The next big step is to start a not-for-profit company to make the development sustainable over time and less dependent on ARC funding," says Laurent. If Loop can become self-sufficient and continue to expand its community, it could find itself playing a crucial role in the mining industry's transition towards a more sustainable future.



# Q&A

## Meet Laurent

**What do you find rewarding about research in geoscience?**

Over the years, I have had the chance to travel to many different places and meet people of many varied cultures. These encounters are always amazing and have made me a much more tolerant person. Our planet is beautiful, and the people inhabiting it are resilient and loving.

**How will geoscientists contribute to solving future challenges?**

Planet sustainability should be at the forefront of future research. Geology, maths, physics, chemistry and biology are all sciences that will be leading this research. Engineering will be important for developing and making the systems that will achieve a more habitable planet. There is also a lot happening in the realm of data science, however, basic geology research is still required and is essential for making use of the outcomes of data analytics.

**Who or what inspired you to become a scientist?**

My year 10 geography teacher taught us about plate tectonics, and that was it! As a kid, I was already collecting rocks and minerals, but without really understanding why, or what they were. I soon realised that I could combine my love for mountaineering, and mountains in general, with studies. Eventually, I studied my PhD in the French Alps, partly because I used to go there every summer.

**What led you to focus on geoscience?**

That lesson about plate tectonics was a eureka moment for me and is engraved in my memory. From then, I knew I wanted to study geoscience at university, and I worked hard to achieve that.

**What attributes have made you successful in your work?**

I have an interest in everything, which can be detrimental as you can touch on too many things without really making progress in any aspects. I am stubborn though, and I believe in my abilities to focus my research on what really interests me. I love fostering and developing relationships with younger scientists to help them develop as people. I love interacting with students, either as a PhD adviser or a teacher. Teaching in the field and in developing countries is so rewarding!

**What are your proudest career achievements so far?**

Leading the Loop initiative is something that I am very proud of. I have also taught in developing countries and worked as part of development teams for research programmes in Africa. Another part of my work that I find extremely rewarding is mentoring my PhD students and seeing them go on to have fantastic careers.

## Pathway from school to *geoscience*

- Maths, physics, chemistry and geology are all essential for understanding the processes involved with our planet.
- Laurent says, "Be passionate, and follow wherever your passions take you."
- Be pro-active and get involved with a research group as soon as you can. If you know a geologist, go and talk to them. If you live near a university, contact its geoscience department and see if there are any volunteering or work experience opportunities available.

## Explore careers in *geoscience*

- Depending on where you are in the world, the Geological Society of Australia (**www.gsa.org.au**), the Geological Society (UK) (**www.geolsoc.org.uk**), and the European Geoscience Union (**www.egu.eu**) are all good places to get information about careers in geoscience.
- Geoscience is just one of a whole range of Earth sciences. People of Earth Science (**www.peopleofearthscience.com**) is a website where you can learn about different Earth science careers directly from scientists' experiences.
- Women in Earth and Environmental Sciences in Australasia (**www.womeesa.net**) has a 'members spotlight' section that showcases some of the amazing work being done by women working in Earth sciences.

# **Meet** *the team*

**Dr Lachlan Grose**

**Role:** LoopStructural Research Lead

**Field of research:** Structural Geology

**I wasn't really exposed to geoscience throughout school and didn't realise it was a potential career path, but I have always been interested in science.** At university, I chose to study geology because it looked interesting and seemed to apply a bit of maths, physics and chemistry together. After my first couple of years doing geoscience, I knew it was what I wanted to do. I'm not a field geologist, but I've still been lucky enough to visit some amazing places, including La Palma in the Canary Islands, the Atacama Desert in Chile, and Kalgoorlie and Broken Hill in Australia.

**In my third year of studying geoscience, I was really interested in geophysics and 3D modelling.** During these classes, I was exposed to work on quantifying geological uncertainties, and this seemed to be a new area of research. I did my honours project on this topic, where my aim was to quantify the interpretive uncertainty that geologists make when drawing a map by comparing maps produced by undergraduate students during a field camp. Following this, I applied to do a PhD project. This involved trying to use structural geology to create 3D models of folds, which are a feature of some sedimentary rocks.

**I am the leader of the 3D modelling component of Loop.** There are two aspects to my current role. Firstly, I need to maintain and develop the 3D modelling code so that others can use it. Secondly, I spend time trying to solve existing problems with the methods we use for building 3D models. This often involves collaborating with other people and supervising students. I regularly work with colleagues in France, the UK and Canada. A typical day for me would involve spending the morning doing research and testing new ideas or writing. I usually spend the afternoons on the less exciting topics, administration and fixing bugs in the 3D modelling code.

**As a chief investigator and work package leader for Loop, I have a lot of responsibility.** I ensure that our 3D modelling tools are both innovative and user-friendly. It can be challenging to balance both aspects. It is very rewarding when attending conferences and workshops and seeing how many people have started to use Loop after only a few years of development.

**I am proud of the growing uptake of the software that we have developed for 3D modelling.** It is nice to see all the hard work being used and appreciated by members of the community. I find this more fulfilling than publishing papers that may or may not be read.

**I hope that with Loop we can change the way resources are managed** by building tools to be able to predict and quantify the geometry of geological features in the subsurface.

## **Lachlan's** *top tips*

1. Follow geological surveys and university departments on social media.
2. Doing an internship can be a great way to see if you enjoy working as a geoscientist.
3. Take any opportunities you are given. You never know where new experiences will lead.

# **Meet** *the team*

## Mr Roy Thomson

**Role:** Senior software developer and software architect

**Field of research:** Software Design

**After floundering between different courses at university, I found that I both enjoyed and was good at understanding and writing computer code.** This is something that my dad – who did programming and system design – suspected but didn't want to force me into. The example my father set with his dedication to detail, seeking solutions to real problems, and letting me find my own path inspired me to pursue a career like his.

**My current role is a combination of software developer, team leader and software architect, so every day is different.** Some days, I am deep into code, finding a bug, writing new features, or rewriting code to be more efficient. Other days, I am reviewing other developers' code or evaluating the structural design of a new module. On yet others, I am looking at the bigger picture of how data should flow from initial data collection in the field, through the process of creating models, to finally making recommendations for further research. This last part is the most nebulous as it requires researching a broad range of available software systems and emerging trends in technology, as well as the ability to decide when a promised technology or trend is too good to be true.

**The focus of my career has been visualising information in understandable and efficient ways.** As this focus is so general, I have been able to apply it to vastly different fields of study, from aerospace to Earth science. Given my interest in geological processes, the opportunity to work with Loop was perfect for broadening my knowledge and diversifying my career.

**The greatest challenge for me is knowing when to stop looking for the perfect solution** and, instead, choose the correct balance between efficiency, usability and resources. Specifically for Loop, there are a huge number of ways to create and compare 3D models and just as many technical solutions. While I would like to systematically experiment with each solution, this would be impossible due to the amount of time it would take.

**The biggest reward for me is seeing my ideas and design come to fruition and making a difference in how an industry does things.** There is quite a lot of excitement about our work within geoscience surveys and a revitalisation of 3D geophysical and geological modelling more generally. It is great to be part of it all.

### **Roy's** *top tips*

1. Find your passion and what you are good at. This can take time, but it's worth exploring your options. If you find both in the same thing, make it your career.
2. Keep up to date with new technology, and look behind the hype into how it actually works. So many things are rebadged old technology that won't work at scale.
3. Seek a variety of opinions as everyone has their own biases, including me.

## Dr Angela Rodrigues

**Role:** Post-doctoral researcher

**Fields of research:** 3D Modelling, Data Science, Mineral Resources

**My family has a long line of stone masons; we are known by the nickname Pedras, which means "stones".** As a child, I was always familiar with rocks, and even had a small rock collection. Later, when I was in school, I learned how studying these rocks helps scientists unravel Earth's history. That is what originally led me to pursue geoscience.

**When I got a job as an exploration geologist, I had the chance to analyse datasets collected from drill-holes.** How to mathematically describe an orebody underground from these datasets quickly became my passion. This is why I pursued a PhD under the supervision of a leading scientist in 3D modelling – Dr Laurent Ailleres.

**On Loop, I am a post-doctoral researcher involved in building a 3D model of the Kalgoorlie terrane, located in Western Australia.** A typical workday encompasses the analysis of geological data collected by the Geological Survey of Western Australia and its integration into a 3D geological model.

**The most challenging part of working on the Loop project is to apply both mathematical and geological concepts in real world data.** Most geological features are underground, so sometimes the geology we observe at the surface might not match the interpretations we make in the subsurface.

**I am looking forward to being involved in the development of LoopResources,** which will deliver an optimised workflow for characterising orebodies and, ultimately, developing more sustainable mining practices.

### **Angela's** *top tips*

1. Set yourself targets and stick to them. This will help you stay focused.
2. Explore different possible career paths before deciding which route to go down.
3. Find a mentor and discuss your options with them.

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## Mr Rabii Chaarani

**Role:** PhD student

**Field of research:** Structural Geology

**My love of geoscience goes back to my childhood** when I was impressed by the drawings of dinosaurs in my parents' encyclopaedia. I read their story over and over for a big part of my childhood. When I got into high school, I chose Earth sciences as a specialty. Then I continued with geosciences at university, where I specialised in structural geology.

**My PhD is focused on optimising field data collection for folded rock layers.** I use Loop to run my experiments to find out how to optimise data collection. When I started my PhD, I was mainly trained to work in the field. With Loop, I learnt a lot about the computational side of structural geology. In the future, this will allow me to work on projects requiring fieldwork and modelling simultaneously.

**My research will lead to efficient data collection for folded rock layers and increases confidence about their geometry at the surface and subsurface.** After my PhD, I would love to work for a geological survey or in the industry where I can keep working with Loop and implementing the strategies I am discovering in my PhD.

### Rabii's *top tips*

1. Studying can be intense. Make sure to take care of your mental health as best you can.
2. Visit the Geology Page website for an excellent overview of various fields in geoscience: www.geologypage.com

## Ms Fernanda Alvarado-Neves

**Role:** PhD student

**Field of research:** Structural Geology

**As a kid, I watched TV shows about palaeontology and volcanoes.** I have also always loved maths and science, so I decided to pursue a degree in geology. During my undergraduate degree, I learnt about many other exciting geoscience fields, such as structural geology, tectonics and hydrogeology. I realised how fun and fulfilling working in the field is.

**My typical day involves coding, academic writing, reading and research, and meetings with my research group and supervisors.** I am also part of the Women in Earth and Environmental Sciences in Australasia committee, so I spend some hours organising workshops and networking events for our community. During my PhD, I also had the opportunity to do fieldwork and present at conferences and workshops in Australia and overseas.

**My PhD aims to develop a method to build 3D geological models of igneous intrusions.** This method is part of the Loop platform, and the research team has been essential to my PhD outcomes. I had little experience in coding and 3D geological modelling before starting my PhD, so I have gained many new skills working with Loop.

**Fieldwork and conferences have been extraordinary experiences, with much learning involved.** When you work with 3D models, every time you visualise a model, and it works as you expected, it is a little eureka moment.

**I believe my research will be a step towards a better characterisation of the Earth's subsurface.** This could be used for different goals, for example, assisting in finding new water and mineral resources, or developing maps for volcanic hazards.

### Fernanda's *top tips*

1. Always be open to new learning opportunities.
2. Be excited! A career in geoscience is super rewarding.
3. Explore all the different options within the field of geoscience.

# Practical activities to help geoscience students develop the skills they need to succeed

Traditional teaching methods that focus on the memorisation and regurgitation of facts rarely lead to genuine learning. **Dr Lisa Doner** and her team from **Plymouth State University** in the US have developed a programme full of practical activities that allow their students to develop the skills needed for a successful geoscience career.

**Dr Lisa Doner**

Associate Professor, Center for the Environment, Plymouth State University, USA

PROFILE

**Field of research**
Geoscience

**Research project**
Developing an educational research programme to help students gain the skills they need for a successful career in geoscience

**Funder**
US National Science Foundation (NSF)

TALK LIKE A ...
## GEOSCIENTIST

**Albedo effect** — the reflection of sunlight from the Earth's surface

**Critical thinking** — the analysis and evaluation of available evidence and arguments to reach a conclusion or create a new idea

**Eutrophication** — the process by which a body of water becomes enriched with nutrients, often leading to algal blooms and the creation of dead-zones

**Watershed** — an area of land that channels rainfall and snowmelt through streams and rivers and eventually into lakes, reservoirs or the ocean

**Runoff** — a major source of pollution, runoff occurs when excess water flows across the surface of land and into nearby streams, rivers or ponds, picking up toxic substances along the way. Nutrient-rich soil or water contains large amounts of nitrogen, carbon, phosphorus, sulphur and potassium

As all high school students know, learning new things can be challenging. Perhaps you have found yourself thinking, "Why would I possibly need to know about the second law of thermodynamics?" or "How is Pythagoras' theorem going to benefit me in the future?" Reciting facts, memorising formulas and deciphering abstract concepts can feel tedious, confusing and pointless.

Traditional teaching methods that focus on the memorisation and regurgitation of facts have bored students for centuries. These methods rarely lead to genuine learning, with students often forgetting what they have learnt as soon as the exam is over or their coursework is submitted. However, there are other ways of teaching that can help students truly understand new concepts and apply them in a range of situations.

For example, taking part in practical activities that require students to use scientific concepts can be a great way for them to cement their learning. This is particularly true if the activity is related to topics that are relevant to the students' lives or local areas. This approach helps to ingrain knowledge and makes the concepts more accessible when students try to apply them in different situations.

The GeoPaths project at Plymouth State University in the US uses practical teaching methods to help its students learn. Led by Dr Lisa Doner, the project also provides mentors for its students and helps them find internships and develop skills that can boost their resumes and career prospects.

### What is GeoPaths?

GeoPaths is an educational project designed to cultivate the scientific knowledge and skills needed to start a successful career in the field of geoscience. Plymouth State University is a predominantly undergraduate institution (PUI), meaning that its main focus is on teaching undergraduate degrees, rather than facilitating the research of professors and lecturers. As a result, students at PUIs generally have fewer opportunities to gain experience and skills in the more niche areas of science.

"Students who dream of studying glaciers," says Lisa, "or exploring the deep sea or the moons of Saturn, might be discouraged with schools that don't have instructors who can teach glacial geology, physical oceanography or planetary sciences." These kinds of specialties are more common in schools that have a greater focus on research. The GeoPaths project is a way to give PUI students the practical skills and career opportunities they might not otherwise receive.

*In Plymouth, New Hampshire, unversity students set up a field of mirrors and temperature sensors to explore the impact of changes in albedo on Earth's surface.*

### What are the aims of GeoPaths?

The overall goal of the project is to inspire students towards a career in geoscience whilst also building the critical thinking and technical skills that will help them along the way. Students enrolled in GeoPaths take part in a research project based around watershed areas. These are areas in which surface water converges at a single point, like a river mouth, or flows into another body of water, like a lake. Students in the GeoPaths project design, calibrate and analyse the data from monitoring devices that they use to study watersheds.

By engaging with the watershed research project, students are helping the local community understand more about their environment. The students gather and analyse essential data which helps to generate new knowledge about the local watershed system, such as how rainfall interacts with the land and how sediments are deposited in lakes.

GeoPaths students do not just gain practical skills from these activities. They can use these experiences to help them bolster their resumes and connect with other scientists, be that through their internships, post-graduate courses or professional careers. Students enrolled in the GeoPaths project are assigned mentors who help them make the most of these opportunities.

### What role do mentors play in GeoPaths?

"Mentoring is about going beyond simple instruction when interacting with students," explains Lisa. "It includes being aware of, and sensitive to, challenges that students may have in their lives that limit their ability to learn at the same tempo as students with fewer challenges."

GeoPaths students come from a variety of backgrounds and so it is important that the mentors reflect this. "Students from non-white communities may not fully benefit from mentoring offered by an entirely white faculty," says Lisa. "A sense of connection may be more easily accomplished if the mentors come from diverse backgrounds."

> **"THINKING ABOUT THE ENVIRONMENT REQUIRES WORKING IN ALL OF EARTH'S SPHERES."**

The mentors engage the students in ungraded activities that are intended to build a student's confidence when working as a scientist. Much of this is done by developing basic skills such as collecting and analysing data, performing calculations and using computer software such as Excel.

### What other activities do GeoPaths students take part in?

The activities offered to GeoPaths students provide them with a range of practical skills and experiences. There are field trips led by expert hydrogeologists, on which students study river overflow; snowpack assessments, in which students examine the layering and stability of fallen snow; and electronics training, in which students program software for temperature sensors. The practical skills that the students cultivate whilst doing these activities are likely to come in handy when they start their careers.

The GeoPaths project also helps its students take the first steps into a successful career in geoscience. Mentors help their students make connections with major research agencies and guide them through the process of searching and applying for jobs. Students are shown how to tailor their resume to their desired job descriptions and pick out areas in which they are making good progress, as well as areas in which they may need to develop new skills.

### What skills are important for a successful career in geoscience?

As well as the practical, technical and professional skills gained from these activities, one of the most important skills is critical thinking. Specifically, critical thinking from a geoscientific point of view. "Thinking about the environment requires working in all of Earth's spheres," says Lisa. "Most environmental textbooks focus almost entirely on the biosphere, but by deliberately bringing geology to the forefront, we can introduce aspects of the environment that are otherwise brushed over."

Take the problem of eutrophication, a process in which bodies of water are overloaded with nutrients that disrupt food webs and kill off wildlife. This is often seen as an entirely biological problem, but geoscience elements are also at work. For example, it is important to understand the role that soil plays in controlling nutrient-rich runoff from agricultural land, or what happens to nutrient-rich sediments when they are deposited at the bottom of lakes. Taking these elements of geoscience into consideration and thinking critically allows scientists to consider solutions more broadly.

### What successes has GeoPath had?

The success of the GeoPaths project is measured, in part, by the careers of its alumni. Of the six students who graduated from the first cohort, three progressed on to graduate school, one is working as a seasonal hydrologic technician, and another is a consultant at a geotechnical firm. Students from the second and third cohorts have completed internships and are well on their way to starting successful geoscience careers.

GeoPaths has also developed an exciting new research project that is used to help train students, teachers and the general public. This project, called MEERCAP, focuses on elements of geoscience that relate to climate change, and engages people from a much broader community than GeoPaths.

# ABOUT *MEERCAP*

Mirror Exploration, Experimentation, and Reflection in Climate Adaptation Planning, or MEERCAP, is a field experiment developed by researchers at Plymouth State University. The project has been designed to investigate whether collections of mirrors can reflect enough sunlight to create a cooling effect in the surrounding environment, and potentially combat climate change.

"The earliest climate modellers understood that changes in Earth's reflectance, or albedo, was a primary factor in causing cooling or warming," explains Lisa. Light-coloured surfaces, like snow and ice, have a high albedo and reflect a large amount of sunlight away from Earth's surface. In contrast, dark, non-reflective surfaces have a low albedo and absorb a lot of sunlight.

For decades, researchers have been investigating different ways of increasing the albedo effect, from painting roofs with white paint to releasing clouds of reflective particles into the atmosphere. MEERCAP's approach, using collections of mirrors, is an affordable and easy-to-implement method of increasing the albedo effect on a local scale. Lisa explains, "Using mirrors improves on the effectiveness of the white roofs idea because mirrors have over 95% reflectance and can be aimed at the sun in the most-effective angle."

MEERCAP has two field sites, each with six plots. These include control plots, which have no mirrors, and experimental plots, each of which have a different number of mirrors. All the plots have an identical network of sensors which capture changes in ground temperature and soil moisture.

### How are students involved in the project?

The third cohort of GeoPaths students were involved in developing the MEERCAP project. "As we worked on the project with the students," says Lisa, "we realised how many additional, job-essential, training activities we could add to the student experience."

When taking part in the MEERCAP project, students help design the frames that hold the mirrors, set-up and repair the sensors, and write the programs that collect and download the data. "Going forward," continues Lisa, "we anticipate that students will create and test their own research questions dealing with the interaction of the sun and the mirrors." The MEERCAP project provides students with a chance to improve their critical thinking skills as well as develop additional practical skills.

### Why are these additional skills important?

"Many children grow up without any practice in using tools," says Lisa. Learning how to hold a screwdriver, wield a hammer and cut and shape materials like wood are important skills. "Almost every job outside of a desk setting includes an occasional need to work with such tools," explains Lisa.

Most repairs to environmental monitoring sites are made by the researchers who use them. Students who know how to use hand tools will be able to apply these skills in problem-solving situations, which will make them valued employees. "Their knowledge in these areas can reduce maintenance delays and save the costs of hiring outside expertise," says Lisa, who speaks from personal experience in field work.

***"THE EARLIEST CLIMATE MODELLERS UNDERSTOOD THAT CHANGES IN EARTH'S REFLECTANCE, OR ALBEDO, WAS A PRIMARY FACTOR IN CAUSING COOLING OR WARMING."***



## Explore careers in *geoscience*

- Explore the Careers and Internships page on the US Fish and Wildlife Service webpage (www.fws.gov/careers). You can see the kinds of opportunities available to budding environmental scientists and apply for roles they are advertising.
- The US Fish and Wildlife Service also offers summer internships designed specifically for students. It provides a range of programmes in locations all across the US.
- The US Geological Survey offers internships to students at all levels of their education: **www.usgs.gov/human-capital/students-and-recent-graduates**
- Many other organisations and universities offer summer schools that focus on geosciences. Contact organisations and universities in your area to see what opportunities they offer.
- Even if universities do not offer summer schools, it is worth getting in touch with professors to see whether they can provide work experience opportunities.

# **Meet** two GeoPaths students

## Emma Cox

Earth Sciences Student,
College of Earth and Mineral Sciences,
Penn State University, USA

**When I graduate, I'd like to do research** about current climate change, study ice cores and climatological records, and receive my doctoral degree.

**I took part in GeoPaths and MEERCAP because I wanted to gain real experience in laboratory and fieldwork research for climate sciences,** especially since this project has so much potential.

**I gained extensive knowledge of how experimentation and research happen in the real world** through constant problem-solving, developing conclusions to help further the experimentation, and learning how to use new tools and software.

**The thing that sticks out for me the most is the importance of collaboration when doing research.** Teamwork is important for solving problems, coming up with new ideas, and getting tasks done more efficiently.

**I would recommend a career in geosciences.** If you love to learn about Earth through both physical interaction and scientific analysis, geoscience is a great path for you.

**My advice is to try to save your notes and textbooks from classes and make connections with professors you like.** It's a wide field with many interesting niches. Explore the field of geosciences confidently, and don't be afraid to ask questions.

*Emma shows fellow interns how to survey the mirror field using a total station.*

## Myles Sornborger

Former Environmental Science and Policy Student, Plymouth State University, USA

**When I graduated, my goal was to start a science career in New England.** I am achieving that as a hydrologic technician with the White Mountain National Forest. I took part in GeoPaths because I wanted to gain real experience early in my college career.

