futurum

Inspiring the next generation

futurumcareers.com

ISSUE 21
July 2023

TEENAGER THERAPY

HELP! MAKE IT MAKE SENSE
Dr Aimee Pugh Bernard and Dr Toni Eyssallenne introduce their health-related podcast

TEENAGER THERAPY AND ASTRO STUDIOS
Gael Aitor and Kayla Suarez tell us about their ambitious mental health podcast network

FUTURUM PODCASTS
6 reasons for academics to create podcasts

Be part of a STEM and SHAPE education community

Want more articles like these from researchers, students and associate organisations?

By signing up to **Futurum Careers**, you are subscribing to a community of academics, educators, employers, students – people like you – who want to show the world just how fascinating and rewarding a career in **STEM** and **SHAPE** can be.

What's in it for you?

As a member of Futurum Careers, you'll receive:

- The **latest articles** from academics and associate organisations
- **Teaching and classroom resources** relating to specific topics in STEM and SHAPE
- **Careers resources,** including PowerPoints, podcasts, animations and articles about inspirational role models
- A free, monthly **newsletter.**

Scan to sign up for free, or visit the website:
www.futurumcareers.com/sign-up

A note about your privacy

Your privacy is very important to us. We will not share, sell, reveal, publicise or market your details in any way, shape or form. Our full privacy policy can be found on the Futurum Careers website: **www.futurumcareers.com/privacy**

WELCOME

ISSUE 21
Podcasts for impact

"A lot of the work I do is mission-driven... When I think about what I'm going to make, I don't think about how much money it's going to create, I think about what kind of impact I want to have," says Gael Aitor who, along with Kayla Suarez, tells us about their hugely successful Teenager Therapy podcast and ambitions for their new podcast network, Astro Studios (p 04).

Founders of the Help! Make it Make Sense podcast (p 34), immunologist Dr Aimee Pugh Bernard and physician Dr Toni Eyssallenne highlight the impact of empowering others. Aimee explains, "We strive to ... explain the information in ways that are easy to understand so that people can feel empowered to make decisions based on this information."

With a passion for informing and impacting others, the Astro Studios and Help! Make it Make Sense teams are using podcasts as the tool for connecting more directly with their audiences, for speaking to – and with – others.

Communicating with a wider audience is why researchers choose to share their work with Futurum and why we are always thinking about how we can best convey research and careers advice to students and teachers. It is why, in addition to articles, activity sheets, PowerPoints and animations, we are producing podcasts that enable academics to 'talk' to young people, by sharing their research stories and inspiring insights (p 82).

Informing, empowering and impacting – goals Futurum and the amazing contributors in this issue strive for. What mission drives you? How could podcasts help you achieve it?

THE FUTURUM TEAM

Karen Lindsay
Director and Editor-in-Chief

Erica Morgan
Editor

Isla Foffa
Assistant Editor

Sophia Kerby
Senior Graphic Designer

Brett Langenberg
Director

Chris Dowell
Project Manager

OUR WRITERS

Jacob Ashton, MA

Joe Aslett, MSc

Kate Wilkinson, MA

PUBLISHED BY SCI-COMM CONSULTING

A limited company registered in England.
Company No: 10791252

CONTACT

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

POWERPOINTS
Our PowerPoints summarise the articles and include reflective 'Talking Points', making them a fantastic classroom resource:
futurumcareers.com/ppts

ANIMATIONS
As part of our free package of education resources, we include animations that bring many of the research stories to life:
futurumcareers.com/animations

PODCASTS
Featuring researchers talking candidly about their personal experiences, our podcasts are accessible, engaging and inspiring:
futurumcareers.com/stem-shape-podcasts

SOCIALS

@FUTURUMCareers @Futurumcareers Futurum Careers @futurumcareers Futurum Careers

CONTENTS

Research articles

70

Research articles

INTERVIEWS

COVER STORY

Teenager Therapy and Astro Studios

04

From Teenager Therapy to Astro Studios: the podcasts that are supporting Gen Z's mental health

With over one million followers, **Teenager Therapy** is the largest teen-hosted mental health podcast in the world. After five years, the podcast is coming to an end – albeit with a bang –, so what does the future hold for co-founders **Gael Aitor** and **Kayla Suarez?** They tell us about their ambitious launch of **Astro Studios**, a teen mental health podcast network.