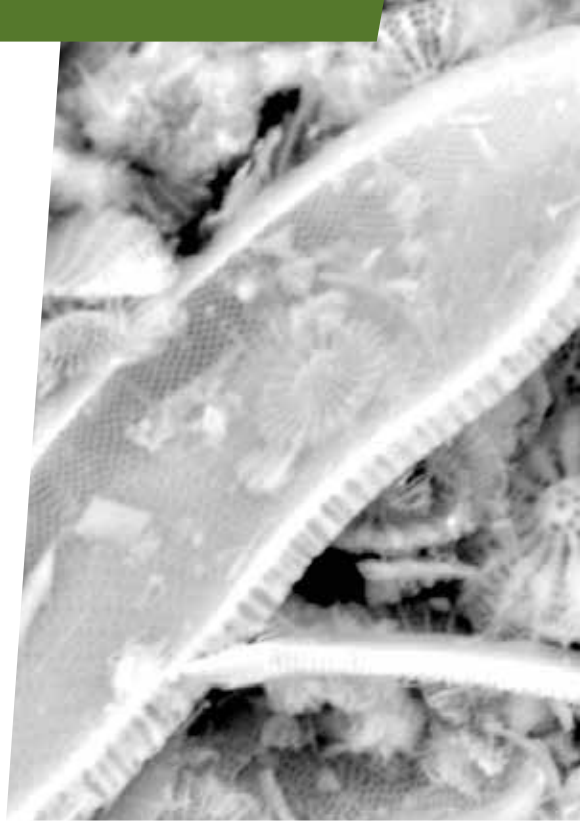
**Thanks to GeoPaths,** I gained a head start in developing soft skills that everyone needs for a successful career, as well as many other skills that make my resume more notable.

**I also received guidance on finding a career path that would fit me,** and my relationships with my mentors have continued beyond the project. I particularly enjoyed the time I got to spend with my mentors and cohort, both in the field and the classroom.

**If geoscience interests you, I would absolutely recommend it.** The career opportunities are there. Get as much practical experience as you can and don't specialise too early.

*Myles at work on his GeoPaths internship, Franconia Ridge, New Hampshire.*

# Can tiny fossils disrupt global communications?



Microfossils are often smaller than a grain of sand, yet when they accumulate on the seafloor, they can have significant impacts on sediment stability. **Dr Julia Reece**, a marine geologist at **Texas A&M University**, USA, believes they may play a role in initiating submarine landslides. These underwater hazards pose threats to coastal communities and global communications, so it is vital to understand how they occur.

**Dr Julia Reece**

Sediment Mechanics Lab, Department of Geology and Geophysics, Texas A&M University, USA

PROFILE

**Fields of research**
Sediment Mechanics, Marine Geology

**Research project**
Investigating the role of microfossils in initiating submarine landslides

**Funders**
US National Science Foundation (NSF, Award # 1945011), US Science Support Office (USSSP)

*The contents are solely the responsibility of the authors and do not necessarily represent the official views of NSF*

## TALK LIKE A ... MARINE GEOLOGIST

**Coastal upwelling** — deep nutrient-rich water rising to the ocean surface near continents

**Consolidation** — volume reduction in sediments by the expulsion of fluids in response to a pressure increase

**Diatom** — a single-celled organism that produces an outer skeleton made of silica

**Hydraulic** — a system defined by moving fluid in a confined space under pressure

**Hydrothermal** — heated water

**Impermeable** — does not allow fluid to flow through

**Pore fluid pressure** — the pressure acting on fluids in rock or sediment pores (the voids between grains)

**Resedimentation** — a technique to simulate the natural process of sedimentation and burial under controlled lab conditions

**Shear strength** — a material property that describes a material's maximum resistance against shear load before it fails

**Shear load** — a force that acts parallel to the plane of loading (like when both hands are aligned and moved past one another in opposite directions)

**Submarine landslide** — an underwater landslide in the ocean

**Triaxial compression** — compressing a sample in the vertical direction while it is subjected to pressure in all directions

**Uniaxial consolidation** — compressing a sample in the vertical direction while it is confined horizontally

When you hear the word 'fossil', what do you think of? The giant bones of T-rex and stegosaurus? The gracefully coiled spiral of an ammonite? These are the fossils that most of us are familiar with. But fossils come in all shapes and sizes, and many geologists would argue that microfossils are the greatest fossils of all – incredibly small and exquisitely beautiful, not only can microfossils teach us about past climates, but they are extremely useful in our everyday life. You can find them in toothpaste, water filtration systems and cat litter!

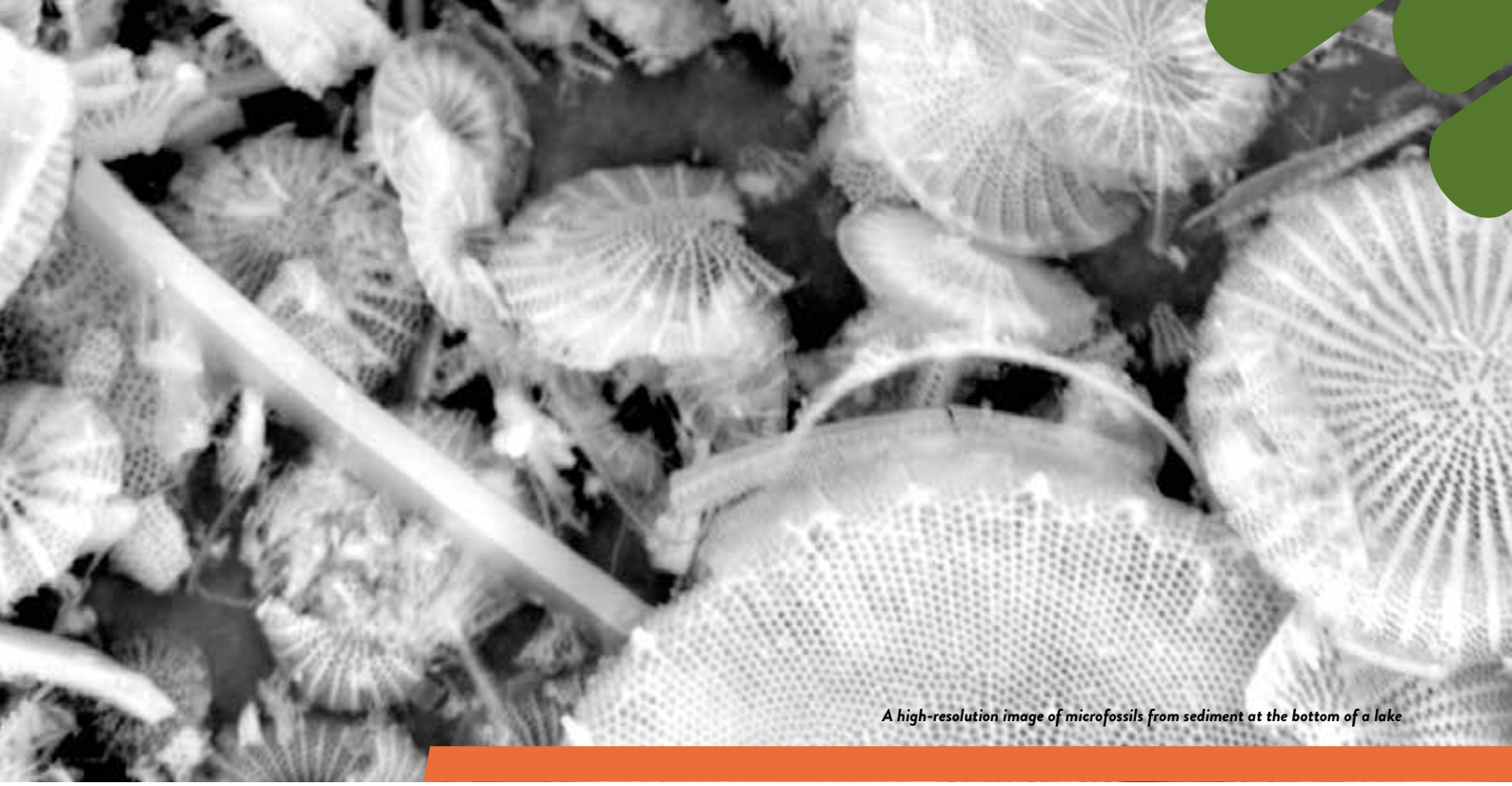
### What are microfossils?

As their name suggests, microfossils are tiny. "They are often smaller than a grain of sand and can only be inspected with a microscope," says Dr Julia Reece, a marine geologist at Texas A&M University. In the ocean, single-celled organisms (such as foraminifera, diatoms and radiolarians) produce outer mineral skeletons composed of calcite or silica. When the organisms die, their tiny skeletons sink to the bottom of the ocean where they join the sediment accumulating on the seafloor. Julia believes these microfossils in seafloor sediments may play a role in initiating submarine landslides.

### What are submarine landslides?

Submarine landslides occur on the continental margin, the slope that exists between the shallow waters surrounding continents and the deep ocean. If sediment deposited on the seafloor becomes unstable, for example in response to an earthquake, it may collapse as a submarine landslide.

"Submarine landslides pose a significant risk to coastal communities and seafloor infrastructure, as they can generate tsunamis and destroy subsea cables and pipelines,"



*A high-resolution image of microfossils from sediment at the bottom of a lake*

explains Julia. The seafloor is crossed by a network of cables and pipes, transporting digital data, electricity, oil and gas between countries. If you phone someone across the sea, or send them an internet message, the data will be sent through a cable lying on the seafloor. Despite living in a wireless age, 99% of all data that crosses an ocean travel through a seafloor cable, meaning submarine landslides can impact global connectivity and communication.

## How might microfossils initiate landslides?

As microfossils are mineral skeletons that once held single-celled organisms, they are hollow. After the cell dies, the fossil fills with seawater. "Large quantities of microfossils can hold significant volumes of water," says Julia. "If microfossils are buried by impermeable clay-rich sediments, the clay will trap the water in the layer of microfossils. This would increase the pore fluid pressure and reduce the shear strength of the sediment, potentially creating a weak layer that is more prone to failure." To test this hypothesis, Julia and her team of researchers in the Sediment Mechanics Lab are conducting experiments and creating numerical models of sediment failure.

## Combining lab experiments with numerical models

Julia uses a technique called resedimentation to create samples for her lab experiments. She mixes microfossil-free marine sediment with varying amounts of commercially available diatoms, allowing her to control the exact proportion of microfossils in each sample.

She conducts uniaxial consolidation tests on each sample by vertically compressing them to simulate the natural burial conditions of seafloor sediments. This allows her to determine how the physical, mechanical and hydraulic properties of sediments change as they are exposed to greater stresses. Julia then performs triaxial shear tests on each sample by applying pressure in all directions and loading it (uni)axially until the sample fails. "This tells us the shear strength of the sediment and diatom mixtures, which is a critical parameter in the stability of continental margin sediments," she explains. Julia also uses high resolution imaging techniques to observe differences in sediment microstructure during these experiments.

Once Julia understands how microfossils influence the stability of sediments in her lab samples, her next challenge will be to scale up these results so they can be applied to continental margins. Using powerful computer software, she will create numerical models of continental margin sediments to analyse their stability. "The results from our lab experiments become the input parameters to these numerical models, as they define the physical, mechanical and hydraulic properties of all sediment layers," Julia explains. Using her models, she will then test the impact of different factors, such as the thickness of a weak layer, on the stability of a continental margin. "Ultimately, we hope to better understand exactly where failure will occur and under which conditions."

## What data is Julia missing?

"The most accurate and realistic geological understanding is achieved when experimental, numerical and field observations are integrated," says Julia. Her team is in the process of performing lab experiments to measure the properties of sediments and simulate natural processes on a small scale. Next, Julia will develop numerical models based on the experimental results, enabling her to test large-scale scenarios not possible in the lab. Field studies would allow Julia to compare her experimental and numerical observations with real-life data. A combination of these three approaches is best to understand geological processes.

*Ryan Elmore conducts grain size analysis in the lab*
*© Texas A&M University*

"To really test our hypothesis, we therefore need to collect sediment cores from a submarine landslide deposit and its undisturbed counterpart that was not caused by an earthquake, but occurred in a coastal upwelling zone, where the abundance of microorganisms is high," Julia says. During a submarine landslide, the failure plane that initiates the landslide will be destroyed. This means that as well as sampling the material deposited during the landslide, it is equally important to sample the undisturbed sediment on the continental margin, as this will contain the weak layers that may form future failure planes. "Recovering the sediment that comprises these weak layers is crucial for understanding their composition and role in the initiation of slope failure."

## How could Julia sample seafloor sediments?

There are several challenges to sampling seafloor sediments, not least that they are covered by hundreds to thousands of metres of water. This means there is no easy way to access them. Scientific ocean drilling is the only method that can collect them, as research ships can drill sediment cores from the ocean floor and return them to the surface for scientists to study. The second major challenge is that it is a difficult and long process to get scientific ocean drilling projects funded by the International Ocean Discovery Program (IODP). This is hardly surprising when it costs almost $300,000 per day to operate their research ship!

Although Julia has been involved with other IODP missions, the proposal to drill into submarine landslide deposits and continental margin sediments, proposed by her and other international scientists, has not yet been approved. For now, Julia must rely on her lab experiments using natural sediments and numerical models to draw conclusions about the role of microfossils in initiating submarine landslides, helping scientists understand when and where these potentially devastating underwater hazards may occur.

# ABOUT *THE INTERNATIONAL OCEAN DISCOVERY PROGRAM*

The International Ocean Discovery Program (IODP) is a marine research collaboration to 'explore the Earth under the sea'. The IODP uses research ships such as the *JOIDES Resolution* to drill into the seafloor to collect samples of sediments, the rocks below them, the fluids flowing through them and the organisms living in them. These expeditions generate data allowing scientists to uncover Earth's geological, climatic and biological history.

### What do ocean expeditions involve?

From June to August 2022, Julia sailed on the *JOIDES Resolution* as co-chief scientist for IODP Expedition 393. "We were interested in how seawater-derived hydrothermal fluids change seafloor sediments and ocean crust over time," she says. "To study this, we drilled a series of cores along a 930 km-long transect line, perpendicular to the southern Mid-Atlantic Ridge." As the ship moved further from the ridge, the team sampled ocean crust ranging in age from 7 million to 61 million years. This allowed them to quantify changes in the fluid-sediment-rock interactions and the microbial communities living on and in the seafloor, as well as better understand Earth's oceanographic and climate history in the South Atlantic Ocean.

"As co-chief scientist, my job was to ensure our scientific objectives were achieved," says Julia. "It's extremely rare that everything goes smoothly on a two-month long expedition!" When weather and technical issues disrupted plans, Julia had to be adaptable to ensure the expedition's time was used efficiently, productively and safely.

### Who participates in ocean expeditions?

The *JOIDES Resolution* carried 106 people during Expedition 393. Of these, 27 were scientists, specialising in a range of fields (including sedimentology, geochemistry, microbiology and micropalaeontology) and supported by 21 technical staff. The ship's crew performed all the ship's operations, from navigation to managing the drilling process to providing medical assistance, while caterers supplied meals and laundry for everyone.

### What is it like onboard the *JOIDES Resolution*?

"Every scientist works 12-hour shifts, from noon to midnight, or midnight to noon," explains Julia. During their shift, scientists work in onboard labs to describe and analyse the drilled core samples that are collected from the seafloor. They also have meetings with team members and write reports on their results.

Meals are at 6am, noon, 6pm and midnight, and nature of the shift pattern means that while some people are eating breakfast, others are eating dinner. "The espresso and ice cream machines quickly become everyone's favourite!" says Julia. In their free time, scientists might connect with friends and family back home, socialise with others onboard, exercise in the gym or spend time on deck.

### What are the joys of ocean expeditions?

"I love being at sea!" says Julia. "It's peaceful to be surrounded by nature and I'm fascinated by the drilling operations." Not only did she enjoy learning about the drilling process, Julia also liked being part of a diverse group of people. "No matter where you're from or what academic level you're at, everyone works together to achieve the scientific mission of the expedition. I found that very inspiring," she says. Unfortunately, some people find it harder to adjust to life at sea: "I am lucky that I don't easily get seasick. If you do, then the start of an expedition may not be as enjoyable!"

## Pathway from school to *marine geology*

- At school, study geography and any additional environmental or Earth science courses that are available.
- At university, degrees in geology, oceanography, Earth science or geophysics could lead to a career in marine geology.
- Julia recommends taking fundamental courses in mathematics, physics, chemistry and biology to ensure you have a strong base knowledge, as well as specialised geology courses in sedimentology, stratigraphy and oceanography. "If, like me, you are interested in the geomechanical behaviour of ocean sediments, I would also recommend taking civil engineering courses in soil mechanics," she advises.

## Explore careers in *marine geology*

- The National Oceanic and Atmospheric Association (NOAA) features profiles of people working in a range of ocean exploration careers, from marine geologists and geophysicists, to the captains and technicians who keep the research vessels sailing: **www.oceanexplorer.noaa.gov/edu/oceanage/welcome.html**
- Environmental Science provides information about what work you might do as a marine geologist, the qualifications you will need and the salary you can expect: **www.environmentalscience.org/career/marine-geologist**
- If you are interested in marine expeditions, check out STEMSEAS (Science, Technology, Engineering and Math Student Experiences Aboard Ships) at Columbia University. This programme allows high school graduates to participate in NSF-funded ocean research expeditions: **mlp.ldeo.columbia.edu/stemseas**

# Q&A
# Meet Julia

### What were your interests when you were younger?

I have always loved nature. I grew up near the coast in Germany, where my love for the ocean comes from. At school, I enjoyed STEM subjects the most, while my creative side came through my hobbies which included crafting, drawing and painting. Initially, I wanted to become an architect and I even completed an internship at an architecture firm. Now, I believe my sketching ability and attention to detail are critical skills as I process scientific data and conduct meticulous laboratory work.

### Who inspired you to become a geologist?

My high school math, physics and geography teachers sparked my interests in STEM subjects. But it wasn't until I attended a university open day aimed at women students interested in studying STEM that I knew I wanted to become a geoscientist. That was the first time I learned about geophysics and marine geology, and I was immediately hooked.

### What experiences have influenced your career path?

As a student, I believe I gained the most insight and direction from research opportunities and participation in expeditions. Those experiences reinforced my passion for marine geology, increased my confidence and provided critical information to guide my path.

As an undergraduate geoscience student at the University of Bremen in Germany, I had the opportunity to sail on two research cruises, aboard the *RV Meteor* and *RV Polarstern*. These expeditions fuelled my love for marine geology and confirmed I was on the correct career path. As a master's student, I sailed on IODP Expedition 308 in the Gulf of Mexico. One of the expedition co-chief scientists then recruited me as a PhD student, which is how I ended up in the US. My PhD research used IODP data and samples, so my involvement in the programme grew from there.

*The JOIDES Resolution*

*Sediment cores collected from below the seafloor*

### What are your favourite IODP expedition memories?

I have so many good memories of my time at sea! It was exhilarating to see new cores pulled up from the ocean floor and lay our eyes on sediment no one had ever seen before. We had fun onboard, with BBQs on deck and a special feast for US Independence Day. Watching whales, sunsets, night skies and bioluminescence were all amazing experiences. Finally, I will never forget the onboard memorial service we had to celebrate the life of Professor Dick Kroon, a leader in the scientific ocean drilling community, who passed away just before our expedition. It was a very emotional and memorable moment.

### What are your research plans for the future?

I look forward to analysing all the samples that I came home with and synthesising the information we collected, during and post-expedition, with the entire science team. While I am happy to be back on land after two months at sea, I hope to sail again someday so I can answer some of our outstanding questions about submarine landslides, by drilling through them and their undisturbed counterparts.

## **Julia's** *top tips*

**1.** Be proactive and talk to professors
**2.** Seek out new experiences and opportunities
**3.** Enjoy what you are doing and be proud of it!

# How can place attachment improve scientific literacy?

At **Furman University** in the US, **Dr Ben Haywood** and **Professor Julia Parrish** from the **University of Washington** are studying how citizen science programmes impact the relationships participants have with the places and ecology they study which might, in turn, increase scientific literacy. They are investigating whether our emotional attachments to the places around us can be harnessed in citizen science programmes to improve how well we understand our world.

**Dr Ben Haywood**

Associate Director, Faculty Development Center, Furman University, USA

**Fields of research**
STEM Education, Conservation, Environmental Geography

**Funder**
US National Science Foundation (NSF)

**Professor Julia Parrish**

Associate Dean, College of the Environment, University of Washington, USA

**Fields of research**
Marine Ecology, Conservation, Citizen Science

**Funders**
US National Science Foundation (NSF), National Oceanic and Atmospheric Association (NOAA)

**Joint research project**
Critical Thinking and People-Place Relationships in Citizen Science

*This material is based upon work supported by the US NSF Advancing Informal Science Learning (AISL) program under Grant Nos. 1322820 and 2031884.*

PROFILES

TALK LIKE AN ...

## ENVIRONMENTAL SCIENTIST

**Citizen science** — voluntary participation by members of the public in authentic scientific projects and programmes, often in an informal, hands-on way

**Civic scientific literacy** — an individual's ability to understand and use science to advance the common good and engage in public scientific discussion and decision-making

**Meaning-making** — the process where people interpret relationships, situations and self-image in light of their own knowledge and experience

**Place attachment** — a meaningful bond between a person and a specific place that may involve emotions, knowledge and beliefs, and behaviours

**Sense of place** — the particular characteristics of a place that make it what it is

**Critical thinking** — careful thinking that involves analysis of available information and arguments to form a sound judgement

Whether it is the place we grew up in, a frequented restaurant, or a local building where we participate in a favourite hobby, most of us have specific places we feel attached to. This feeling of place attachment is being studied by Dr Ben Haywood at Furman University in South Carolina, as he asks the question of whether place attachment can affect how well we engage with and understand science and the environment. Ben is working with Dr Julia Parrish, a professor at the University of Washington, who is also the Executive Director of the Coastal Observation and Seabird Survey Team (COASST), an environmental, hands-on citizen science programme. Together, Ben and Julia are collaborating to research whether COASST participant place attachment shapes understanding of the local environment and specific critical thinking skills.

"In COASST, we have seen time and time again the deep care that programme participants maintain for the places they study," says Julia. "At the same time, participants gain knowledge about science, scientific processes and the natural components they study. We wondered whether there was a link between connections to place and the learning that occurs there."

### Why is citizen science important?

While formal science education – the science we study in school or college – provides important scientific skills and knowledge, a lot

*Velella velella, pictured here, is a floating hydrozoan and a member of the cnidaria family (jellyfish and sea fans). Observations by COASST participants allowed programme leaders to analyse and publish on the occurrence of mass Valella velella beachings in 2021. (© Steve Morey)*

of learning occurs outside of formal settings. Citizen science allows people to choose what project appeals to them, and engage in ways suited to them.

"Research in social psychology suggests that individual identity and life experience can influence whether or not science is perceived as relevant and influences the degree to which science is used in decision-making processes," explains Ben. This means we learn and understand science best through a highly personalised lens – the sum of our lived experiences. "Historically, formal education has focused on science content in a universal, remote and de-contextualised form. On its own, this has failed to foster the kind of civic scientific literacy necessary in the 21st century," says Ben.

Hands-on, out-of-doors, environmental citizen science, where participants have the chance to visit their data collection site repeatedly, can offer unique opportunities for learning and personal connection. "These projects allow for extended participation where people can refine their skills, integrate their observations across time, and develop a deeper understanding of the phenomena or place," explains Julia.

## How are Ben and Julia working on this?

COASST is a 23-year-old citizen science project, recruiting coastal residents in the Pacific Northwest and Alaska to participate in marine ecology and conservation research on the beach. To assess patterns of seabird mortality due to natural and human-induced events across both time and space, COASST participants collect data in three different areas: beached birds, marine debris and evidence of human use of the beach environment. "For this project, we focused specifically on the COASST beached bird module," says Julia. "Most participants come to the programme with little-to-no bird identification experience and live within 20 km of their data collection beach."

Ben and Julia used two social science research methods to gather data. Firstly, they surveyed nearly 300 participants about place attachment and programme participation. Secondly, they interviewed 30 participants about critical scientific thinking and programme engagement.

## What do the results show?

After analysing the research, Ben and Julia found that there are a certain set of place attachment catalysts that appear across diverse sample types within the COASST programme. These catalysts help explain why individuals feel attached to the places they monitor in the programme. "The six catalysts are self-identity, science affinity, natural/environmental bonding, science community bonding, family and friend bonding, and social rootedness," says Ben.

For example, the self-identity category means that, for some individuals, the attachment they feel to their COASST beach relates to their sense that that place makes up part of who they are – their perception of self. Natural/environmental bonding means individuals feel connected due to the nature or environment in that place (such as the plants and animals found there), and social-rootedness means individuals feel attached because the place is part of their history or ancestry.

"This helps us understand how the power and significance of a place might be leveraged in a more personalised and targeted way through place-based citizen science programmes," explains Ben. "The results show us how citizen science might help people harness the connection they have to a place and use that for positive action," says Ben.

## How has participating in citizen science affected people?

Ben and Julia found that COASST participants improve their identification accuracy over time – a result of repeated and consistent identification practice and engagement with COASST staff who train and provide opportunities to learn. "Participants experience deep learning about a specific place through repeated interactions, observations of the place, and processing of hands-on information with feedback from project staff," says Ben. "We believe that the knowledge participants gain about scientific processes or the ecology of that place is not limited to that one context. Instead, we suggest that such understanding goes beyond that one place. Accordingly, we hypothesise that the deep relationships and interactions between participants and specific places observed through the COASST programme have broader impacts on the ability of those participants to think critically and with a scientific lens."

Ben and Julia's results also show that engaging in the COASST programme influences participants' sense of environmental responsibility and can increase their desire to engage in science-based processes to understand and monitor places of importance. "This can also lead to specific behavioural outcomes (like engaging in more citizen science) and means there seems to be a relationship between place attachment, science affinity, and a sense of stewardship and care," explains Ben.

## How can citizen science programmes be the best they can be?

Instead of just being the backdrop from which data are collected, strengthening or capitalising on the relationships between people and the places where they might engage in citizen science can play a central role in increasing interest in public research participation.

How exactly can programmes do this? "Firstly, research programmes can develop opportunities for local residents to collect repeated, frequent observations of a place or environmental phenomena," says Ben. "Secondly, they should include tasks that require participants to ask questions and make sense of the data collected from a place, instead of just collecting data and submitting it. This might include making connections between the information collected and the lives and livelihoods of those that use the places under study. Thirdly, programmes should have a structure that supports peer interaction and engagement, so that participants share their knowledge of place with others and can compare and contrast experiences to make broader inferences."

# **ABOUT** *ENVIRONMENTAL GEOGRAPHY*

Environmental geographers study the relationships between organisms and the environment. Ben explains more.

"Given the growing separation between people and nature in our modern world, there is great need for geographers to find ways to reconnect people with the environment and educate them about how their actions impact our ecological home.

"My research is rewarding because I get to ask questions about ecosystems, the creatures in them and the people and cultures that rely on and interact with them. I am able to learn about things that are fascinating to me and also find ways to better care for the things and places that I study.

"The opportunities are so diverse that it's hard to think of a pressing challenge that isn't open to geographical examination! For example, geographers look at how our coastlines will respond to sea-level rise, how political borders influence the products we buy in the grocery store, and how conservationists can manage conflict."

## **Pathway from school to** *environmental geography*

- Ben recommends studying an undergraduate degree in Earth and environmental science, biology, chemistry or mathematics. "However, environmental geography is a very interdisciplinary field, and those who want to work within it need training in social science as well – including psychology, sociology, political science and communications," says Ben.
- If you are more interested in social science, consider studying this as an undergraduate degree and environmental geography as a postgraduate degree.
- The American Association for Geographers has an interactive map on college geography courses in the Americas: **www.aag.org/guide-to-geography-programs-opportunities**

## **Explore careers in** *environmental geography*

- Environmental Science provides information on careers in environmental science, sustainability and geography. It also explains what being a geographer is like and has a list of various college programmes that will help you become a geographer: **www.environmentalscience.org**
- Because environmental geography is such a diverse area of study, the pay can vary widely. According to Glassdoor, the average salary of an environmental geographer in the US is $61,164 per year. See the full range of salaries here: **www.glassdoor.com/Salaries/environmental-geographer-salary-SRCH_KO0,24.htm**

# **How did Ben become** *an environmental geographer?*

**"I spent much of my time outdoors as a child.** I loved observing and learning about the animals and natural systems around me and was especially interested in birds. I became fascinated with farming and growing food. I also became interested in travel as a way to see new places and ecosystems, and developed a love of writing and forms of creative expression.

**"I used to watch TV shows about nature and animals** and read books about conservation, veterinary medicine and science fiction. Several passionate math and science teachers encouraged me to learn more about the world through observation, experimentation and curiosity.

**"My career pathway has been anything but direct.** My undergraduate degree focused on communications and marketing, and I thought I would be an environmental journalist. I spent years volunteering with environmental and educational non-profit organisations and realised that being able to understand environmental policies and systems of governance was critical for protecting natural resources. I completed a master's degree in public administration and environmental policy and pursued my doctorate in environmental geography. I'm glad to have this interdisciplinary pathway into STEM. My diverse education allows me to look at the scientific challenges we face today from different perspectives.

**"Some of my most impactful experiences emerged from the volunteering** I did as an educational guide at my local zoo, an assistant in a bird banding field station in college, and as an environmental education intern. Each of those experiences opened doors for me and shaped my next steps.

**"The work I've done to inspire care for birds is perhaps my proudest work so far.** Whether it's through the courses I teach, the research I conduct or the writing I do to highlight the significance of our feathered friends, it gives me great meaning to be able to engage in this work.

## **Ben's** *top tips*

1. Try a lot of experiences and learn about as many different things as possible – this will help you identify what you are most passionate about. Doing something you love will lead you to your greatest success.
2. Spend time observing the natural world around you and recording your observations.
3. Foster skills at communicating and interacting with people, especially in negotiating multiple interests at once.
4. Always take advantage of opportunities to learn new things.
5. Start small and be persistent – small actions eventually add up to big results.

# ABOUT *MARINE ECOLOGY*

Marine ecology is the study of how organisms in salt water habitats, from the deep sea to the open ocean to coastal beaches, survive and thrive in their environment. Marine conservation acknowledges the negative influence humans have on ocean systems and seeks to work cooperatively with non-science organisations to find lasting solutions.

"How will marine species deal with warmer or more acidic water?" asks Julia. "Will coastal development and the associated disturbance and pollution force some species to abandon nesting, feeding habitats, or migratory routes? What can we do about this? The chance to be a part of the solution, instead of just part of the problem, is the most rewarding thing."

> **"HOW WILL MARINE SPECIES DEAL WITH WARMER OR MORE ACIDIC WATER?"**

Being a marine ecologist might allow you to work in some fantastic places. "I've been tremendously privileged over my career to work on remote seabird colonies and on research vessels in some wild, beautiful places that most people will never see," says Julia.

*Photo captipn: The Kalaloch area of Olympic National Park in Washington offers a sample of the variety of wild and rugged coastal habitat protected by the park. Beach 4 (pictured here) is one of several beaches monitored by COASST participants in the area. (© Brian Burgess)*

## Explore careers in *marine ecology*

- The MarineBio Conservation Society is a great resource for learning more about ocean life and marine science. It also has a page specifically on marine ecology: www.marinebio.org/conservation/marine-ecology

## Pathway from school to *marine ecology*

- Some universities offer degrees in marine ecology, but studying a degree in ecology, marine biology, environmental science, geology, chemistry or oceanography is also an option.
- Julia advises, "It's important to be able to translate phenomena into numbers to enable analysis, so take statistics and data science courses."
- Julia also encourages students to learn about science history and ethics. "We're taught that science is a truth, but that's as subjective as any other statement. What is studied, how it's studied and how we understand the world is as much about who is in charge as anything else. It's critical to go into science with open eyes to that bias if we hope to create an equitable and truly creative space."

## How did Julia become *a marine ecologist?*

**"I had a chance to spend an undergraduate semester** at the Duke Marine Lab. It was slightly scary as it meant leaving my university and friends and going somewhere new, but it was a great experience. It opened up graduate school as an opportunity for me, and I never looked back.

**"I'm proudest of COASST.** It's an internationally acclaimed citizen science programme producing great science that is published in scientific literature and highly cited by other marine scientists and conservationists, simultaneously digging deep into why people join, what makes them stay, and how they understand themselves to be a part of the science team."

### Julia's *top tips*

1. Get out there. Observe. Get wet and muddy. Pick up slimy things. Ask questions!
2. Don't try to leap directly into saving the world. Take the time to understand the world and how it works. Otherwise, you may end up saving the wrong parts or missing what's important.
3. Everyone will have unique choices and opportunities. Don't be afraid to take advantage of them and go outside of your comfort zone.

*Carcass identification is often a group activity that relies on collective experience and feedback for accuracy. Here, three COASST participants on a beach on the shores of Mendocino National Forest (CA) work together to examine a beach cast bird. (© Julia Parrish)*

# A meal with the devil: How the eating habits of Tasmanian devils affect their ecosystems

In a healthy ecosystem, each microbe, plant and animal has its own important role to play. They may not be the most glamorous, but scavengers play a vital role in recycling nutrients back into an ecosystem. **Dr Laurel Lynch**, an ecosystem ecologist from the **University of Idaho**, USA, has been studying one particular scavenger, the Tasmanian devil, to better understand the impact they have on their ecosystems.

**Dr Laurel Lynch**

Department of Soil and Water Systems, University of Idaho, USA

PROFILE

**Fields of research**
Ecosystem Ecology, Biogeochemistry

**Research project**
Investigating how the scavenging behaviour of Tasmanian devils affects nutrient cycling within their ecosystems

**Funder**
US National Science Foundation (NSF)
*This work was supported by NSF Award DEB-2054716*

TALK LIKE AN ...

## ECOSYSTEM ECOLOGIST

**Carrion** — the decaying flesh of dead animals

**Microbial community** — a group of inter-related microorganisms, typically bacteria and fungi

**Niche** — the role that an organism plays in its ecosystem

**Nutrient cycling** — the process by which nutrients are transferred from living organisms into the non-living parts of an environment

**Pitfall trap** — a method to collect small animals, in which a hole is dug that animals then fall into. Typically, soil ecologists use pitfall traps to collect soil invertebrates, such as beetles, that also drive decomposition

**Population gradient** — the change in density of a population across an area

**Scat** — animal faeces

The next time you are in a forest, meadow or your local park, take a moment to pause and look around. Look closely. What do you see? Do you see bees bumbling lazily from flower to flower? Or pigeons collecting fallen sticks to construct their nests? What you will not see are the wispy tendrils of fungi that exchange nutrients with tree roots and the millions of microbes in the soil that break down dead matter.

Zoom out, and you might realise that you are looking at an intricate web of relationships in which every plant, animal and microbe are inter-related. Or, in other words, an ecosystem. Healthy ecosystems are incredibly complex. Within them, countless organisms are connected to each other and their surroundings, with each organism having its own niche to fill.

Scavengers, for example, play a vital role in ecosystems. They recycle nutrients back into the food chain by eating dead animals. As they digest their food, they convert organic matter into a form that other organisms can use to grow and generate energy. As a result, the carcasses of animals, called carrion, can create hotspots of biodiversity.

When microbes break down carrion, they deliver nutrients to the soil below that can be used by plants and other microbes. In contrast, when vertebrate scavengers eat a carcass, they redistribute nutrients throughout the ecosystem via their waste products. The decomposition of carrion is an integral part of healthy ecosystems, so studying this process helps researchers understand how animal behaviour affects ecosystems. Dr Laurel Lynch, from the University of Idaho, is studying Tasmanian devils and their scavenging behaviour to understand the role they play in their ecosystems.

### What are Tasmanian devils?

Tasmanian devils are native to Tasmania, an island off the south-eastern coast of Australia. About the size of a small dog, these devilish creatures are the world's largest carnivorous marsupial. "Since the extinction of the Tasmanian tiger, devils have occupied a unique niche, acting as the island's top predator and scavenger," explains Laurel. Devils' activity has a direct impact on the behaviour of smaller scavengers like ravens, possums and feral cats. "Their activity may also impact other ecosystem processes, like plant productivity and soil nutrient cycling," says Laurel.

### Why are Tasmanian devils interesting to study?

"Devils are one of a few scavengers worldwide that are osteophages, or bone consumers," says Laurel. "Skeletal material stores a lot of calcium and phosphorus, both of which are critical elements for


© Susan Flashman/Shutterstock.com

plant and microbial growth." Laurel is interested in whether devil scavenging accelerates the cycling of these nutrients from carrion into the soil, where they can drive microbial activity and plant growth.

In Tasmania, devil populations have been declining due to the spread of an infectious cancer called Devil Facial Tumour Disease (DFTD). DFTD spreads through social interactions and is nearly 100% fatal. As the disease has spread across the island, it has created a natural population gradient from the east, where devil numbers have declined dramatically, to the west, where some populations remain unscathed. Although this disease has tragic consequences, the population gradient provides an ideal opportunity to research devil behaviour and the impact it has on their natural habitat.

## How is Laurel studying the devils?

Laurel and her team established four research sites that span the devil population gradient, from a site with no devils in the east, to a site with a thriving devil population in the north-west. By comparing results from these four sites, Laurel will be able to understand the impacts that devils have on their ecosystems.

At each site, Laurel set up three different experimental treatments: a staked carcass that could be accessed by all scavengers, a caged carcass that could be accessed by smaller scavengers but not devils, and devil scat latrines, or toilets, that allowed Laurel to determine what nutrients were being delivered from devil waste into the soil.

Once the carcasses were in place, Laurel and her team set to work collecting data. They deployed pitfall, aerial and camera traps to document the number, species and behaviours of different scavengers that visited the carcasses, and they took soil samples to test how nutrient availability and microbial communities were affected. They also collected leaf samples and tree cores, which record past climate and environmental stressors (like water and nutrient availability).

> **"MANY ECOSYSTEM ECOLOGISTS OVERLOOK ANIMALS, AND MANY POPULATION AND COMMUNITY ECOLOGISTS OVERLOOK THE ECOSYSTEM."**

After collecting their data, Laurel and her team processed their samples in laboratories. They are currently analysing plant and soil samples, which will allow them to determine the concentrations of different nutrients, like carbon, nitrogen and phosphorous, at each of the treatment sites. In addition, by extracting DNA from soil samples, they will be able to discover how communities of bacteria and fungi were affected by the different treatments. By comparing these results to data from the camera traps, Laurel will determine the effects of Tasmanian devil scavenging behaviour.

## What has Laurel discovered so far?

"Devils are extraordinarily effective scavengers," says Laurel. "They can consume an entire carcass in one sitting!" In areas with lots of devils, the amount of nutrients being delivered directly into the soil is minimal, because carrion is removed so quickly. "However," says Laurel, "indirect impacts of devil scavenging may be dispersed throughout the landscape through their scat." To support this finding, Laurel is analysing soil samples from below the devil scat latrines to test for nutrients like calcium and phosphorous, which are plentiful in the bones that devils eat. In contrast, carcasses in regions with fewer devils, as well as caged carcasses which excluded devils, were consumed more slowly. As a result, the carrion remained in the habitat for a longer time, allowing it to decompose and release its nutrients into the soil. As she analyses the soil from these treatment sites, Laurel expects the microbial communities will have transformed so as to take advantage of these high-quality resources.

## Why is this research important?

Laurel's research has combined the fields of population and community ecology, forest ecology, soil biogeochemistry and microbial ecology. Cross-discipline collaborations like this are vital to gaining a clear understanding of how complex ecosystems function. "Many ecosystem ecologists overlook animals, and many population and community ecologists overlook the ecosystem," says Laurel. "But it is ultimately feedbacks and interactions among organisms and their environment that shape ecosystem function."

Understanding these feedbacks is needed to make broader predictions about how ecosystems will respond to global climate change. As ecosystems experience the dramatic consequences of climate change, such as wildfires, droughts and floods, scientists and policymakers are realising that action must be taken to protect them. Cross-disciplinary collaborations such as Laurel's will play an increasingly vital role in this process. The field of ecosystem ecology incorporates learning from many disciplines and is therefore well placed to help initiate these collaborations.

"Although carrion availability and decomposition might seem like a side story, it is one of the most crucial, yet understudied, processes in ecosystem ecology," says Laurel. Lessons from Laurel's research could be critical in reducing nutrient limitation in a warmer, drier world. Not only that, but it could provide a lesson to the whole scientific community on how collaborations are vital to advance science and protect our planet.

# ABOUT *ECOSYSTEM ECOLOGY*

Ecosystem ecology is the study of both the living and non-living parts of an ecosystem, and of how these parts interact. Laurel's research focuses on how scavengers interact with their ecosystems, specifically looking at how nutrients from carrion are cycled back into soils, microbes and plants.

### What other topics can ecosystem ecologists study?

Like Laurel, a lot of ecosystem ecologists focus on soils. Soils can draw carbon dioxide out of the atmosphere and store it underground. Understanding this process could have a significant impact on the world's fight against climate change, so there is currently a lot of interest in this area.

Other topics in ecosystem ecology include the cycling of organic molecules in rivers and streams, the role that forest fires play in nutrient cycling and habitat regeneration, and how food webs are influenced by environmental factors.

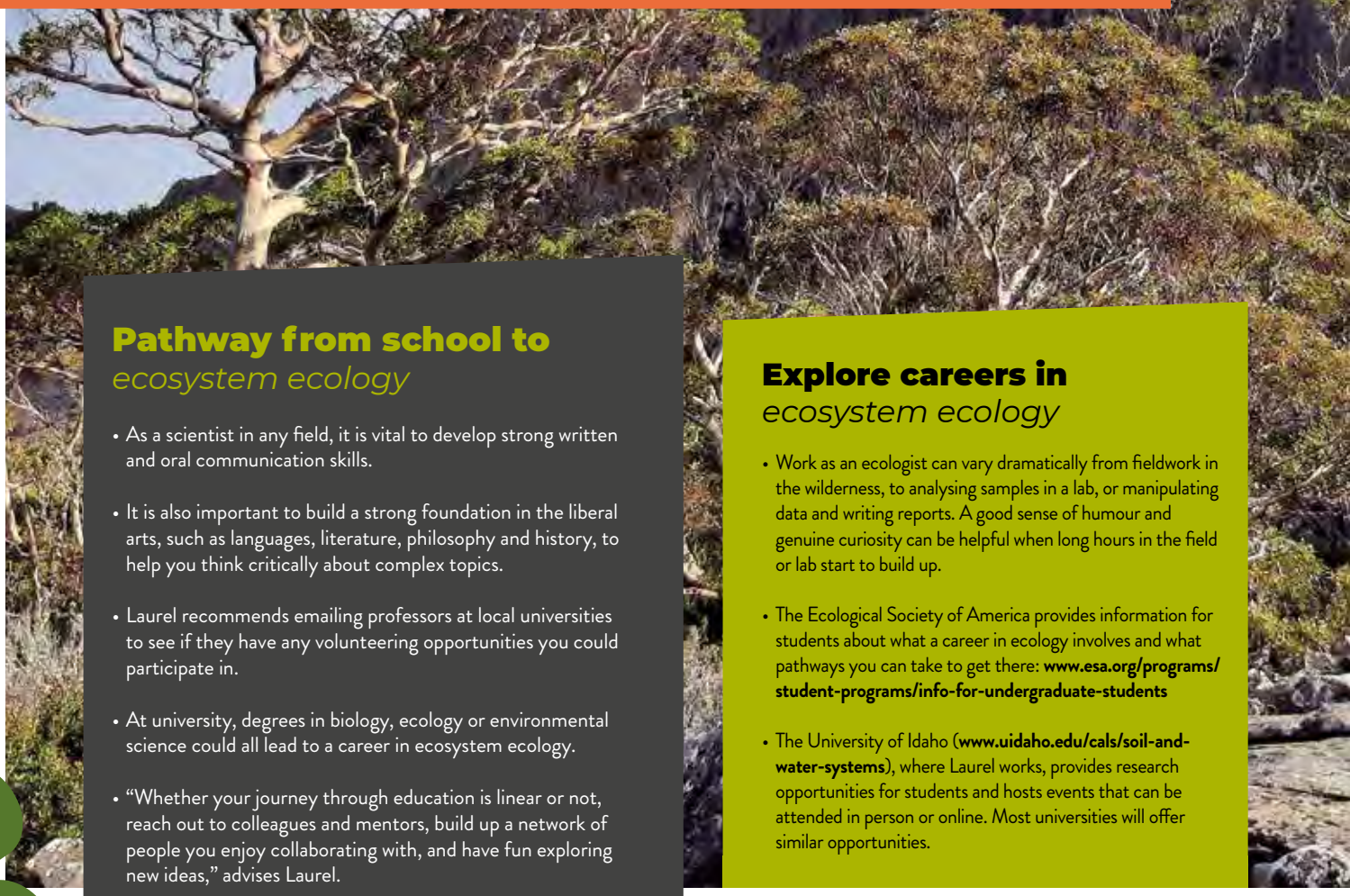
### What does ecosystem ecology fieldwork involve?

There is a lot to do before fieldwork begins. "The most important order of business," explains Laurel, "is identifying a compelling research question and designing a well-crafted experiment." Then comes the planning, preparation and travel. "When we arrive, there is a flurry of activity as we perform final site selections, assemble equipment and deploy the experiments," says Laurel. "From there, we're off to the races!"

Sometimes data collection can be a quick process followed by months of lab work. Other times, the data collection can take months and involve lots of hard work in all kinds of weather conditions. "Data collection doesn't stop just because the weather has turned or the sun has gone down," says Laurel.

### What are the most enjoyable parts of being an ecosystem ecologist?

The cross-disciplinary nature of ecosystem ecology makes for a lot of interesting conversations and collaborations. Learning from other disciplines is a great way for scientists to look at their own research with a fresh perspective. Ecosystem ecologists are often confronted with complex datasets that require careful analysis to uncover underlying patterns. "I have learnt to enjoy the challenges of analysing data," says Laurel.



## Pathway from school to *ecosystem ecology*

- As a scientist in any field, it is vital to develop strong written and oral communication skills.
- It is also important to build a strong foundation in the liberal arts, such as languages, literature, philosophy and history, to help you think critically about complex topics.
- Laurel recommends emailing professors at local universities to see if they have any volunteering opportunities you could participate in.
- At university, degrees in biology, ecology or environmental science could all lead to a career in ecosystem ecology.
- "Whether your journey through education is linear or not, reach out to colleagues and mentors, build up a network of people you enjoy collaborating with, and have fun exploring new ideas," advises Laurel.

## Explore careers in *ecosystem ecology*

- Work as an ecologist can vary dramatically from fieldwork in the wilderness, to analysing samples in a lab, or manipulating data and writing reports. A good sense of humour and genuine curiosity can be helpful when long hours in the field or lab start to build up.
- The Ecological Society of America provides information for students about what a career in ecology involves and what pathways you can take to get there: **www.esa.org/programs/student-programs/info-for-undergraduate-students**
- The University of Idaho (**www.uidaho.edu/cals/soil-and-water-systems**), where Laurel works, provides research opportunities for students and hosts events that can be attended in person or online. Most universities will offer similar opportunities.

# Q&A

## Meet Laurel

### What were your interests when you were growing up?

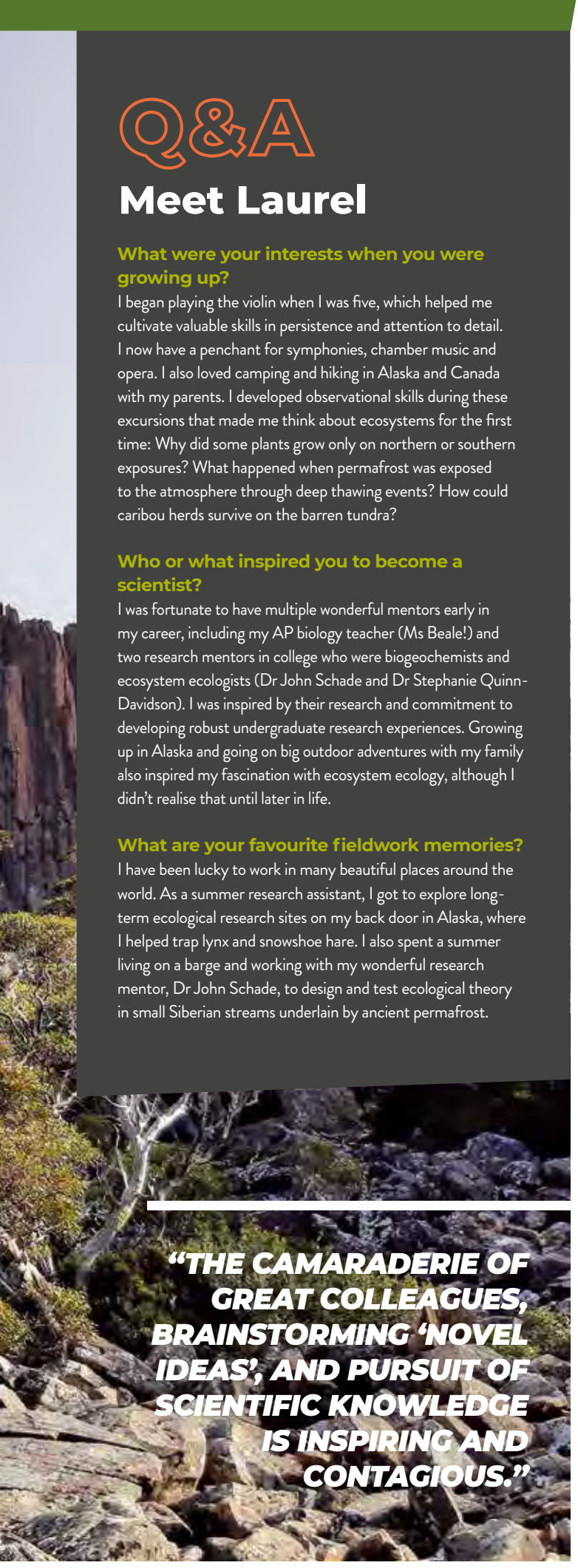
I began playing the violin when I was five, which helped me cultivate valuable skills in persistence and attention to detail. I now have a penchant for symphonies, chamber music and opera. I also loved camping and hiking in Alaska and Canada with my parents. I developed observational skills during these excursions that made me think about ecosystems for the first time: Why did some plants grow only on northern or southern exposures? What happened when permafrost was exposed to the atmosphere through deep thawing events? How could caribou herds survive on the barren tundra?

### Who or what inspired you to become a scientist?

I was fortunate to have multiple wonderful mentors early in my career, including my AP biology teacher (Ms Beale!) and two research mentors in college who were biogeochemists and ecosystem ecologists (Dr John Schade and Dr Stephanie Quinn-Davidson). I was inspired by their research and commitment to developing robust undergraduate research experiences. Growing up in Alaska and going on big outdoor adventures with my family also inspired my fascination with ecosystem ecology, although I didn't realise that until later in life.

### What are your favourite fieldwork memories?

I have been lucky to work in many beautiful places around the world. As a summer research assistant, I got to explore long-term ecological research sites on my back door in Alaska, where I helped trap lynx and snowshoe hare. I also spent a summer living on a barge and working with my wonderful research mentor, Dr John Schade, to design and test ecological theory in small Siberian streams underlain by ancient permafrost.



**"THE CAMARADERIE OF GREAT COLLEAGUES, BRAINSTORMING 'NOVEL IDEAS', AND PURSUIT OF SCIENTIFIC KNOWLEDGE IS INSPIRING AND CONTAGIOUS."**

*Laurel holds a partly-decomposed carcass*

As a PhD student, I spent multiple summers working in tundra ecosystems in Alaska. The fieldwork was extremely challenging. We often spent 20+ hours at our field sites battling hordes of mosquitoes and unexpected snowstorms. At the end of our field experiments, we excavated hundreds of pounds of freezing soil by hand and shipped them back to our labs at Colorado State University, where we spent months in the lab conducting incubation experiments and preparing samples for detailed instrumental analysis. The camaraderie of great colleagues, brainstorming 'novel ideas', and pursuit of scientific knowledge is inspiring and contagious.

### What are your ambitions for the future?

My long-term goals are to continue learning about new systems, integrating new fields, and challenging myself intellectually. I'd like to follow in the footsteps of my postdoctoral mentor, Dr Johannes Lehmann, who challenges himself to reinvent his lab every five years.

### What do you enjoy doing when you are not working?

I love reading for fun, travelling, and exploring nature through mountain biking, skiing, and rock-climbing adventures.

### **Laurel's** *top tips*

1. Seek out high school and undergraduate research opportunities.
2. Read broadly and deeply to uncover gaps in scientific knowledge.
3. Collaboration is important and is vital to conducting good research.

# Why do post-election protests occur?

Democratic elections have played a crucial role in making societies fairer and more equal. However, what happens when you live in a country where a political party rejects the election result, where post-election protests are common, or where the election itself might have been fraudulent? At the **Australian National University** in Canberra, Australia, political scientist **Dr Svitlana Chernykh** is researching why post-election protests occur.

**Dr Svitlana Chernykh**

School of Politics and International Relations, Australian National University, Australia

PROFILE

**Field of research**
Political Science

**Research project**
Analysing the causes of post-election protests and why political parties reject election results

**Funder**
Australian Research Council (ARC)

TALK LIKE A ...

## POLITICAL SCIENTIST

**Democracy** — a form of government in which citizens choose their leader

**Electoral compliance** — when political parties do not undertake any actions to overturn an election result

**Electoral fraud** — illegal interference with the process of an election, usually by falsely increasing or decreasing the votes for a candidate

**Empirically** — when something is tested by observation or experimentation rather than by theory or logic

**Heterogeneity** — the quality of having differences

**Incumbent** — being in power when an election happens

**Multiparty election** — an election where multiple political parties run for office

**Political repression** — the act of preventing citizens from expressing political opinions, e.g., imprisoning people for their political views

Elections are the cornerstone of democracy, allowing a country's citizens to choose who leads them. However, these elections do not always go smoothly, or even fairly. Protests following elections occur around the world for a variety of reasons. Political parties that lose an election may refuse to accept the election results, and this frequently leads to political, economic and social repercussions.

At the Australian National University, Dr Svitlana Chernykh is examining post-election protests in countries in the former Soviet Union, Sub-Saharan Africa and Southeast Asia, to discover what conditions cause them to occur. Svitlana chose to compare countries in these regions because many of them started holding multiparty elections around the same time, in the late 1980s and early 1990s. "This allows us to establish a non-arbitrary starting point for our analysis," she explains. Most importantly, however, these regions account for over 60% of all post-election protests that have happened worldwide in the last 30 years.

Despite these similarities between the regions, there are also crucial differences. "In terms of political conditions, countries in these regions offer heterogeneity with respect to regime type, electoral systems, organisation of electoral management bodies, quality of elections, economic conditions and other variables that have been hypothesised to affect electoral compliance," Svitlana explains. "This variation is important as it allows us to explore the impact of these different factors on post-election protests."

### What is novel about Svitlana's research?

Svitlana examines post-election disputes at national, electoral and party levels, and she combines qualitative and quantitative data to gain a more accurate perspective. Her approach is different from the ones usually used by political scientists to study post-election protests, allowing her to generate new insights into the topic.

While many political scientists focus solely on post-election protests, Svitlana treats them as only one of the possible strategies that a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political party might use in response to election defeat. She also examines the characteristics of the political party itself, not just the election or the country, to see how the characteristics of the individual parties might affect electoral compliance. While other researchers have primarily looked at election fraud to determine why losing parties might reject election results, Svitlana looks beyond the quality of the election to consider other factors as well. "Election fraud may take many forms and it is too broad a concept to generate any useful, non-obvious explanation for parties' post-election strategies," she says.

Since election fraud is illegal, it is difficult to observe empirically. "In this project, I advance a theory that focuses on the strategic incentives for electoral rejection, thus allowing us to unpack the black box of electoral manipulation and test the impact of different factors at both the election level and the party level," Svitlana explains.

## What has Svitlana discovered?

Svitlana found that events before an election have an impact on post-election events. If election-related rules are changed before an election (e.g., a new voting system is introduced), then there is a higher chance that losing political parties will reject the election result and stage post-election protests.

Svitlana and her colleague, Dr Sam Bell, also discovered that incidences of political imprisonment affect the probability of post-election protests. Political imprisonment is when an individual is imprisoned because of their political views, usually for expressing opinions or conducting activities that oppose the government.

## How does political imprisonment influence protests?

Svitlana and Sam statistically analysed data from all national elections worldwide, from 1982 to 2012, and examined whether pre-election political imprisonment increased the probability of post-election protests, accounting for the effects of opposition party strength, economic conditions, fraud and other factors that cause election protests. "We found that when an incumbent party won an election, and there was no recent history of political imprisonment, the probability of post-election protests was just 8%," says Svitlana. "However, when there was widespread political imprisonment before the election, the probability of protests more than doubled to 20%." This discovery that pre-election political repression contributes to post-election protests was an important revelation.

> ***"IN A WORLD WHERE A LARGE NUMBER OF ELECTIONS ARE REJECTED AND FREQUENTLY SPIRAL INTO POLITICAL, ECONOMIC AND HUMANITARIAN CATASTROPHES, IT IS IMPERATIVE TO UNCOVER WHY POLITICAL PARTIES CHOOSE TO REJECT ELECTORAL OUTCOMES."***

## A case study: What happened after the 2020 elections in Belarus?

In August 2020, the incumbent president of Belarus, Alexander Lukashenko, claimed re-election victory with 80% of the vote. The election was followed by widespread protests throughout the country, with protesters declaring the results fraudulent and demanding a new election. "The Belarusian government responded with violent repression, detaining and allegedly beating thousands of protesters," says Svitlana.

Before the election, Lukashenko had imprisoned many political activists and opposition party leaders. "For example, in May 2020, Siarhei Tsikhanouski, a well-known Belarusian vlogger and activist, announced he would run in the election. Two days later, Lukashenko had him arrested. The Belarus election authorities then ruled Tsikhanouski ineligible to run for president," Svitlana recounts.

Svitlana analysed the Belarus election and found that the protests occurred for four reasons: election fraud, a poor economic situation, the recent post-election protests in nearby countries, and political repression (especially political imprisonment). "The first three factors have been widely connected to post-election protests in previous research," says Svitlana. The results of her research with Sam explain the contribution of political imprisonment.

## What are the implications of Svitlana's research?

Svitlana's work will help improve electoral management and the quality of democracy around the world. "This is of great significance to the millions of people who live in emerging democracies," she says. As well as being useful for academics working in political fields, this research will be helpful for non-governmental organisations (NGOs), policymakers and other individuals working to promote free and fair elections. "In a world where a large number of elections are rejected and frequently spiral into political, economic and humanitarian catastrophes, it is imperative to uncover why political parties choose to reject electoral outcomes."

# ABOUT *POLITICAL SCIENCE*

Working in political science is very different to working in politics, though these two areas are often confused. "Careers in political science include academic and non-academic positions," says Svitlana. You could become a professor at a university, where you teach political science and conduct research, or you could conduct political science research for an international organisation such as the United Nations or World Bank. In contrast, careers in politics usually involve working in governance. "This includes people who are elected politicians, as well as their support staff, such as legislative assistants, policy analysists and campaign managers," explains Svitlana.

### What are the challenges and rewards of political science?

"The best part of being a political scientist is knowing that my work may help make the world a better place, by improving the lives of people and making the world more peaceful," says Svitlana. "The challenge is that it takes times to see the impact of my work. It's different from being a medical doctor, for instance, where you help people and immediately see the results of your work."

Working at a university means that Svitlana also spends time teaching students, an aspect of her job that she finds very rewarding. "When a student thanks me for a course or tells me how my class made a difference for them, it is absolutely incredible."

### What does a typical day for Svitlana involve?

"As an academic, my role includes research, teaching and service," she explains. "During a typical day during the semester, I may end up doing all three. For my research, tasks include writing, data analysis and data collection. If I am teaching, I will spend time preparing for the class and then teaching it. I also spend time answering emails and attending meetings."

## Pathway from school to *political science*

- Many universities offer undergraduate degrees in political science or international relations. You could also become a political scientist after studying politics or economics.
- Visit the School of Politics and International Relations at the Australian National University to explore the courses offered and discover what research is conducted: **politicsir.cass.anu.edu.au**
- When at university, Svitlana recommends taking courses in mathematics, statistics and research design. A lot of political science is quantitative, so being good with numbers is important!
- Communicating with others is an important skill for political scientists, so work on developing your written and spoken communication skills. "Speaking additional languages is very useful in political science," says Svitlana.

## Explore careers in *political science*

- If you're interested in a career in political science, Svitlana suggests reading the news regularly and getting involved in practical political-related activities. "There are many ways to get practical experience," she says. "You can participate in Model United Nations programmes (**www.nmun.org**), volunteer as a research assistant on a university-led project or do a summer internship with a policy or government department."
- "Learning to do 'deep work', where you stay focused on a cognitively demanding task for a protracted period of time, is very important for political science, and for generally being successful in college," says Svitlana. "Time management is also important." Cal Newport has a great website with tips for students to improve their deep work and time management skills: **www.calnewport.com/blog**

***"THE BEST PART OF BEING A POLITICAL SCIENTIST IS KNOWING THAT MY WORK MAY HELP MAKE THE WORLD A BETTER PLACE, BY IMPROVING THE LIVES OF PEOPLE AND MAKING THE WORLD MORE PEACEFUL."***



# Q&A

## Meet Svitlana

**What inspired you to become a political scientist?**

When I was younger, I was interested in sports, especially running, and languages. I became interested in political science and international relations in high school. My initial interest in political science was sparked by observing how different countries transitioned to democracy in the early 1990s. Some were successful, others less so. I was curious about why these differences occurred.

**As a political scientist, is it hard to keep your personal political opinions out of your research? How do you ensure your research remains neutral and impartial, if you have strong feelings about the way governments are acting?**

This is a great question! I try to work only on topics where I know I can stay impartial and objective. This means sometimes not working on projects which might be personal. I also use a mixture of different methods, datasets and methodological approaches when trying to answer my research questions as this helps to keep my own feelings out of my conclusions.

**In what ways do you benefit from your international background?**

I studied for my bachelor's degree in international relations in Ukraine, then got my master's and PhD in political science in the US. I then worked in the UK for several years, before moving to Australia. This has allowed me to meet, work with and learn from many incredible people around the world. I have gained experience from studying and working in different environments and I have seen how different universities and departments operate. This has all resulted in making me a better political science researcher and teacher.

**What do you enjoy doing in your free time?**

I still love running. I also enjoy doing any other physical exercise, such as playing tennis or going hiking.

### **Svitlana's** *top tips*

1. Finding your 'why' is important. Always ask yourself: Why would you like to do something?
2. Read the news regularly!
3. Start by casting the net wide and reading about lots of different things. Once you find what you are interested in, narrow it down and learn more about your chosen topics.

# What misconceptions do people have about careers in the tech industry?

**Catherine Boddy** and **Zoe Grist** have carved out impressive careers at **Orange Cyberdefense**, the cybersecurity arm of Orange Group, proving that the tech industry is not just for men and tech geeks.

ORANGE CYBERDEFENCE

## Meet Catherine

Catherine Boddy is Head of the Vulnerability Operations Centre (VOC) for the UK and South Africa. Catherine started at Orange Cyberdefense in February 2020, just four weeks before the national lockdown hit during the COVID-19 pandemic. Her role at the time was CyberSOC (Security Operations Centre) delivery coordinator. This involved a great deal of project management, even though she had no previous experience of managing a team.

Having rapidly progressed up the career ladder, Catherine has managed two job roles simultaneously, as well as teams, and created a new global service for Orange Cyberdefense's VOC.

Catherine is passionate that women in the tech industry gain recognition and have a voice. She believes there is no reason for tech to remain an industry dominated by men, and that women should aim for what they want to achieve and work their way up until they get there. Here, Catherine describes her role in more detail and why she is an advocate for women in tech.

### What does the VOC do?

We provide a managed vulnerability scanning service for different customers around the world, meaning we help them identify vulnerabilities in their computer systems and provide the information necessary to remediate them. We are also a payment card industry approved scanning vendor (PCI ASV), which enables us to ensure that the systems customers use are compliant for processing and storing payment card data.

### What do you love about your role as Head of the VOC?

No day is the same when working with different people around the world. I love having such an amazing team that I can rely on to provide the best service to our customers and working in a constantly evolving industry.

### Have you followed a traditional career path?

I followed an eclectic career path. I did not go to university, spent summers abroad working in Greece, and only settled down into a career in tech at the age of 25. Six years later I'm managing my own team and travelling to South Africa for half of the year!

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### Which has been more valuable to your career, your education or your experience?

Definitely experience, as school can only teach you so much: 95% of the things you learn are on the job. Three years ago, I had no clue what a PCI ASV was and now I am in charge of the delivery and service around this.

My first role in the tech industry threw me into the deep end and I was forced to learn on my feet. This made me realise that I needed to build experience and knowledge to advance to a managerial position.

### What is the biggest factor that has helped you be successful?

I had project coordination and administration experience from my previous roles so was able to show I could progress and move into the management side of things. However, you still need to have someone who is willing to give you a chance and that is what I had in my first manager at Orange Cyberdefense. She could see my potential and was willing to mentor and shape me into the person I have become today.

### How do you keep yourself and your team motivated?

One obstacle we have had to overcome is remote working, as I am based in the UK and my team is in South Africa. Although it is more beneficial for me to be in South Africa with them, we have overcome this by adapting our ways of working. This includes having a daily meeting to ensure everyone is OK and check in on day-to-day tasks. Being able to communicate well within a team is crucial because it lets members know they can speak openly and honestly.

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### Why are you a passionate advocate for women in tech?

When working in an industry dominated by men, women's achievements sometimes go unrecognised. This is why the different awards and recognition that have been created for women in tech are so important as they show how much the industry has advanced. Lots of women are now in positions that were previously dominated by men.

As women, we often need to prove ourselves more than men in the same role, so to be able to help other women break into industry, in the same way I was supported, is a good opportunity to give back and empower women.

### What are some misconceptions people have about a career in tech?

- It is mainly an industry dominated by men, and women struggle to break into a career in tech.
- You need to be technical and have good technical knowledge in order to work in industry.
- People in tech work 24/7 and spend all their time behind a computer screen without a social life. In fact, I met some my closest friends from working together in the tech industry.

*Payment Card Industry (PCI)Company Recertification 2022*

### Who do you look up to for inspiration?

When I started in the tech industry, Reshma Saujani had just done a TED talk. She inspired me to believe that one day I could be the CEO of a company and hopefully make a difference in the industry, like she has done with Girls Who Code.

### What are your top three insider tips for a career in tech?

- There are so many different areas within the tech industry. Find the one you are passionate about to enjoy the job you do.
- The tech industry is constantly evolving and changing. It is a fantastic industry for anyone who enjoys learning new things.
- Build relationships with your colleagues. Being able to bounce ideas around and help each other out is a big part of any role.

**Connect** with Catherine

**catherine-boddy**

> ***"DIFFERENT AWARDS AND RECOGNITION HAVE BEEN CREATED FOR WOMEN IN TECH, SHOWING HOW MUCH THE INDUSTRY HAS ADVANCED."***

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# **Meet** Zoe

Zoe Grist is the head of the Security Operations Centre (SOC) in the UK. Zoe studied criminology at university and, after graduating, started working for the police force. In 2018, she joined Orange Cyberdefense as a junior service delivery manager, a role that combined her passion for cybersecurity with her history of customer service roles.

After becoming more involved in daily SOC processes and developing her knowledge of the industry, she sought a position with more responsibility. She took on a SOC support manager role, which in turn led to a promotion to head of SOC.

Zoe currently manages all aspects of the daily operations and management of Orange Cyberdefense's UK SOC. This includes heading up a team of technical engineers who provide specialist support, monitoring and security management to customers. She achieved this at the age of 28, after just four years in the industry. Here, Zoe explains what she loves about her role and how she found her passion for cybersecurity.

### What does the SOC do?

The SOC is a team of 32 engineers based in the UK and Mauritius, responsible for delivering managed security services to customers to protect their digital infrastructure. As cybersecurity experts, we focus on providing proactive value-added support to our customers with the aim of unburdening them from the IT security challenges that businesses face today.

> ***"LIFE IS TOO SHORT TO SPEND IT DOING SOMETHING THAT MAKES YOU UNHAPPY. YOU CAN CHANGE YOUR MIND ON THE CAREER YOU WANT AT ANY AGE."***

### Can you describe some of the things you love about your role as Head of SOC?

First of all, it is the diversity - no two days are the same. Each day there is a different challenge that needs to be tackled. I also love being part of, and having impact on, a global organisation. My role has enabled me to travel to different countries, meet like-minded people and support my team of engineers to succeed in their own careers.

### Why did you study criminology?

I decided to study criminology at Southampton Solent University because of my interest in the criminal mind and pursuit of a career within the police force. I wanted to get a broader understanding of 'what makes people tick'. The course itself captured my interest due to the diverse range of topics being taught by industry leading experts.

### How did you become interested in cyberterrorism?

My interest in this topic developed in my final year when I selected an additional module to learn about cyberterrorism. From there, I decided to write my dissertation around the existing argument of old versus new terrorism, with the aim of analysing what cyberterrorism actually is/was (back then) and how the 'cyber' dimension adds a somewhat new perspective to the debate. Having recently re-read my dissertation, I've realised how much has changed since writing it in 2014 and how quickly the cyberterrorism landscape can evolve!

### What did you learn from your experience working with Kent Police?

I thought landing my dream job as a police officer was the end goal for me. I enjoyed the job overall but struggled with the work-life balance. I had worked so hard throughout school, sixth form and university to get to where I was, but things did not end up the way I had envisioned. Making the decision to leave the police to pursue a different career path was one of the hardest but best decisions I have ever made. It taught me that, no matter


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what, life is too short to spend it doing something that makes you unhappy. You can change your mind on the career you want at any age. Just because you seem to be heading in one direction does not mean you have to stay on that path; some things might work out and others might not.

### What transferable skills do you have that have helped you get to where you are today?

The main skills that have allowed me to get to where I am today are interpersonal and communication skills, and having a good work ethic, drive and grit. None of these skills has anything to do with directly working in cybersecurity, but with the right foundations you can truly pursue any career or goal you want.

### What is the biggest factor that has helped you be successful?

Truly understanding what I am passionate about has allowed me to consistently deliver in the variety of roles I held previously. This, combined with surrounding myself with the right people, and having the drive and perseverance to succeed, has meant that I have been able to overcome any challenges that have come my way.

*Zoe with her nephew at her Police Graduation Passing Out Parade, 2017*

### If you could start all over again, what would you do differently?

Nothing comes to mind – because if I were to change anything I would not be where I am today. All the challenges along the way were lessons learnt and experience gained.

### What are your top three insider tips for a career in cybersecurity?

- You do not have to do things in the traditional sense, such as school, college or university. Real life experience is just as valuable.
- It is more important to find your passion and what motivates you. If you find yourself interested in cybersecurity, then identifying this will help you in whatever specific job role you wish to do.
- The cybersecurity industry is constantly evolving. You need to be willing to learn every day, develop your skills and adapt to change quickly.


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## **Connect** with Zoe

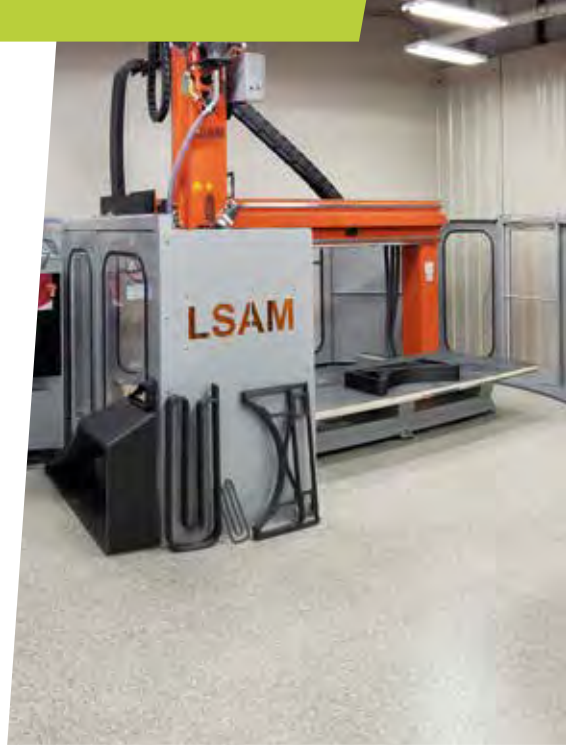
**zoe-grist**

## **About** Orange Cyberdefense

Orange Cyberdefense is a part of Orange Group and provides cybersecurity services to organisations all over the world.

Discover more about Orange Cyberdefense

**orangecyberdef**
**www.orangecyberdefense.com**




# Creating the world's largest 3D-printed structure

**Dr R. Byron Pipes**, of the **Composites Manufacturing and Simulation Centre** at **Purdue University** in the US, forms part of a team that was involved in the development and installation of the world's largest 3D-printed structure – located within the US National Football League's Las Vegas Raiders' Allegiant Stadium.

**Dr R. Byron Pipes**

John L. Bray Distinguished Professor of Engineering, Composites Manufacturing and Simulation Centre (CMSC), Schools of Aeronautics and Astronautics, Chemical Engineering and Materials Engineering, Neil Armstrong Hall of Engineering, Purdue University, USA

PROFILE

**Field of research**
Advanced Composites

**Research project**
Engineering the world's largest 3D-printed structure, the National Football League's (NFL's) Las Vegas Raiders' stadium torch

**Funders**
US Department of Energy (DOE), US National Science Foundation (NSF), Boeing, Saab, other global industry players

TALK LIKE AN ...

## ADVANCED COMPOSITES ENGINEER

**3D printing** — the construction of a three-dimensional object from a CAD model or a digital 3D model

**Anisotropic** — a physics term describing something that changes in property depending on the direction in which it is measured

**Carbon fibre-reinforced polycarbonate composite** — a material that is ideal as a structural component with high strength and stiffness-to-weight, excellent surface quality and dimensional stability

**Compressive stress** — a stress that causes a structure to lose its shape or become crushed

**Digital twin** — a real-time virtual representation of a real-world physical system or process that serves as the indistinguishable digital counterpart of it for practical purposes

**Extrusion deposition** — in 3D printing, where material is melted, driven through a nozzle, deposited layer-by-layer and compacted to ribbon form

**Large scale additive manufacturing** — a production process where a 3D printer creates large workpieces and finishes them through router machining

The National Football League (NFL) is the most popular and successful sport in the US and is proving to be increasingly popular globally. Given the NFL's prominence and the prestige of its players, it is not surprising that the NFL teams are often in the news. What might surprise you is that one team, the Las Vegas Raiders, can now make the unusual claim of being the proud owners of the world's largest 3D-printed structure, one that was built as a homage to Al Davis, an American football legend who served as head coach and general manager of the Las Vegas Raiders.

In early 2022, the Al Davis memorial – the Las Vegas Raiders' stadium torch – was installed at the Raiders' home, the Allegiant Stadium. This 93-feet tall 3D-printed structure is the tallest that has ever been created, anywhere in the world, and is testament to the sheer scale of the NFL and the esteem that Al Davis is held in – and nowhere seems more apt as a home than larger-than-life Las Vegas! The stadium torch is an impressive structure, but how much work goes in to installing such a feature? It is one thing to commission the world's largest 3D-printed structure, but entirely another to build it in a way that works. And this is where Dr R. Byron Pipes comes in.

### Practicalities

Dimensional Innovations (DI), a Kansas-based design, technology and fabrication firm, was tasked with building the 3D-printed torch structure. To achieve this, it used a large-scale additive manufacturing solution that was developed by Thermwood Corporation. When designing the torch, the aesthetic concerns were given precedence – it was a case of working backwards in many ways, where the desired appearance of the torch was decided on before experts were drafted in to determine the feasibility and practicalities of such an undertaking.

Collaborating with structural engineers, Byron and his team, based in the Composites Manufacturing and Simulation Centre at Purdue University, were tasked with studying the behaviour of the structure under different environmental stresses, such as wind, as well as the internal stress of its own weight. It was their responsibility to make the idea of this monumental structure a safe and practical reality.


*The Thermwood LSAM Research Laboratory at Purdue University is a collaboration between Purdue University and Thermwood with the purpose of working together to further enhance, promote and advance large scale additive manufacturing technology. (©Purdue University)*

## Modelling

Byron and the team employed a technique whereby a 'digital twin' of the structure was created. "A digital twin of a structural geometry such as the Las Vegas Raiders' torch is developed by constructing a model of the structure that includes the anisotropic material properties of the printed system, as well as the multiple joining elements," explains Byron. "The torch geometry was achieved by first printing smaller elements of the structure and then joining them into ring geometries that were assembled together to create the beautiful form of the torch." The digital twin – based on real-time data – allowed the team to produce an overall structure that was fit for purpose, as well as aesthetically pleasing.

## Safety

As befits a memorial in a sporting environment, the Al Davis Memorial Torch is an impressive and awe-inspiring sight; it aims to inspire fans and celebrate sporting endeavour. Like any football match where victory looks easy for the dominant team, it also looks elegant and effortless. Except, of course, no football match is effortless, and no structure, especially the world's largest 3D-printed structure, is without its challenges. The team knew the torch would look good, but would it be safe?

To ensure its safety during the construction phase and once in place in the stadium, the team modelled how the structure would 'behave' in different adverse circumstances. The stress of the structure's self-weight and wind loading were modelled, and its deformations and internal stress state were used to predict the torch's safety. The buckling instability – the changing shape – of the structure due to compressive stresses was also examined. To doubly ensure safety, a conventional space frame structure was constructed inside the torch to provide for additional constraints to excessive deformation in adverse circumstances.

## Material

Carbon fibre-reinforced polycarbonate composite was decided upon as the ideal material for this ambitious 3D printing project because it possesses a combination of 'printability' characteristics and structural performance properties. "Printing rates of 500 pounds per hour required adequate flow characteristics, while structural performance was assured by the carbon fibre fraction of the composite," explains Byron. "The torch was constructed of 225 3D-printed blocks, each weighing approximately 350 lbs. Over 100,000 lbs of raw material were used to print the blocks."

## Large-scale

You might have done 3D printing in school or even have your own 3D printer at home and, if so, you will be familiar with the layer-by-layer process 3D printing uses. However, you are unlikely to be familiar with the scale of 3D printing that the memorial torch project involved. The large-scale additive manufacturing the project used is based on extrusion deposition, where solid pellets of the carbon fibre-reinforced polycarbonate are melted and, printed out' of the machine in a 'ribbon'. By using this method, three-dimensional geometries can be created in the layering process that is typical of additive manufacturing, with printing rates of up to 500 lbs per hour. Hobbyists and students in schools use much smaller printers, which use a solid filament that is melted and then deposited but does not transform the filament to the ribbon form. In addition, the systems you might be familiar with print at much lower rates of grams per hour.

## Teamwork

Innovative projects such as this always rely on team effort and the combination of a huge range of skills and expertise. The Purdue University team was led by Sergii Kravchenko, a post-doctoral research assistant, who bought his expertise in aeronautics, astronautics, advanced composites and structural mechanics to the project. Dr Kravchenko is now Assistant Professor of Materials Engineering at the University of British Columbia in Canada.

Despite the novelty of this particular project, the work involved can be considered typical of the research and development projects undertaken by Byron's team in the Composites Manufacturing and Simulation Centre at Purdue University. "It must be pointed out that my team is generally geared towards studying the manufacture and performance of automotive and aerospace products where weight saving is desired," explains Byron. "However, the tools, methods, skills and knowledge we employed in our work on the torch were very similar, despite the difference in project focus."

## Potential

These are exciting times for Byron and the team, with much work on the horizon. "Future projects include the establishment of an industrial consortium to support the further development of extrusion deposition additive manufacturing. New material forms will be created by adding continuous fibre to the discontinuous fibre composite form of conventional extrusion deposition additive manufacturing," explains Byron. "In so doing, the structural performance properties of the additive manufactured structure will facilitate wider application of large-scale additive manufacturing."

The potential for large scale 3D printing is wide open. "The future applications of large scale, extrusion deposition additive manufacturing will be limited only by the imagination and creative characteristics of future engineers," says Byron. "I am confident that this is just the beginning of an exciting period of engineering creativity."

### The Al Davis Memorial Torch in numbers

Al Davis is an American football legend who served as head coach and general manager of the Las Vegas Raiders. The torch designed to commemorate his contribution to the sport and his team is the world's largest 3D-printed structure. These numbers help contextualise just how enormous the structure is:

- 93 feet tall
- Composed of 226 3D-printed subcomponents
- Also composed of 5,580 printed layers of material
- Weighs 101,228 pounds (46,000 kilograms)
- Upper 60% of the torch is clad in 1,148 unique aluminium panels

# **ABOUT** *ADVANCED COMPOSITES ENGINEERING*

We tend to think of advances in digital technologies in terms of the new phones, laptops and screens in front of us, but digital transformation permeates many different fields – and engineering is no different. It is anticipated that advanced composites engineering (as well as other fields within engineering) will undergo rapid changes and developments in the near future. "The digital systems model and the digital twin enable partners to integrate their decision making in a shared process that speeds product development and ensures decision traceability over the product life," explains Byron. "The digital twin of the manufacturing process is a primary focus right now, because of its ability to both capture unique manufacturing details and help assess changes in product performance and operational and maintenance needs across the product lifecycle."

**What other aspects of advanced composites engineering will be improved by technological developments?**

Additive manufacturing will soon provide individualised products at manufacturing costs now only achieved by large-scale, automated production. Replacement parts will also be able to be produced onsite before long, without the need to stock inventory – it means we will live in a world where parts will be created as and when required, thereby minimising waste. "Major corporations have already installed systems that demonstrate a dramatic positive impact on both cost and time-to-build for critical industrial components, such as very large production moulds, tools and fixtures," explains Byron. "The future potential and benefits of this emerging technology could be highly significant to creating and maintaining a competitive advantage for major US industries worldwide."

**What research opportunities will be open to the next generation of advanced composites engineers?**

Byron expects that his primary interest in the future will be manufacturing research in advanced composites. "Manufacturability is the primary economic factor in determining product success," he says. "As long as this remains the case – and I expect it will for some time yet –, it will provide great rewards to society. It is also the primary barrier to application in many needed products, and I expect the next generation of engineers will be focused on this alongside researchers like myself."

## **Explore careers in** *advanced composites engineering*

- Learn more about what a composites engineer does: **www.engre.co/blogs/articles/what-is-a-composite-engineer**
- Byron recommends looking at the American Society of Composites website: **www.asc-composites.org**
- The Composites Manufacturing and Simulation Centre (**www.purdue.edu/cmsc**) hosts its own online composites community resource, known as the Composites Design and Manufacturing HUB (**www.cdmhub.org**), which was launched as an exciting and informative educational tool for budding engineers.
- According to **www.raise.me**, the average salary for composites engineers in the US is between $86,000 and $93,000, although this is dependent on experience: **www.raise.me/careers/architecture-and-engineering/materials-engineers/composites-engineers**

## **Pathway from school to** *advanced composites engineering*

Byron is unequivocal in his recommendations for students wishing to work in advanced composites engineering. "Studies in engineering and science are the primary preparation for a career in advanced composites engineering. Given the extraordinary growth in simulation technology, experience with software tools such as SOLID WORKS, CATIA and ABAQUS (all in the 3DEXPERIENCE Platform) which are becoming the language of innovation, are essential," he says.


*Digital twin of the Las Vegas Raiders' Torch*

# Q&A

## Meet Byron

**What were your interests when you were growing up?**

Engineering and creativity have always been linked in my mind and, early on, my interests were in architecture, where 'form follows function' while simultaneously creating beauty. Perhaps the earliest manifestation of my interest in engineering occurred when I saw a sign in a General Motors dealership advertising the Soap Box Derby race for boys aged 12-15. The race required the boy (girls joined the race in the 1970s) to build his own car while following a few specific directions and goals. The Soap Box Derby organisation supplied a steering wheel, four wheels and two axles (purchase price $25, circa 1953), but the rest was up to the boy.

**Wow! How did you go about building the car?**

My father helped me access a large-scale band saw to make the curved cuts required for the aerodynamic shape of the car. Our neighbourhood appliance store owner agreed to supply the $25 in exchange for painting the 'Brown Brothers Appliances' name on the side of the car. Constructed largely of plywood, my car was designed as a ribbed structure with a thin skin of ¼ inch plywood and sheet metal. It was painted dark green with the tiger shark of the Flying Tigers P-52 (a World War 2 plane) on the nose of the car for aesthetic advantage. The learning experience in creating an engineered system to meet a set of specifications revealed just what technical creativity could be, and I was hooked!

**Who or what inspired you to pursue advanced composites engineering?**

I have always advised my students upon graduation to look for a position where significant and continued learning must occur, where exciting new ideas are being developed. I took my own advice in 1969 when I joined the Composite Structures Group at a major aerospace conglomerate, General Dynamics. Composed largely of doctoral graduates in engineering, the team was challenged by the US Air Force to develop advanced composites to provide weight savings for fuel efficiency and performance gains for military aircraft. In a few short years, all future aircraft — commercial and defence — would contain components constructed of composite materials, and, indeed, stealth technology would demand that the aircraft be made entirely of composites.

**What are your proudest career achievements, so far?**

In 1987, I was elected to the US National Academy of Engineering and in 2018, the University of Edinburgh, in the UK, awarded me the honorary degree of Doctor *honoris causa*, which remain my proudest moments to date.

**What are your ambitions for the future?**

Doing more of the same creative scholarship in composite materials manufacturing!

# Are you ready for the robot revolution?

Transportation is about to go electric and drive itself, meaning every car technician will need to understand how artificial intelligence works. Bringing us up to speed are **Dr Justin Starr** and **Robert Koch**, professors at the **Community College of Allegheny County** in the US.

**Dr Justin Starr**

Endowed Professor of Advanced Technology

**Robert Koch**

Professor of Automotive Technology

Community College of Allegheny County, USA

**Field of research**
Future Transport Technologies

**Research project**
Incorporating the latest transport technology, such as AI, into college training for automotive and mechatronics technicians

**Funders**
Mobility21 University Transportation Consortium, US Department of Transportation

PROFILES

TALK LIKE A ...

## ROBOTICS ENGINEER

**Artificial intelligence (AI) —** computer systems able to perform tasks normally requiring human intelligence

**Autonomous vehicle —** a vehicle that is able to drive itself without human input

**Computer vision —** AI software used to automatically interpret images; for example, to identify pedestrians on the road ahead

**Mechatronics —** technology combining electronics and mechanical engineering

For a hundred years, roads have been ruled by the internal combustion engine. By burning fossil fuels such as petrol and diesel, these engines have driven us into a bustling new age of high-speed transport. But there is a new revolution on its way.

Cruising into view is the electric car, and just around the corner, the self-driving bus. Climate change is pushing us to take cleaner and safer on-board technologies, and we all need to be ready. In particular, the technicians who service tomorrow's vehicles need to understand how they work, and this is where Dr Justin Starr, Professor of Advanced Technology, and Robert Koch, Professor of Automotive Technology, come in. Based at the Community College of Allegheny County (CCAC) in Oakdale, Pennsylvania, Justin and Robert have been working to prepare the next generation of technicians for a computerised transport age.

### Is it the end of the road for the internal combustion engine?

Currently, fossil-fuel driven cars are still the norm. However, Justin thinks we have reached an "inflection point" for surface transportation. We are yet to fully move towards electric vehicles, but the momentum is certainly heading that way. Not only that, "but the coming decades could see cars swapping human drivers for computerised ones," adds Robert.

The problem for internal combustion engines is what comes out of their exhaust pipe and into the atmosphere – gases that are heating the planet and particles that are choking up people's lungs. In the US, it is estimated that around a quarter of greenhouse gas emissions come from fossil fuel transport. One way of reducing these emissions and avoiding catastrophic climate change is to switch to electric vehicles, ensuring their batteries are charged with renewable electricity, such as wind or solar.


The other problem with today's cars is that they crash too often. Usually due to human error behind the wheel, around 40,000 people are killed by road collisions every year in the US. Giving up the driver's seat to robots could reduce this figure dramatically, although the technology to do so is yet to be perfected.

For a robotics engineer like Justin, the approach of autonomous vehicles is an exciting prospect. The shift will affect everyone, though. "Transportation touches every part of our lives, so there is no opting out of this change," he says. An understanding of autonomous vehicles will be required for anyone transporting themselves or goods from A to B, simply crossing the street, or planning their career.

## What role will you play in the revolution?

As a young person today, you will not simply be looking on as these changes take place. In fact, your generation will be the one to shape the future of transport. Justin describes the coming decades as a rare opportunity for students to take part in a technological revolution.

"Autonomous vehicles are evolving as today's students enter the workforce," says Robert. "This gives them a unique opportunity to influence this emerging technology. Their interactions with autonomous systems – whether as drivers, technicians, researchers or consumers – will define an industry."

For example, the youngest engineers today grew up in the age of the internet, so they are used to thinking about interconnected systems and are forming ideas that older engineers would never think of. Furthermore, the next generation will need to decide how important privacy is. Will you be happy for your car to share your location with other vehicles and companies, or will you want this data to be anonymous?

## How are autonomous vehicles "the new space programme"?

Big technological challenges lead to innovations that trickle their way down into society. For example, NASA's programme of space exploration has contributed to a wide range of computing, imaging and material technologies. Justin thinks that the development of autonomous vehicles is playing a similar role.

> **"WHEN TECHNOLOGY RACES AHEAD, EDUCATION NEEDS TO KEEP PACE."**

By working towards safe driverless vehicles, the industry has developed new ultra-fast computer vision systems. Justin explains, "Pedestrian detection systems developed by autonomous vehicle companies are now a part of almost all internet-connected cameras, and the technology used to automatically read road signs is enabling apps to do 'on-the-fly' translation."

## How do we get ready for robotic cars?

"When technology races ahead, education needs to keep pace," says Robert. He and Justin are working to ensure that college students are prepared to work with self-driving cars and the components they contain. They do this by working with researchers who are part of a project called Mobility21. A collaboration between Carnegie Mellon University, the University of Pennsylvania and Ohio State University, Mobility21 is developing cutting edge technologies for a cleaner and more efficient transport system in the US.

Justin and Robert aim to incorporate the latest developments into college level teaching for vehicle technicians. For example, students now need to understand AI technologies, such as computer vision, in order to work with autonomous vehicles. "Self-driving car companies are looking for technicians who can work with software, so a basic understanding of programming, as well as electronics and mechanical systems, is now part of the required skill set," says Justin.

Robert agrees that now is the time for students to develop the skills future technologies will require. "Training technicians on this technology now will allow them to gain a better understanding of systems as they evolve. This will improve 'fix-it-right' repairs down the road," he explains.

## Are we heading in the right direction?

The Mobility21 project has already had success in introducing AI to apprentice technicians. In one workshop, students learned the basics of self-driving cars through a simulation. In the simulation, they could train their own virtual vehicle to drive itself using AI in a virtual world, before racing each other. "Without any prior programming experience, our students were up and racing in just a few hours," says Justin.

Justin and Robert feel programmes like this are helping to democratise the future of transportation – to make the technology accessible to all. Some people might think that AI is too complicated to understand without being an expert in mathematics or computer science, but this does not have to be the case. "With the right teaching tools, could get to grips with the concepts behind driverless cars," says Robert.

In the future, Justin and Robert believe we will see AI technicians as skilled tradespeople, similar to electricians or carpenters. "We have shown that today's community college students can absolutely be a part of these cutting-edge technological advances," Justin says. "AI may teach cars to drive themselves, but it won't teach them to fix themselves."

# Q&A

## Meet Justin

### What motivates you to work in mechatronics education?

When I was Chief Technology Officer of a robotics company, we couldn't hire enough skilled electronic technicians. The challenge with mechatronics is that students must know a little bit about quite a few areas. There just weren't enough people with the ability to troubleshoot circuit boards, solder fixes, flash firmware and work with embedded devices. Our programme trains students to be the workers I so desperately wished to hire when I was in industry.

My experience in developing robotic systems really drove my engagement in the project – I like to show students how they can work with advanced sensors like Radar, Lidar and stereocameras. Understanding the inputs and outputs of these technologies and how they are connected is much more important than understanding every possible signal or integrated circuit in a device.

### What challenges have you had?

When I joined the Community College of Allegheny County, I was lucky enough to begin working closely with our automotive technologies faculty who laid much of the groundwork for this project. My biggest challenge has involved getting up to speed with everything that is happening in transportation. Technology in this area evolves much more quickly than I realised – what I thought I knew became obsolete so quickly!

### What do you find most rewarding about research in your field?

It is great to see students get family-sustaining jobs. Also, by showing them they can be a part of technology that might seem intimidating or complex, we help make their voices heard.

***"LOOKING AT PREVIOUS INNOVATORS, ANALYSING THEIR SUCCESSES AND THEIR FAILURES, AND ADAPTING YOUR OWN BELIEFS CAN BE EXTREMELY VALUABLE."***
***JUSTIN***

Some students say they don't like technology, when, really, they mean they don't enjoy social media. These students can be incredibly effective workers when dealing with complex systems. When they get just a little bit of background knowledge, they are extremely effective at troubleshooting complex Lidar devices, computer vision systems and even autonomous vehicles.

We have a group of students working on a co-op project to make a self-driving autonomous mobility scooter. A few years ago, if you proposed doing this at the community college level, you would not have been taken seriously.

### What attributes have made you successful in your field?

I think three things have really helped me. Firstly, I am always trying to learn new things and adapt to changing systems. I've always believed that you need to stay one step ahead of technology because once you fall behind, it is almost impossible to keep up.

That said, the second thing is that I always try to respect and learn from history. If you are always chasing the next big innovation, it is so easy to lose track of what came before and repeat mistakes others have made in the past. Looking at previous innovators, analysing their successes and their failures, and adapting your own beliefs can be extremely valuable.

Finally, I always try to admit when I don't know something and make an effort to learn it. There is no room in this space for those who feign competence. Sometimes you just have to dig in and learn something new.

### Who or what inspired you to follow the career path that you're on?

My parents always led by example, and I wouldn't be where I am without some great teachers in my past. Now, I find I am mostly motivated by my son, Augustus, and trying to make the world he will inherit a better, safer place.


# **Meet** Robert

**Robert teaches college students the skills they need for a successful career in the future automotive industry.**

**I got involved in Mobility21 over six years ago.** My role as department chair has always been to seek out opportunities for our students and improve the college's outreach in the community. In every school I visit, and at every event I participate in, I try to inform students and others about upcoming job opportunities in transportation. The skills and knowledge the students are acquiring in our automotive classes directly relate to some of the same skills that will be, and currently are, needed for these upcoming jobs.

**I think Mobility21 benefits from our outreach efforts**, as they help the workforce and the public to be better informed about all the coming changes in transportation. As an example, I helped to coordinate an event called Odyssey Day, which was open to the public. During Odyssey Day, we showcased a whole range of alternative fuels for transportation, including compressed natural gas, liquefied petroleum gas and biodiesel, as well as electricity.

> ***HELPING STUDENTS LEARN THE CORRECT REPAIR TECHNIQUES AND DIAGNOSTIC PROCESSES IS EXTREMELY REWARDING.***

**The COVID-19 pandemic was a massive challenge for outreach.** As we all know, it caused a range of issues with schools and events. You could not get in to talk to anyone, and, as an instructor, I had to deal with social distancing and remote training in an environment that is not set up for it.

**I've always had a love for cars.** Helping students learn the correct repair techniques and diagnostic processes is extremely rewarding.

**I think my work ethic and skill in using my hands have made me successful** in the field of automotive technology. My proudest career achievement was helping automotive teachers in Suriname, South America, to rebound after a devastating war. I spent a couple of months teaching new automotive teachers how to teach the new technologies on vehicles at that time.

**My father and grandfather inspired me to follow this line of work.** They were both automotive mechanics and could fix literally everything! I loved to work with my hands, and they showed me a possible career path that matched my interests.

# The fastest electric motor ever is another step towards a sustainable future

**Professor Rukmi Dutta** and her team at the **University of New South Wales,** Australia, have developed a new electric motor that runs at high speeds and uses less power, which ultimately means less pollution.

**Dr Rukmi Dutta**

Associate Professor
School of Electrical Engineering and Telecommunications, University of New South Wales, Sydney, Australia

PROFILE

**Field of research**
Electrical Engineering

**Research project**
Developing high-speed interior permanent magnet synchronous machines for electric vehicles

**Funder**
Australian Research Council (ARC)

## TALK LIKE AN ... ELECTRICAL ENGINEER

**Alternating current (AC) —** a form of current where electrical charges periodically reverse the direction of their motion

**Centrifugal force —** an apparent outward force on an object that is moving in a circle. For example, a moving merry-go-round can make you feel like you are being propelled outwards.

**Direct current (DC) —** a form of current where electrical charges move in only one direction

**Electric motor —** a machine that uses magnetism to convert an electric current into motion

**Magnet —** an object that produces a magnetic field. There are different types of magnets (see **www.toppr.com/guides/physics/electronics/types-of-magnets**).

Rukmi works with permanent magnets, which are formed of naturally-occurring minerals with magnetic properties. Conventional electric motors and generators mostly use electromagnets, which are formed via magnetic induction

**Rotor —** a moving magnet, a key element of an electric motor

**rpm —** revolutions per minute, the unit of rotational speed

**Stator —** an unmoving magnet, one a key element of an electric motor

**Torque —** a measure of the force that can cause an object to rotate around an axis

**Work —** in physics, a force causing the movement - or displacement - of an object

To fight climate change, we must phase out the use of fossil fuels such as coal, oil and gas. This is easier said than done: decarbonising our societies and maintaining high standards of living for people around the world requires not only changes in behaviour, but also technological innovation. Associate Professor Rukmi Dutta of the School of Electrical Engineering at the University of New South Wales (UNSW Sydney) is improving the efficiency of electric motors and, therefore, reducing their environmental impact. Given that these motors can be used in electric cars and even aircraft, this will make an important contribution to the fight against climate change.

### What is an electric motor?

An electric motor uses the principles of magnetic fields to transform electric currents into work. The idea is simple. An electric motor has a stator, a stationary magnet that creates a magnetic field. Inside the stator – and therefore inside the magnetic field – is another part, usually a cylinder called the rotor. Because moving charges generate a magnetic field, the rotor also becomes a magnet when an electrical current runs through it. The 'north' pole of the rotor is attracted to the 'south' pole of the stator, causing the rotor to rotate. The direction of the current is switched at the exact moment when the rotor and stator align, transforming the north pole of the rotor's magnet into a south pole. The new north and south poles are then attracted to opposite poles of the stator, and the rotor continues to turn. The constant switching of the current's direction keeps the rotor spinning. When the rotor is attached to, for example, the wheels of a car, this motion is turned into useful work.

There are many types of electric motors: some use alternating current (AC), while others use direct current (DC); some rely on the induction of magnetic fields, as described above, while others contain permanent magnets; and some have magnets on the surface of the rotor, while in others the magnet is embedded within the material of the rotor itself.


Rukmi works on a specific type of electric motor called an interior permanent magnetic synchronous machine (IPMSM). These motors typically use AC and have permanent magnets embedded in the rotor.

### How did Rukmi innovate and improve on existing IPMSMs?

IPMSMs have several features that make them better than other electric motors. Embedding the magnets inside the rotor generates more torque: the cylinder spins not only because of interaction between the magnet and the AC but also because of additional rotation caused by the resistance of the rotor material to the magnetic field, a property called 'magnetic reluctance'. These machines can also run at a high speed without needing a lot of power, which means smaller IPMSMs can do the same amount of work as other types of larger motors. Compact, light motors are ideal for use in cars and planes, where space and weight capacity are limited.

However, IPMSMs also have a weakness. The internal magnets are held in place by thin iron bridges. As Rukmi explains, "If the rotors are spun at a very high speed, such as 50,000 rpm or more, these bridges are subjected to high mechanical stress caused by the centrifugal force. If we widen the iron bridges to make them withstand the stress, it will compromise the electromagnetic performance of the IPMSM."

To build stronger iron bridges without reducing performance, Rukmi and her team drew inspiration from the longest railroad bridge in South Korea. Gyopo Bridge uses a 'double arc' technique to withstand very high loads. Rukmi's team used this same concept to redesign the rotor's iron bridges. "The result was amazing," she says. "This motor can run up to 100,000 rpm and the power rating is 5 kilowatts. The motor is no longer than a pen, and the diameter is no bigger than a coffee mug. We designed one of the world's fastest-turning IPMSMs using commonly used electrical steel lamination and permanent magnets."

> **"THIS MOTOR CAN RUN UP TO 100,000 RPM AND THE POWER RATING IS 5 KW. THE MOTOR IS NO LONGER THAN A PEN, AND THE DIAMETER IS NO BIGGER THAN A COFFEE MUG."**

### What are the advantages of Rukmi's new design?

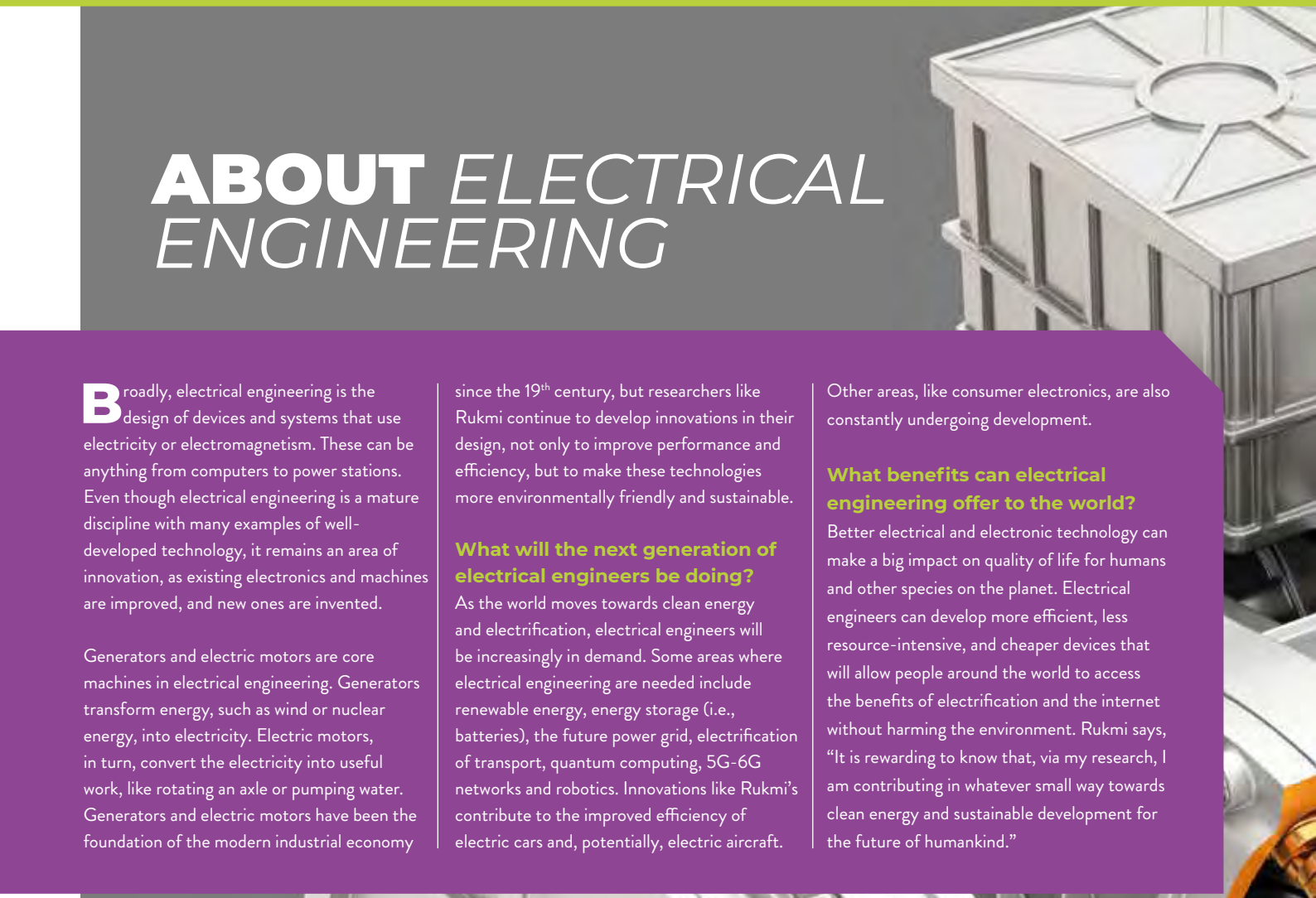
In engineering, small changes in design can have considerable impacts. Rukmi's new bridges allow the motor to reach a higher rpm without becoming damaged. This means the new machine can generate more power without needing more material.

Permanent magnet motors use rare-earth metals such as neodymium and dysprosium in their magnets to achieve high energy density and temperature resistance. These materials are rare, difficult to mine, and expensive to use. They are found in only a few countries, leading to issues with supply chains and resource conflicts. Extracting rare-earth metals is also damaging to the local environment. Rukmi's motor uses less rare-earth metal to achieve better performance, lessening the demand for these materials. In addition, permanent magnet motors that rotate at 20,000 rpm or more, including IPMSMs, usually need a sleeve around the rotor to make it more robust. Designing and fitting this protective sleeve can be expensive and laborious. Even though it is the fastest IPMSM in the world, made with commercially available materials, Rukmi's design is so mechanically strong that it does not need a protective sleeve.

Electric vehicle companies already use IPMSMs in their cars. Adopting Rukmi's motor would be a simple switch, enabling electric cars to travel for longer before needing to be recharged. Even long-established technology like the electric motor can, and must, be reconsidered and improved by innovative researchers like Rukmi to achieve our goals of a sustainable, high-tech future.

*The team's high-speed 5kW, 100,000 rpm IPMSM is the length of a pen and its diameter is no bigger than a standard coffee cup. © G. Chu*

# **ABOUT** *ELECTRICAL ENGINEERING*



Broadly, electrical engineering is the design of devices and systems that use electricity or electromagnetism. These can be anything from computers to power stations. Even though electrical engineering is a mature discipline with many examples of well-developed technology, it remains an area of innovation, as existing electronics and machines are improved, and new ones are invented.

Generators and electric motors are core machines in electrical engineering. Generators transform energy, such as wind or nuclear energy, into electricity. Electric motors, in turn, convert the electricity into useful work, like rotating an axle or pumping water. Generators and electric motors have been the foundation of the modern industrial economy since the 19th century, but researchers like Rukmi continue to develop innovations in their design, not only to improve performance and efficiency, but to make these technologies more environmentally friendly and sustainable.

### What will the next generation of electrical engineers be doing?

As the world moves towards clean energy and electrification, electrical engineers will be increasingly in demand. Some areas where electrical engineering are needed include renewable energy, energy storage (i.e., batteries), the future power grid, electrification of transport, quantum computing, 5G-6G networks and robotics. Innovations like Rukmi's contribute to the improved efficiency of electric cars and, potentially, electric aircraft. Other areas, like consumer electronics, are also constantly undergoing development.

### What benefits can electrical engineering offer to the world?

Better electrical and electronic technology can make a big impact on quality of life for humans and other species on the planet. Electrical engineers can develop more efficient, less resource-intensive, and cheaper devices that will allow people around the world to access the benefits of electrification and the internet without harming the environment. Rukmi says, "It is rewarding to know that, via my research, I am contributing in whatever small way towards clean energy and sustainable development for the future of humankind."

## **Explore careers in** *electrical engineering*

- UNSW Electrical Engineering and Telecommunications is the largest school of its kind in Australia. The school spans five research disciplines – Energy Systems, Telecommunications, Systems and Control, Nano/Micro Systems and Signal Processing. Similarly, most other universities that offer electrical engineering degrees also allow students to specialise in one of several disciplines.
- The world's largest association for electrical engineers and other engineering disciplines is IEEE (**www.ieee.org**). IEEE hosts conferences, publishes peer-reviewed academic journals, offers networking opportunities, and has a student membership programme.
- A typical entry level electrical engineer earns around £35,000 in the UK, €60,000 in Germany, US$70,000-$80,000 in the USA, and AUD$50,000 in Australia. Salaries can be much higher, depending on experience and discipline, ranging up to $150,000+ in Australia.

## **Pathway from school to** *electrical engineering*

- Key subjects at secondary and high school level are mathematics and physics.
- Most universities offer undergraduate degrees in electrical and/or electronic engineering, which are sometimes combined with computer science. Usually, a bachelor's degree is enough to get a job as an electrical engineer in industry. Many companies have engineering or research departments that design new electrical or electronic products.
- Degrees or training programmes in electrical engineering often include an internship or apprenticeship with a company to acquire practical experience.
- Academic career paths are available for electrical engineers who, like Rukmi, want to work in fundamental design and innovation research. A PhD is required to become a university professor in electrical engineering.



# Q&A

## Meet Rukmi

### You have a bachelor's degree and PhD in electrical engineering. Did you always know you wanted to be an electrical engineer?

Yes, to an extent. I wanted to be an engineer since I was in high school, even though an engineering career was not considered suitable for women. I was not any different from the other girls with whom I grew up, and neither did I have any particular talent for engineering, but I had a thirst for knowledge, and learning about new things always excited me. I was also an avid reader. I once wanted to read all the books in the district library, which was a two-floor building full of books!

### How did where you grew up influence your career choice?

I grew up in Nagaon, a small sleepy town in the state of Assam in the north-east corner of India. It is a relatively remote place far away from the megacities of India. Assam is known for its natural beauty and resources, but in the 80s and 90s, it was infested with insurgency problems. Economic backwardness, low development and high unemployment were all around me when I was growing up. One of the most frustrating things in my childhood was routine power cuts in the evenings. In those days, I would say to myself, when I grow up, I will be an electrical engineer and solve this power cut problem forever. I was naïve to think I could solve all problems by myself, but it did influence my career choice.

### You are a member of the Women in Engineering and Women in Research networks. Why are these networks important to you?

Engineering has a gender equity problem worldwide. There are very few successful women in engineering and research. The gender equity problem in electrical engineering is even more acute. IEEE's Women in Engineering and UNSW's Women in Research are valuable networks for me: I found mentors, role models and support among like-minded people.

### What is the biggest risk you have taken and why?

There are actually two important risks that I took, and both allowed me to grow and become what I am today. The first risk was to move to a place more than a thousand kilometres away from my home state, where I joined a very large petrochemical industry as an electrical engineer – my first job. The second risk was moving to a completely different country in pursuit of higher education. I came to Australia to do my PhD, where I did not have any friends or family.

*Rukmi is improving the efficiency of electric motors and, therefore, reducing their environmental impact.*

### What is the biggest factor that has helped you be successful?

I believe hard work and persistence on my side, and support from family and mentors are the biggest factors. My parents never discriminated between my brother and me, and provided me with equal opportunities in all aspects, which I am grateful for. Then, in later years, it was my husband who supported me during my PhD and beyond. In my career development, I am grateful to my mentor, who was also my PhD supervisor. He exposed me to the joy of research, inventing new things and discovering new knowledge. My career at UNSW provided me with the academic freedom to pursue research that is close to my heart.

### **Rukmi's** *top tips*

1. Make sure you have a strong fundamental knowledge of mathematics and physics.
2. Have a thirst for knowledge!
3. The most important thing is hard work and persistence against all odds.

# Examining the extremely small

Nanoscience is the study of the very small. It has many applications, from creating molecules that can deliver drugs to specific targets in the body, to improving the efficiency of solar cells. In Munich, Germany, nanoscientists from all fields are coming together to share ideas and expertise, thanks to the work of the **Center for NanoScience.**

**Dr Susanne Hennig**

Managing Director, Center for NanoScience (CeNS), Munich, Germany

**Funder**
Ludwig-Maximilians-Universität

**Project**
CeNS is a collaborative network of nanoscientists in Munich

PROFILE

TALK LIKE A ...

## NANOSCIENTIST

**Base** — in DNA, two base molecules combine to hold the DNA strand together, like a rung on a ladder

**Diffraction** — the process of a beam of light being spread out by passing through a material

**Genome** — the complete set of genetic material in an organism

**Light emitting diode (LED)** — a type of lightbulb in which a semiconductor glows when voltage is applied

**Microscopy** — using a microscope

**Solar cell** — an electronic device that converts sunlight into electricity

**Spectroscopy** — the study of 'colours' from visible light

**Spectrum (plural: spectra)** — the band of wavelengths contained within electromagnetic radiation

What is the smallest thing you can see with your naked eye? Most scientists will tell you that the answer is human hair – a single human hair has a thickness of ~0.02-0.18 mm. To observe anything smaller, we need help, which usually comes in the form of a microscope. With the most powerful microscopes, scientists can not only see the intricate details of a human hair, they can even observe individual proteins and DNA molecules – objects that exist at the nanoscale.

### How small are things at the nanoscale?

A nanometre (nm) is a unit of measurement equal to a billionth of a metre, or 0.000001 mm. So, nanoscale objects are incredibly tiny! In nature, these include biological molecules such as proteins (typically 3-6 nm) and DNA (~2 nm wide), biological structures such as viruses (20-400 nm) and even individual atoms (0.1-0.5 nm).

### What is nanoscience?

Nanoscience is the study of objects and materials at the nanoscale. It involves using a variety of analytical techniques to observe and characterise nanoscale properties, such as atomic structure, particle size and electric charge. Nanoscience has applications in all fields of science: physicists can determine the structure of atoms, biologists can observe the structure of molecules, materials scientists can control the properties of new materials and computer engineers can develop faster electronics. There are many branches of nanoscience, including nanotechnology (applying nanoscience in new technologies) and nanomedicine (using nanotechnologies for medical applications).

### The importance of nanoscience collaborations

With so many topics within, and applications for, nanoscience, collaborations between nanoscientists working on different projects are crucial for sharing knowledge and advancing the field. This realisation inspired the creation of the Center for NanoScience (CeNS), a network of nanoscience research groups in Munich, Germany.

"CeNS is an interdisciplinary network of scientists exploring the nanoscale," explains Dr Susanne Hennig, Managing Director of CeNS. "Its mission is to support scientific collaborations, provide training for early career scientists and encourage technology transfer from scientific findings to practical applications."

A key reason for supporting this collaboration is the diversity of research within the field of nanoscience. "Nanoscientists manipulate materials at the atomic and molecular level, and thus nanoscience merges physics, chemistry, materials science and biology," explains Susanne. Universities are traditionally structured into distinct disciplinary departments, with different


subjects often located in different buildings. "Nanoscience goes beyond these traditional borders, which is why CeNS strives to bring together researchers from physics, chemistry, biology, pharmacy and medicine."

## What does CeNS do?

CeNS facilitates collaborations between nanoscience researchers in the Munich area by encouraging an 'open-lab' policy, whereby if a scientist or research group needs help with a certain experiment (for example, they do not have the necessary instruments to conduct the experiment or the expertise to analyse the results), they can reach out to other groups in the network. There are currently 38 research groups in CeNS, and they share their skills and equipment with each other, resulting in scientific discoveries that could not be achieved if individual nanoscientists were working alone.

CeNS actively supports early career scientists by providing funding for projects and by holding workshops and seminars where they can develop transferable skills, plan their future career in nanoscience and make friends with other researchers. "Our early career researchers are the next generation of leaders in the field," says Susanne. "Their work drives the research at CeNS and so it is essential that we provide them with excellent conditions that allow them to develop their academic independence."

## How are researchers benefiting from CeNS?

"Scientific research is so complex that it is impossible for a single research group to do everything by themselves," says Professor Alexander Urban from the Faculty of Physics at Ludwig-Maximilians-Universität (LMU). "Our research into optoelectronics strongly benefits from CeNS, with many scientists from different research groups offering complementary expertise and tools which help our projects. We are also striving to become experts in specific techniques so that we can help other groups gain insights into their own research."

"Being a member of CeNS has been extremely helpful," says Dr Amelie Heuer-Jungemann from the Max Planck Institute of Biochemistry, who has found several collaborators for her DNA origami research through CeNS. Amelie's research has also benefited from receiving CeNS funding. "One project has generated very interesting results that will have a large impact on the scientific community, and this collaboration and research would not have happened without CeNS."

"CeNS creates a stimulating environment for interdisciplinary research and collaboration between groups with different scientific expertise," says Dr Evelyn Ploetz from the Faculty of Chemistry and Pharmacy at LMU. Evelyn and her team have developed a new imaging system for observing how nanomaterials absorb molecules locally, an approach other research groups in CeNS could use to study their own experimental systems. "CeNS rendered these experiments possible by supporting our activities and collaborations."

Professor Knut Müller-Caspary's research group, which is also at the Faculty of Chemistry and Pharmacy at LMU, has been developing new imaging techniques to investigate samples using a transmission electron microscope (TEM). "For us, CeNS is the ideal hub to catch the scientific questions in physics, chemistry, materials science and biology that can be addressed with TEM," he says. "Having contact with different people involved in interdisciplinary projects allows us to learn a lot, hear different points of view and gain new input into our research," says Knut. "This results in creative and innovative ideas."

"CeNS organises conferences and meetings, allowing nanoscientists from different research groups to come together to discuss results and new ideas," says Professor Tim Liedl from the Faculty of Physics at LMU. "My research benefits from multiple interactions with the CeNS network. For example, Knut will use his state-of-the-art TEM techniques to help me image atomic details of DNA nanostructures."

## From academia to industry

As nanoscience has many applications in the real-world, CeNS is keen to encourage members to take their scientific discoveries out of universities and into industries. To facilitate this, CeNS provides training on entrepreneurship, connects research groups with established spin-off companies and provides financial support for start-ups. "Over the years, more than 15 high-tech companies have been founded by CeNS members, which now employ over 800 people in the Munich area," says Susanne. "In this way, CeNS has given back to society and we see this as a large success for our work."

> ***"BEING A MEMBER OF CeNS HAS BEEN EXTREMELY HELPFUL. ONE PROJECT HAS GENERATED VERY INTERESTING RESULTS THAT WILL HAVE A LARGE IMPACT ON THE SCIENTIFIC COMMUNITY, AND THIS COLLABORATION AND RESEARCH WOULD NOT HAVE HAPPENED WITHOUT CeNS."***

## Looking to the future

Since its creation in 1998, the CeNS network has fostered a spirit of collaboration and scientific exchange and has provided support for the next generation of nanoscientists. This has resulted in a wealth of successful interdisciplinary endeavours in the field. "In the future, I hope that CeNS will be a platform for the transfer of technology into meaningful applications," says Susanne, "and that new research ideas will develop from fruitful collaborations."

# The art *of origami*

Have you ever practised the ancient Japanese art of origami? With a single sheet of paper and some simple folding techniques, you can create spectacular birds and flowers. Some nanoscientists, such as Dr Amelie Heuer-Jungemann and Professor Tim Liedl, use a similar concept, but for folding DNA molecules. Amelie and Tim are both leading research groups at CeNS to investigate the applications of DNA origami.

## What is DNA origami?

"In our research, we don't fold paper into shapes," explains Tim. "Instead, we produce an ~8000-base-long strand of DNA then fold it, with the help of short (~30 bases) DNA strands, into designed shapes."

Unlike in paper origami, where the skill lies in creating complex shapes from folding only, without the use of glue, in DNA origami the long strand of DNA (known as the 'scaffold') must be held together with 'staples'. "These staples are just like the staples used to hold pages of paper together," explains Amelie. "The short strands of DNA are the staples, which hold the long scaffold DNA together in specific places. Each DNA origami structure will require a different set of ~150 staples, allowing us to create hundreds of different structures from a single scaffold." The scaffold used in DNA origami is the genome of a specific virus that infects bacteria (and is harmless to humans). As scientists know the exact sequence of DNA in this virus, and they know which DNA bases can bind to each other, they can design exactly how the scaffold will fold on itself and be glued together with the staples.

"The actual folding of the DNA origami happens by itself in a salt solution," explains Amelie. "We simply add the scaffold and respective staples to a salt solution, apply heat and let the DNA self-assemble." The four bases in the DNA of any organism are adenine (A), cytosine (C), guanine (G) and thymine (T). "Base A always pairs with base T, and C always pairs with G," explains Tim. "Using this rule, we design components that will 'find each other' in solution, leading to self-assembly of the desired structure. Self-assembly is the opposite of building IKEA furniture, for example, where you follow a plan to build components piece by piece. Instead, after programming the components of the mixture, the hundreds of billions of components will assemble themselves!"

## How might DNA origami become important in biomedicine?

Amelie's research group is investigating how DNA origami can be used for biomedical applications, such as drug delivery. When creating a DNA origami structure, not only does Amelie have full control over the shape and size of the molecule and the exact position of every staple, but she can also modify these, allowing the structure to attach to other molecules or form opening and closing mechanisms. "For example, we can design a box with DNA origami that could be filled with a therapeutic molecule, such as a drug, that will only open to release its contents if it encounters a certain trigger, such as specific enzyme, in the body," she says. "This would enable highly specific drug delivery."

## How can DNA origami mimic the colours of butterfly wings?

Tim's research group is investigating how DNA origami can be used to build crystalline structures. The beautiful colours of a butterfly's wings are the result of the intriguing optical properties of photonic crystals. "Photonic crystals have a regular, periodic structure that allows light of certain wavelengths to pass while preventing other wavelengths of light from entering them," says Tim. The photonic crystals in a butterfly's wings form the intense colours we observe. "In our research, we assemble DNA origami structures that can combine with each other in all directions (front, back, up, down, left and right)," Tim says. By letting these building blocks sit in solution for several days, crystals grow to form designed shapes. "We now hope to mimic the nanoscale geometry of butterfly wing photonic crystals and obtain materials exhibiting similar optical properties."

***"THE ACTUAL FOLDING OF THE DNA ORIGAMI HAPPENS BY ITSELF IN A SALT SOLUTION. WE SIMPLY ADD THE SCAFFOLD AND RESPECTIVE STAPLES TO A SALT SOLUTION, APPLY HEAT AND LET THE DNA SELF-ASSEMBLE."***

*DR AMELIE HEUER-JUNGEMANN*

## **Meet** Dr Amelie Heuer-Jungemann



Max Planck Institute of Biochemistry, Germany

**Research project:** Using DNA origami for biomedical applications

**Funder:** Deutsche Forschungsgemeinschaft

**I've always been interested in how things work and amazed at natural phenomena.** When I was younger, I devoured children's science books, watched lots of science shows on TV and dreamt of one day receiving a Nobel Prize.

**I had an amazing chemistry and biology teacher in high school,** who inspired me to study chemistry with biochemistry. Once I started studying at university, I was hooked! It was clear that science was what I wanted to do for the rest of my life. Even standing in a smelly chemistry lab with stains all over my lab coat, I couldn't be happier!

**It's very cool to design DNA origami** and fascinating to observe the complex structures through a transmission electron microscope. Every time I see a perfectly folded structure, I get a little fuzzy feeling of happiness!

**I am excited about research** as I love troubleshooting problems and seeing successful results when something finally works. I hope our research will lead to the design of future therapeutics for diseases. I have many ideas, and I hope at least some of them will pave the way for positive impacts for society.

**I believe there is still a lot to discover using DNA nanotechnology** for biomedical, physical and computing applications, which is why, in my opinion, it is one of the most attractive fields to have a career in.

## **Meet** Professor Tim Liedl

Faculty of Physics, Ludwig-Maximilians-Universität, Germany

**Research project:** Using DNA origami to construct photonic crystals

**Funders:** European Research Council (ERC), Deutsche Forschungsgemeinschaft, State of Bavaria

**My interest in physics evolved over time.** I enjoyed it in school, where physics classes were about mechanics, perhaps because I enjoyed playing with toy planes and cars and building primitive catapults.

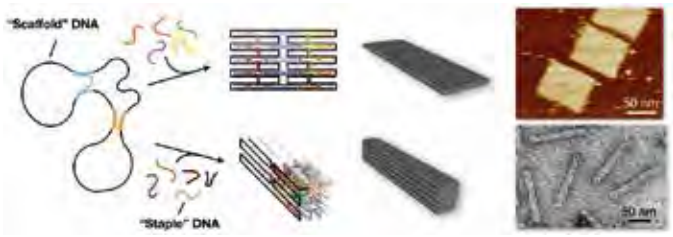
**I initially wanted to become a doctor,** so I worked in a hospital to gain experience. This sparked my interest in medical equipment, so I instead chose to study physics and took classes in biophysics and medical physics, with the hope of developing ultrasound and X-ray equipment. It was only during the final year of my studies that I discovered how much I enjoyed working in a laboratory.

> ***DNA NANOTECHNOLOGY OFFERS RICH AND COMPLEX QUESTIONS FOR PHYSICISTS, CHEMISTS AND BIOLOGISTS.***

**Usually, scientists add small pieces of understanding here and there through our research.** In this way, the scientific community collectively advances knowledge of the field. The contributions of my research group to the greater field of DNA nanotechnology involve the arrangement of gold (and other metal) nanoparticles with the help of DNA origami nanostructures.

**DNA nanotechnology offers rich and complex questions for physicists, chemists and biologists.** How do DNA molecules build such defined structures? Can DNA nanostructures increase the activity of catalysts? Can we use DNA structures to deliver drugs to specific targets in the body?

*'Scaffolds' and 'staples' allow DNA molecules to fold into specific DNA origami structures*



# The physics *of spectroscopy*

Spectroscopy is the study of the interaction of electromagnetic radiation (light) with matter. By analysing spectra of electromagnetic radiation before and after interaction with a sample, spectral changes (for example due to emission, absorption or scattering) can provide information about the sample's composition, physical properties and structure at atomic, molecular and macro scales. Different electromagnetic wavelengths can be used to investigate different scales. For instance, X-rays provide data about individual atoms and electrons, visible light provides data about the electronic configuration of molecules, and infrared radiation provides data about molecular structure.

"Combining spectroscopy with microscopes or telescopes allows scientists to investigate from the nanoscale to astronomical distances," says Dr Evelyn Ploetz, who uses laser light in the visible to near-infrared range to investigate how porous materials absorb and release molecules.

### What research is Evelyn conducting?

Evelyn's lab develops advanced microscopy methods, combining microscopy with spectroscopy to study how small molecules are taken up and transported in materials at the molecular level. In one project, researchers in her lab are examining gas uptake and storage in porous materials. "Droughts are an increasing problem worldwide, and metal-organic frameworks (MOFs) are a promising class of material that could harvest water from the atmosphere," explains Evelyn. "We develop spectroscopic techniques to monitor and quantify water uptake and release from single MOF crystals to understand how materials could be designed for water harvesting."

Another project deals with the transport of molecules, such as gases or metabolites, by porous nanoparticles into cells. "MOF nanoparticles can act as carriers in drug delivery applications due to their highly flexible designs," says Evelyn. The team can control the design of MOFs to enter cells. However, it is not yet understood how the nanoparticles then degrade in the cell to release their cargo. "We aim to follow the chemical composition of MOF nanoparticles in cells over time to monitor their impact on cellular activity," explains Evelyn.

### What successes has Evelyn had?

Evelyn's research group has successfully designed a new multi-modal system for optical spectroscopy and imaging that combines several spectroscopic and microscopic techniques to analyse a sample in 3D in both time and space. This is not only helping the team monitor the transport of small molecules, but has also already been used successfully to study microplastics in ocean sponges and to observe the temporal changes in the distribution of proteins in clusters of cells.

## Meet Dr Evelyn Ploetz

Faculty of Chemistry and Pharmacy,
Ludwig-Maximilians-Universität, Germany

**Research project:** Using applied spectroscopy to study the transport of nanoparticles

**Funder:** Deutsche Forschungsgemeinschaft

**I have always been a creative person with a passion for music and mathematics.** It was an interest in astronomy that inspired me to study physics and become a spectroscopist. When reading about the origin of stars and galaxies at school, I learnt that spectroscopy is the tool used to monitor the composition and movement of stars. I was intrigued about how we study objects we cannot reach or touch, so I wanted to know more about spectroscopic techniques.

**During my studies, I fell in love with optics.** I realised how sensitive and powerful spectroscopy is for probing the structure of molecules. Light is an amazing phenomenon! It can be manipulated and combined with microscopy to non-invasively investigate the internal structure of materials. Spectroscopy is universal and applicable to many different sample systems in life sciences, material sciences and engineering.

**Today, state-of-the-art spectroscopic techniques are not only used for fundamental research,** but also in industries. For example, the automobile industry uses spectroscopy to inspect materials while the pharmaceutical industry uses it to characterise drugs.

***"LIGHT IS AN AMAZING PHENOMENON! IT CAN BE MANIPULATED AND COMBINED WITH MICROSCOPY TO NON-INVASIVELY INVESTIGATE THE INTERNAL STRUCTURE OF MATERIALS."***

*DR EVELYN PLOETZ*

# The nature *of nanocrystals*

When was the last time you looked at a phone screen or turned on an LED lightbulb? Did you know that both these electronic devices, along with others (such as lasers and solar cells), are known as optoelectronics? "Optoelectronics are electronic devices that interact with light," explains Professor Alexander Urban. His research group is using nanospectroscopy to investigate how halide perovskite nanocrystals can improve the efficiency and sustainability of optoelectronics.

### What is nanospectroscopy?

Nanospectroscopy involves applying spectroscopic techniques at the nanoscale. "Nanoscale objects are too small to be seen with an ordinary microscope," says Alexander. "So, in nanospectroscopy, we need to develop new ways of investigating these materials and determining how they interact with light."

> **HALIDE PEROVSKITES INTERACT VERY STRONGLY WITH LIGHT. THEY CAN TRANSFORM SUNLIGHT INTO ELECTRICITY OR TURN ELECTRICITY INTO LIGHT OF NEARLY ANY COLOUR.**

### What are halide perovskite nanocrystals?

Perovskite is a crystalline mineral that contains calcium, titanium and oxygen. When part of the mineral consists of halide ions (e.g., chloride, bromide, iodide), it is known as a halide perovskite, and individual crystals exist at the nanoscale. "Halide perovskites interact very strongly with light," explains Alexander. "They can transform sunlight into electricity or turn electricity into light of nearly any colour. Accordingly, they are nearly perfect materials for developing a new generation of more efficient and sustainable optoelectronic devices."

### What is Alexander's research group doing?

Alexander's research group is using nanospectroscopy and microscopy techniques to understand the properties of halide perovskite nanocrystals. This involves monitoring the light absorbed and emitted by the material and examining how energy and charge are transported in nanocrystals, which is important for understanding how to create electricity from solar cells and for making light from LEDs. "We also deposit individual nanocrystals onto substrates and cool them down to -269 °C to study their energetic structure and how it is influenced by the nanocrystals' shape and size," says Alexander, allowing his team to contribute to nanotechnological advances in optoelectronics.

*The nanoscale properties of halide perovskites mean they are ideal for optoelectronic devices, such as solar cells © asharkyushutterstock.com*

## Meet Professor Alexander Urban

Faculty of Physics, Ludwig-Maximilians-Universität, Germany

**Research project:** Using nanospectroscopy to investigate the properties of halide perovskites for optoelectronics

**Funders:** European Research Council, Deutsche Forschungsgemeinschaft, Bavarian State Ministry of Science, Research and Arts

**It was my first-grade teacher who got me excited about science** and fascinated by astronomy and space exploration. While my interests have since shifted from astrophysics to solid-state physics, I still retain a strong passion for space exploration and stargazing.

**The field of nanoscpectroscopy is very versatile and never gets boring!** It lies at the intersection between physics, chemistry, engineering and biology, so I interact with people who approach science from many different angles. While this can be challenging, it is also rewarding, and these new perspectives lead to better results.

**It is exciting to conduct research on materials that have never been made before,** and to establish collaborations with colleagues around the world. Our focus on energy-related applications means this research is becoming ever-more relevant for society.

# Exploring the atomic world *with powerful microscopes*

Have you ever looked down a microscope in your biology class to observe the features of a cell? Microscopes allow us to view the details of small things, and electron microscopes are the most powerful of all, allowing scientists to observe the tiniest details in a material. "Transmission electron microscopy allows us to view inside atoms!" says Professor Knut Müller-Caspary.

### What is a transmission electron microscope?

A transmission electron microscope (TEM) fires a beam of high-energy electrons (travelling at 70% of the speed of light) at a sample. The electrons pass through the material and form an image of the sample's internal structure. As TEM can create images with a resolution of 0.05 nm, and the bonds between atoms have a length of ~ 0.1-0.2 nm, this means TEM can observe the atomic structure of matter.

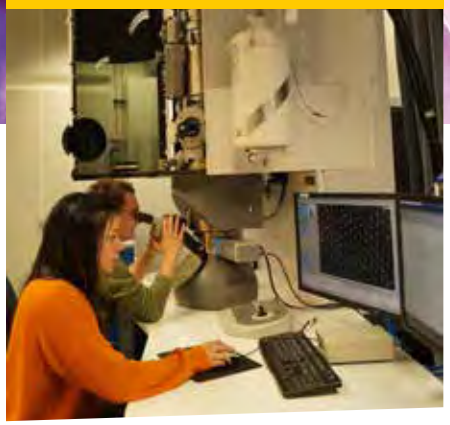
### What research is Knut's group involved in?

In Knut's lab, his team is developing interpretations of the complex diffraction patterns that form when an electron beam inside the TEM is focused into a single atom. "We use basic quantum mechanics to relate the diffraction pattern to the electric field in the illuminated volume," says Knut. "By scanning the electron beam across a specimen, we can measure the electric field distribution produced by the positively charged protons and the negatively charged electrons in individual atoms."

### What are the applications of TEM?

"TEM has a plethora of applications, including in nanotechnology (to determine the position and type of atoms in semiconductor optoelectronics), materials science (to characterise the atomic structure of materials) and structural biology (to uncover the molecular structure of viruses)," says Knut, highlighting how useful this technique is for increasing our understanding of matter.

*PhD students Ziria Herdegen and Tizian Lorenzen operate the TEM with the atomic resolution of their sample on the screen*



## Meet Professor Knut Müller-Caspary

Faculty of Chemistry and Pharmacy, Ludwig-Maximilians-Universität, Germany

**Research project:**
Improving transmission electron microscopy techniques for studying the atomic structure of materials

**Funders:** Deutsche Forschungsgemeinschaft, EQAP One Munich, Hightech Agenda of the State Bavaria

**When I first used TEM, it took my supervisor a while to align all the optics of the machine** and so I spent an hour watching a boring, dense fog on the screen. But then, suddenly, with a turn of the focus knob, the fog disappeared and revealed the atomic pattern of a crystal. It was amazing to see atoms in ultra-sharp definition on the screen, and my passion for resolving the atomic world has lasted since then.

**TEM plays a key role in fundamental science** – it is a measurement tool and a versatile nano-laboratory. It makes the most beautiful experiment of all time (the demonstration of wave-particle duality) an everyday life experience. What further reason would one need to become an electron microscopist?

**It is the fascinating respect for the unknown** that motivates my research group. When asked why they are passionate about science, here are some responses from my lab group members:

- "Curiosity is essential for a scientist. As a scientist, you spend every day learning new things. What more could you wish for?!"
- "I have always asked questions. Why does the sea look blue? Why does my phone battery die when it's cold? I kept asking, and eventually reached a point where no one had an answer. That's the moment I decided to become a scientist."
- "Science is the key to understanding the world around us, and this knowledge then enables us to shape the world to our benefit. As a scientist, you learn things every day about how to understand and shape reality!"

# About *nanoscience*

### Get involved and learn more about nanoscience

CeNS participates in outreach events such as Munich Science Days (**forscha.de/fo**) and the nationwide Girls' Day (**www.girls-day.de**). On Girls' Day, companies and institutions open their doors to women pupils. The programme at CeNS includes visits to the labs, hands-on experiments (such as creating batteries from fruit) and career talks, all presented by women students and research group leaders to inspire and encourage girls to consider careers in fields still dominated by men.

The Max Planck Institute of Biochemistry offers the 'Was Wissen schafft' lecture series (**www.biochem.mpg.de/en/news/publicseminars/wiss_jed**). Once a month, different researchers from the institute explain their research to the public in an accessible way that everyone can understand.

The Max Planck Institute of Biochemistry also hosts the MaxLab (**www.bi.mpg.de/maxlab**), an interactive, hands-on science lab for school classes and visitors of all ages. The MaxLab offers courses covering different scientific topics, all related to the research currently being conducted at the institute.

The Max Planck Institute of Biochemistry has a wealth of educational resources for schools on a variety of scientific topics: **www.max-wissen.de**

The Faculty of Chemistry and Pharmacy at LMU organises an annual Student Information Day (**www.cup.lmu.de/schuelerinfotag**). School students can take guided tours of the different research labs, listen to exciting lectures from professors and students, watch researchers conducting fascinating experiments and learn about studying chemistry, biochemistry and pharmacy at LMU.

Contact the CeNS research groups (**www.cens.de/research/groups**) or the departments that host them if you are interested in arranging a visit or internship!

## Pathway from school to *nanoscience*

- "A solid foundation in science and maths is essential for nanoscience," says Susanne, so study these subjects at school.
- Some universities offer specific degree programmes in nanoscience or nanotechnology.
- As nanoscience combines physics, chemistry, biology and engineering, you can approach the field from any of these directions. Depending on your interests, you could study physics, chemistry, molecular biology, materials science or engineering to begin your career in nanoscience.
- "If you are interested in electron microscopy, you need a solid knowledge of physics, especially quantum mechanics, scattering theory, optics and electrodynamics, to understand the interaction between electrons and a specimen," says Knut.
- "DNA nanotechnology is an incredibly interdisciplinary field," says Amelie, "so you can study any natural or physical science subject and then get into DNA nanotechnology."

## Explore careers in *nanoscience*

- As a nanoscientist, you could conduct research at a university or within a company. Many industries rely on nanotechnology, so you could apply your skills to addressing challenges in pharmaceutical, biotechnology or semiconductor companies, to name just a few.
- CeNS has information about academic and non-academic careers in nanoscience: **www.cens.de/careers**
- This article from NanoTech News explains what nanoscientists do, where they may find themselves working, and what skills and qualifications they need: **www.nanotechetc.com/nanoscientist-education-and-skills-needed-for-the-job**
- Career Explorer provides information about careers in nanotechnology engineering, the branch of nanoscience that creates tiny technology: **www.careerexplorer.com/careers/nanotechnology-engineer**

# How can we measure gases dissolved in seawater?

Nitrous oxide ($N_2O$) is a greenhouse gas that is 300 times more powerful than carbon dioxide. The ocean is a significant source of $N_2O$, but there is currently no easy way to measure how much $N_2O$ is dissolved in and released from seawater. At the **University of Washington** in the US, **Dr Anuscheh Nawaz** and her team are developing a technique to measure the concentration of dissolved $N_2O$ in our oceans directly and more efficiently.

**Dr Anuscheh Nawaz**

Department of Ocean Engineering, Applied Physics Laboratory, University of Washington, USA

PROFILE

**Fields of research**
Ocean Engineering, Instrumentation, Networked Sensors, Small Low-Power Sensor Systems

**Research project**
Developing a carbon nanotube sensor to measure the concentration of dissolved nitrous oxide ($N_2O$) in seawater

**Funders**
National Oceanographic Partnership Program (NOPP), US National Science Foundation (NSF)

*This work was supported by the NOPP and NSF under award number 1841927. The contents are solely the responsibility of the authors and do not necessarily represent the official views of NSF.*

TALK LIKE AN ...

## OCEAN ENGINEER

**Atmosphere (atm)** — a unit of measurement for pressure. One atmosphere is equal to the Earth's average atmospheric pressure at sea level

**Hypoxia** or **hypoxic waters** — very low oxygen levels in a body of water. The usual oxygen concentration in seawater is ~8 mg/litre, in hypoxic waters it is below 2 mg/litre

**In-situ** — in the original place. An in-situ measurement is made directly on-site at the location of the variable being measured

**Microbes** — tiny, single-celled organisms, such as bacteria or fungi

**Microbial cycle** — the life and/or nutrient cycle that a microbe undertakes in combination with its environment

**Nanometre** — one billionth of a metre

**Phytoplankton** — microscopic marine algae which are a key part of ocean ecosystems

**Wastewater** — water that has been used, such as water from sinks, toilets, food scraps and chemicals

Across our planet, deep within the oceans, oxygen minimum zones (OMZs) exist. Occurring at depths of around 200 m to 1 km below sea level, these zones are the places in the ocean where oxygen levels in seawater are at their lowest.

OMZs can be created naturally or caused by humans. When humans allow fertilisers or wastewater to run into the oceans, the phytoplankton living at the ocean's surface overfeed, which, in turn, can lead to coastal hypoxia or 'dead zones'. "After there is an overshoot in nutrients at the ocean's surface, the excess phytoplankton dies off and begins to decompose. Microbes responsible for decomposition use up the oxygen and create these so-called dead zones," explains Dr Anuscheh Nawaz, a research scientist in the field of ocean engineering at the University of Washington. In dead zones, the concentration of oxygen is so low that very few organisms can survive.

"In areas of the water where little or no oxygen is available, a microbial cycle called 'denitrification' can occur where nitrous oxide ($N_2O$) is released into the environment," says Anuscheh. While a lack of nitrogen in the ocean can starve the ecosystem by not providing enough nutrients, too much nitrogen can create excessive plant growth, followed by decay that consumes oxygen, therefore suffocating fish and other organisms.

As a result, it is important that scientists have a way to measure the concentration of dissolved $N_2O$ in OMZs. "Nitrous oxide is the third most important greenhouse gas after carbon dioxide and methane," says Anuscheh. "Direct measurements of it would be invaluable to know where marine microbes are exhaling $N_2O$ and how much they are exhaling."

*The SCUID mass flow controller setup in Anuscheh's lab*

### What are the limitations of current measurement techniques?

"So far, oceanographers can only directly measure dissolved methane ($CH_4$), carbon dioxide ($CO_2$) and hydrogen sulphide ($H_2S$) in the world's oceans," says Anuscheh. To measure other gases, scientists carefully take samples of seawater and send these to a laboratory for analysis. "Scientists sometimes even put the laboratory on a ship, but it is cumbersome!" she adds.

Not only is this sampling method expensive and difficult, but for some very reactive gases, such as nitric oxide (NO), it can also be quite imprecise. This is because gases can change concentration through biological processes before they reach the laboratory to be measured. To develop a better technique, Anuscheh turned her attention to carbon nanotubes.

### What are carbon nanotubes?

"Carbon nanotubes are very cool. They are layers of carbon atoms arranged in a tube shape with the cross-section of a hexagon," Anuscheh says. Carbon nanotubes are extremely strong, only nanometres in diameter, and can be either electrically conductive or act as semiconductors.

"These carbon nanotubes can measure gases because the gas's molecules adhere to their surfaces, which changes the nanotubes' electrical properties," Anuscheh explains. "To measure the concentration of a certain gas, we implant – or 'dope' – different materials, for examples metals, on the carbon nanotube's surface." This enables a resistance change when the nanotube is exposed to a particular gas of interest. "For example, to detect $N_2O$, the carbon nanotubes are doped with gold particles which act as a catalyst." This is known as a carbon nanotube-based gas sensor.

Anuscheh's team can make the sensor selective so that it clearly distinguishes which gas it is responding to, by adding several differently doped nanotube materials to the sensor array. This ensures the sensor is responding to $N_2O$ specifically and not to oxygen concentrations, humidity, or any other condition that might affect the sensor's response.

> **"NITROUS OXIDE IS THE THIRD MOST IMPORTANT GREENHOUSE GAS AFTER CARBON DIOXIDE AND METHANE."**

### What carbon nanotube technology is Anuscheh developing?

Anuscheh calls her research project SCUID, which stands for Submergible Carbon nanotube Underwater Instrument for dissolved gas Detection. "With SCUID, we are striving to solve the problem of being able to measure important greenhouse gases in-situ in the ocean," she says.

SCUID uses current technologies and works alongside technology companies, such as ProOceanus which makes a submergible instrument that can determine the total pressure of gases dissolved in water. The ProOceanus instrument's housing is made of titanium, so that it can withstand the huge pressures it is exposed to while underwater. This is important, as with every 10 m of water depth, pressure increases by one atmosphere. "The instrument can descend to 6000 m below the water's surface," Anuscheh explains. "It has a semi-permeable membrane that lets gases through but stops liquids, which means that water cannot enter the casing, but the gases dissolved in the water can."

Anuscheh combined this instrument with carbon nanotube gas sensors made by Dr Jing Li's research group at NASA Ames Research Center. This allowed her to create a submergible device that can measure dissolved gases far below the water's surface.

"When developing SCUID, we had to understand exactly what environment the carbon nanotube sensor needed to function in, and come up with engineering solutions to create this environment inside the submergible instrument," says Anuscheh.

Anuscheh then had to account for all the different conditions that the SCUID instrument would find when underwater. "The carbon nanotube sensors would experience different temperatures, humidity levels and gas concentrations, compared to what they would experience in a pure laboratory setting," she says. These differences needed to be accounted for so that they would not affect SCUID's measurements. For example, Anuscheh's group implemented a resistive heater on the carbon nanotube sensor chip so that its temperature would stay constant.

### What challenges did Anuscheh face?

Anuscheh's project involved people spread all over the continent, which meant that processes often took much longer than expected. When COVID-19 hit, co-ordination among the team became even more difficult. "For a while, the number of people allowed in one room was limited, which made testing our technologies hard. Our collaborators could not come to visit us and the materials we ordered took a long time to arrive," she says.

Despite solving these hurdles, Anuscheh and her team unfortunately ran out of time and money to test SCUID in the ocean. However, setbacks such as this are part of the research process. High-risk-high-reward science often involves difficulties and Anuscheh is looking to the future. If she can tackle the remaining research questions and successfully deploy SCUID in the future, it will clear the way for the oceanography community to measure many gases of interest in-situ more efficiently which will improve our understanding of the oceans.

# ABOUT *OCEAN ENGINEERING*

Ocean Engineering is the branch of engineering that develops new equipment and techniques for exploring the ocean and its resources. The subject is interdisciplinary as it combines mechanical, electrical, civil and chemical engineering with an understanding of the ocean. In recent years, as the world's population and the number of people living and working on the coast have increased, coastal engineering has become a bigger part of ocean engineering. Coastal engineers might focus on dealing with pollution issues from people living near the sea or look at how the consequences of climate change, such as rising sea levels resulting in erosion, may affect a community.

**How did Anuscheh combine her knowledge of engineering and oceanography to create SCUID?**

"SCUID was born from a conversation I had with a colleague who is a chemical oceanographer," Anuscheh recounts. "Combining my expertise with his in-depth knowledge on denitrification led me to propose SCUID. To be able to propose and execute on interdisciplinary projects, I believe you need to be curious and open to learning from others. You also need a team that contains the necessary experts in their specific domains and the ability to lead with a vision in a way that brings the team together."

## Explore careers in *ocean engineering*

- Marine Insight has a useful page of information describing different careers within ocean engineering and marine science: **www.marineinsight.com/careers-2/a-list-of-unique-and-interesting-marine-careers**
- Anuscheh recommends taking community college courses while finishing high school. In the Pacific Northwest of the US, Everett Community College has an Ocean Research College Academy (ORCA) where students can study marine science: **www.everettcc.edu/programs/stem-health-prof/orca/faculty**
- According to Salary Expert, the average annual salary in the US for an ocean engineer is $73,000, but can be much higher if you are leading projects and paving the way for new science.

## Pathway from school to *ocean engineering*

- "To get into ocean engineering, a mechanical or electrical engineering degree is a straightforward path to take," says Anuscheh. "Try to specialise in ocean-relevant themes whenever you can." Some universities also offer undergraduate degrees in oceanography or ocean engineering.
- "Understand physics, chemistry, and/or biology deeply. If you can do that, you can recognise the underlying mechanisms of any problem," says Anuscheh.
- Ocean engineers learn how to think as problem solvers. "Ask questions from different angles and remember that struggle is where learning happens," says Anuscheh.
- Consider taking science communication or writing classes while at university, as good communication skills are useful for working in ocean science. "Being able to convey problems in a way that is simple but does not distort the concept is very important," says Anuscheh.
- "In my opinion, we tend to specialise too early, and a breadth of experiences – anything from software programming to art or biotech – is valuable," explains Anuscheh. "If you want to have unusual ideas, you need to have unusual experiences!"

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# Q&A

# Meet Anuscheh

### What were your interests when you were younger?

I wanted to help humans, animals and plants live together peacefully, and I very much believed it was within our ability to do so.

### Who or what inspired you to become a scientist?

My father believed in me when others wouldn't. My 5th grade teacher told me I would need to find other areas to focus on because mathematics was not for me. But both my parents, especially my father, told me that teachers have but one view into your capabilities and life, and that their opinions are not what define you. So I didn't let me teacher's comments discourage me. My father instilled in all of us kids the idea that science is a calm, deep way of looking at nature, and that mathematics is a beautiful way to describe it.

### You have a background in plasma physics and space science. What pathway has led you to your current position as an ocean engineer?

During my degree in aerospace engineering, I was drawn to new and exciting research, which I found was more abundant in space sciences. I felt honoured to be offered a project in pulsed plasma research at the University of Stuttgart in Germany. After completing my PhD, I joined the NASA Ames Research Center to put techniques I had learnt during my PhD into practice. From there, I was powered by the desire from my early childhood to help the planet and humans live in symbiosis, and I started a company aiming to make gas sensors wearable and accessible for people anywhere. Having gained valuable skills and experience, I combined the research and networked gas sensor worlds and entered environmental instrumentation development at the Applied Physics Laboratory (APL).

### What personal attributes have helped you to be such an interdisciplinary scientist?

I am motivated by my drive to make human life on this planet both possible and beautiful for years to come. The background I draw from every day, and when working on interdisciplinary subjects, is physics and the art of asking questions. What phenomenon can explain what I am seeing? How can this be matched with processes in physics? What is the next good question I can ask?

I would consider myself brave, ambitious, persistent and curious. I think broadly at first and fill in the details later. These attributes have helped me do interdisciplinary research. I align with engineers by training, with physicists and scientists in the way I ask questions, with artists in my heart, and with world travellers in the way I like to take things one step at a time.

### What have been the highlights of your career so far?

I have many! Being at the University of Berkeley in the US opened my eyes to how international and creative the research world can be. Getting to work on my very own project from scratch during my PhD in Germany, with some of the most hard working and brilliant students I have met, was a fantastic experience. I am also very grateful to work with the NASA Ames Research Center in California and interact with technology and people every day. Winning the Greenovations challenge with my gas sensor start-up company in Seattle was thrilling, and having the opportunity to work at APL on oceanographic instrumentation was a dream come true.

### What are your ambitions for the future?

I am intrigued to explore how humans can live in harmony by finding their personal way of connecting with nature. I believe this can ultimately resolve environmental problems that would otherwise be perpetuated in a different way.

### What do you enjoy doing in your free time?

I enjoy being physically active: hiking, yoga, rock climbing, cycling. I also love martial arts, singing, making music with others and travelling.

## **Anuscheh's** *top tips*

1. Learn to be okay with standing out, and ask questions without wondering if someone else might already know the answer.
2. Whenever you can, find a community of other people who support you and cheer you on.
3. Don't shy away from hard work. When curiosity has taken its course, grit can take you through the rest of what needs to be done.
4. Trust your gut – you will know when it is time to start a new chapter in life.

# A superpowered model of the whole Universe

The mysterious substance of dark matter and the engimatic force of dark energy may hold the key to how the Universe formed. But how can scientists study something that cannot be seen or explained? At **Durham University** in the UK, **Dr Sownak Bose** is using techniques from computational cosmology to uncover the mysteries of the early Universe.

**Dr Sownak Bose**

Institute for Computational Cosmology, Department of Physics, Durham University, UK

PROFILE

**Field of research**
Computational Cosmology

**Research summary**
Using sophisticated simulations of the Universe to uncover the properties of dark matter and how it influenced the development of galaxies and stars

**Funder**
UK Research and Innovation (UKRI) Future Leaders Fellowship (grant number MR/V023381/1)

TALK LIKE A ...

## COMPUTATIONAL COSMOLOGIST

**Dark energy** — a theoretical form of energy thought to act in opposition to gravity and drive the accelerating expansion of the Universe

**Dark matter** — a theoretical form of matter that has significant gravitational effects on the Universe

**Gravitational lens** — matter between a distant light source and an observer that can bend the emitted light through its gravity

**Gravity** — the force that attracts a body towards the centre of another body due to its mass

**Intensity mapping** — using radio waves to survey the large-scale structure of the Universe

**Supercomputer** — a computer with a very high level of performance

There are mysterious forces at work around us. Scientists have long pondered over unseen but important sources of gravity and energy that have shaped the development of the Universe. "Dark matter and dark energy are terms used by astronomers to describe some of the strange observed phenomena that we see in the Universe, but that we can't explain with standard physics," explains Dr Sownak Bose, a computational cosmologist at Durham University. "The term 'dark' doesn't just mean we can't see it; it also means that we don't understand it!"

However, our understanding is increasing every day as the technology and techniques used to observe and model the Universe become ever-more advanced. Sownak is contributing to solving these mysteries by developing sophisticated simulations of the Universe using high-powered supercomputers.

### The power of dark matter

Gravity is key to the makeup of our Universe. Any object with mass generates gravity, and the bigger the mass, the bigger the gravitational field. It is gravity that keeps us fixed to our planet, our planet orbiting the Sun, and the Sun orbiting the centre of the Milky Way galaxy. "In the mid-20th century, astronomers observed that stars on the outskirts of galaxies appeared to be moving much faster than would be expected based on the observed mass of the galaxies' centres," says Sownak. "This implied there was extra mass somewhere that we couldn't see. It was hypothesised that galaxies must be surrounded by invisible 'haloes' of matter that generated this extra gravity."

This unobservable matter was termed 'dark matter', and it has since been realised that it may hold the key to the formation of galaxies and of the Universe itself. "Because ordinary matter can 'feel' the gravitational influence of dark matter, concentrated spots of dark matter draw ordinary matter towards them," says Sownak. "In the early Universe, these spots would have drawn in hydrogen gas, collecting and compressing the gas into highly dense structures that ultimately became stars and galaxies."

Dark matter is very difficult to study because it appears to have little or no interaction with ordinary matter, except through gravity. "We can't observe dark matter using the electromagnetic spectrum – it doesn't interact with light, for instance," says Sownak. "Instead, we have to find ways to infer its presence." One method of inference is called gravitational


lensing, which refers to how far-away galaxies appear 'stretched' when viewed through a powerful telescope. "This stretching implies there's a large gravitational field in between us and the galaxy. We can't see a source, but we can infer it."

## Simulations and observations

Computer modelling has revealed that properties of the early Universe were strongly dependent on the properties of dark matter. To determine exactly what these properties were involves altering them in a model and then comparing the model results to real world observations. One such technique is intensity mapping, which uses large arrays of radio telescopes to map the distribution of radiation that was created by the first stars and galaxies, which can be used to infer when and where these stars and galaxies were born. Comparing modelled and observed data has led astronomers to settle on the properties of dark matter within the Lambda Cold Dark Matter (LambdaCDM) model as the best theory we have, so far, for the formation of galaxies and other structures. "We find high levels of similarities when comparing the predictions of this model with observed data," explains Sownak.

These two main sources of data – observations and simulations – both rely upon the other to push the boundaries of our knowledge. "Sometimes, testing a robust simulation of a theory requires observations beyond the capabilities of our telescopes and other technologies," says Sownak. "That's why there is so much excitement when new technologies launch, like the James Webb Space Telescope (launched in 2021), because they open up a huge array of new possibilities."

## Creating a virtual Universe

"We have to ensure our theoretical predictions match the observed Universe as faithfully as possible, so we don't come to misleading conclusions," explains Sownak. "This involves very detailed and realistic simulations, which require a lot of work and computing power." Collaborative efforts between Durham University in the UK, the Max Planck Institute for Astrophysics in Germany, and Harvard University in the US have led to one of the most sophisticated simulations of galaxy formation ever created. "The MilleniumTNG simulation is enormous in size and has extremely high-resolution," says Sownak. "To bring it to life, we had to develop new computational techniques and use state-of-the-art supercomputers." The main calculation took 57 days to process and involved 122,880 supercomputer processing units. This model produced fascinating findings, and Sownak believes they have only just scratched the surface.

> **"I AM VERY INTERESTED IN SEEING WHAT THE NEXT DECADE BRINGS. THERE'S AN ENORMOUS COMMUNITY EFFORT HAPPENING TO MAP THE LARGE-SCALE STRUCTURE OF THE UNIVERSE THROUGH TIME IN EXQUISITE DETAIL."**

The aim is for it to be possible to model any 'real-life' observation within the simulations to indicate their level of accuracy, in particular the role of dark matter in the early days of the Universe. For instance, the team's largest and most detailed simulations, using the LambdaCDM, produce modelled galaxies similar to our own Milky Way. "We can actually place an 'observer' within this simulation at the location of our Sun to act as a viewpoint for observing the virtual Universe," says Sownak. "Then, we compare this virtual 'viewpoint' to our own. If we've got the model right, they should match." The models show high levels of agreement with observed data, though the latest data from the James Webb Space Telescope has highlighted some mismatches, which could be due to uncertain observations or incomplete theoretical models. This indicates that even with these highly sophisticated models, there is still more to be done – and much to discover.

## From dark matter to dark energy

As the science around dark matter becomes more established, focus turns to the exploration of another mysterious force – dark energy. It has been observed that the Universe is expanding outwards, and this expansion is accelerating. As with dark matter, we cannot see what is driving this. "Dark energy plays very much the opposite role to dark matter," says Sownak. "Rather than bringing material together through gravity, dark energy drives the accelerated expansion of the Universe."

Just like the expansion of the Universe, our understanding of this phenomenon is accelerating as technologies and computers become more sophisticated. "I am very interested in seeing what the next decade brings," says Sownak. "There's an enormous community effort happening to map the large-scale structure of the Universe through time in exquisite detail." This includes powerful observational instruments such as the Dark Energy Spectroscopic Instrument (DESI) survey, and space-based surveys like *Euclid* that are currently in development.

Like much of science, the hope is not just to use these observations to rule out theories, but to also develop and explore new ideas. "This next level of statistical precision will enable us to disprove certain cosmological models attempting to explain accelerated expansion," says Sownak. "It's possible we're in for a far bigger surprise than anticipated – it might turn out that Einstein's theory of general relativity is not the final answer to the laws of gravity after all!"

# ABOUT *COMPUTATIONAL COSMOLOGY*

Cosmology is the branch of astrophysics that studies the development of the Universe. As computers have become more powerful in recent decades, computational cosmology has become an important branch of the field. Supercomputers can process vast quantities of data and provide a means to model the Universe through time. These can be compared with real-life observations to reveal the most likely scenarios for the formation and development of the Universe. Sownak explains more about this field:

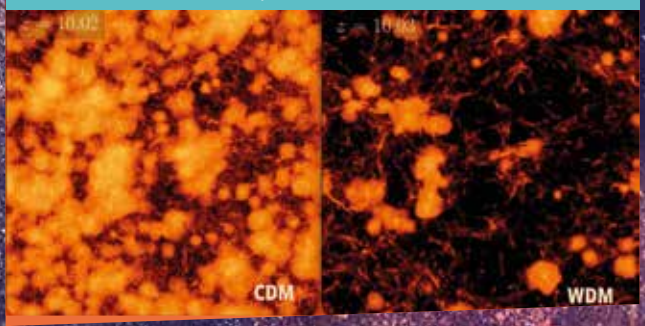
**"Cosmology is a unique subject because of the enormous range of scales involved.** A typical cosmological simulation requires solving the laws of physics covering scales from tens to billions of light years. Such calculations would take hundreds of years to process on everyday computers, but supercomputers can perform them within months or weeks! Supercomputers are essentially many thousands of 'ordinary' computers linked up into one system where all their computational power is addressing a specific problem.

**"Particle physics, cosmology and high-performance computing can be thought of as three rungs on a ladder.** The theories of particle physics give us interesting models for dark matter and their underlying equations. The laws of cosmology – gravity, dark energy, etc. – tell us how our simulated Universe should evolve and what to expect. Finally, high-performance computing helps us combine inputs from particle physics and cosmology and so we can perform these calculations efficiently.

**"One of the coolest aspects of my work is that I'm studying questions that nobody has looked into before.** I am often the first person to actually visualise how the Universe might look under different theories for dark matter. Being at the cutting edge of such questions is fascinating for me!

**"Problem solving and computer programming are obvious skills useful to computational cosmologists.** But I also think that two underrated skills are public speaking and writing. One of a scientist's most important responsibilities is to communicate our findings. The ability to speak and write coherently on complex subjects is extremely important."

*Sownak's simulations predict the properties of the Universe under different model conditions. These images show the primordial radiation fields from a cold dark matter model (left) and a warm dark matter model (right).*




## Pathway from school to *computational cosmology*

- Sownak recommends studying maths and physics at school and post-16 to learn the fundamentals of cosmology. He also advises gaining exposure to computer programming as soon as possible, as computing is essential for many fields of science.
- University degrees in physics, astrophysics, astronomy or computer science could all lead to a career in computational cosmology.

## Explore careers in *computational cosmology*

- Most computational cosmologists work in universities or research institutions, where they develop computer simulations to advance our understanding of the Universe.
- The Institute of Computational Cosmology at Durham University runs an active outreach programme, where you can learn more about the Universe: **icc.dur.ac.uk/index.php?content=Outreach/Outreach**
- The Astronomy Group at Durham University also participates in science festivals and invites school students to participate in internships with researchers in the department: **www.astro.dur.ac.uk**
- The Royal Astronomical Society hosts an array of educational materials and provides details of astronomers in the UK who are willing to do outreach: **www.ras.ac.uk/education-and-careers/outreach**
- Prospects provides information about careers in the wider field of astronomy, including the qualifications you need and the salary you can expect: **www.prospects.ac.uk/job-profiles/astronomer**

"I AM OFTEN THE FIRST PERSON TO ACTUALLY VISUALISE HOW THE UNIVERSE MIGHT LOOK UNDER DIFFERENT THEORIES FOR DARK MATTER. BEING AT THE CUTTING EDGE OF SUCH QUESTIONS IS FASCINATING FOR ME!"



# Meet Sownak

**As a child, my dream was to be a football manager – maybe it still is!** I then wanted to be a writer, then an economist. My interest in science came rather late. I'd never anticipated the career I am in now, and don't think I had any special scientific aptitude when I was younger!

**As a teen, a TV documentary on cosmology and the Universe had a profound impact on me.** I think my eventual journey into cosmology was driven by the fascination sparked by the questions it explored about the origins of the cosmos. I even had my university applications all prepared to study economics when I watched it – so if not for that one night in front of the TV, who knows?

**A main career highlight for me is working with students and young researchers.** Watching them develop into independent researchers is the most rewarding career an academic can have. The UKRI grant I have gives me the flexibility to build a group with a research strategy and culture that's consistent with my ideals. I hope to develop this group, so its members become both scientific and community leaders.

**Research is funded with public money, so I believe that giving back to the community is an important responsibility for researchers.** I also believe that science communication is important to help us reflect on how to effectively translate our work into something impactful. It's common to find that explaining a complex theory in non-technical terms actually helps me understand these complex ideas better.

**For me, some of the most fun outreach activities involve talking about astronomy to school children.** This is particularly true when visiting areas where research careers might seem impossible. I recently worked on a project exploring the connections between physics and football. It was great to see the wonder in kids' faces when revealing the physics behind their favourite sport!

**The most exceptional thing about cosmology** is that, despite the fact that we as humans occupy such a minuscule fraction of the cosmos, we can create and test theories about the formation and development of the Universe over the course of its 14-billion-year lifespan.

**I mainly spend my free time watching, writing about and ranting about football.** I'm also currently creating an astronomy-themed podcast called *The Open Universe* which discusses both old and new topics in an informal way.

## **Sownak's** *top tips*

1. Find something that excites you and that you are passionate about.
2. Don't worry about whether you are 'smart enough' to pursue science. As long as you are motivated, everything else will fall into place.

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