Whose idea was it to start Teenager Therapy?

Gael: It was my idea. I was 15 years old and had been listening to a lot of podcasts when I was a freshman at high school. I started listening to one called Couples Therapy with Candice and Casey and I remember thinking, wow, this is really good. I was listening to other people's problems, and it was helping me with my own issues. Then, I thought it would be even more helpful if something similar was available for teenagers. When I searched, there wasn't anything specifically aimed at teenagers, so I decided to make a podcast myself. I asked four of my friends whether they wanted to help make it and they all said, 'yes'. The rest is history!

Thomas and Kayla celebrate with Gael for his 20th birthday. @ Teenager Therapy

Did you have to learn some new skills?

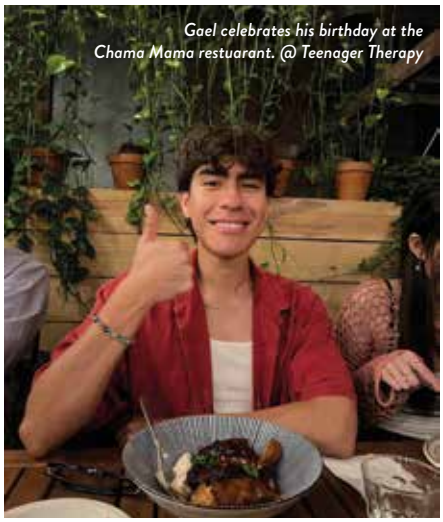
Gael: Yeah, I definitely had a lot to learn. We went super DIY with the recording, using an old DSLR camera that had a microphone. The four of us sat around it, talked into the microphone and that was it. I had no idea how to upload the podcast, so I searched 'podcast' on the internet and came across a tool that puts your podcast on all the platforms for you.

How popular was your podcast in the beginning?

Gael: The first episode got such a good reception that, overnight, we had a couple of thousand plays. We wanted to make sure that the next episode was better quality, so over the course of the week, I obsessed over getting better equipment – better but cheap. I remember everyone telling me not to buy stuff because we didn't know if the podcast was going to do well, but I was sure it would, and I bought the equipment.

What was your aim for the podcast then, and how has that aim changed?

Gael: At the time, I thought people would want to listen to the podcast because teenagers are nosy and like drama. Listening to other teenagers' problems was what was going to make them want to listen to Teenager Therapy. But after a while, I realised that people were attracted to Teenager Therapy because they wanted to feel less alone. Our vulnerability and authenticity were incredibly relatable for our listeners. As teenagers, we go through universal issues, even though we might experience them in different ways. That was what was resonating with our listeners.



Gael celebrates his birthday at the Chama Mama restuarant. @ Teenager Therapy

Over time, I've become much more conscious of the power of vulnerability. We should all try to be a bit more vulnerable in our lives because that's how you develop true connections and feel less alone.

Do you hold things back when you're talking?

Kayla: I was definitely shyer and more reluctant to share in the beginning because the whole experience was so new. Sharing experiences was something I only did in private with friends or at home. But, as time passed, the others gave me the courage to

Teenager Therapy was awarded the 2022 Gotham/Variety Audio Honors award. @ Teenager Therapy

speak out because they were sharing their stories, and it only seemed right that I share mine. Now, I've reached a point where I feel comfortable talking about my experiences. We're essentially in our friend's bedroom, talking. I don't like to think of the thousands of listeners we have when we're recording, though, because then I tend to filter what I'm saying.

How do you decide what to talk about in each episode?

Kayla: Honestly, we usually decide on the day. Before recording, we talk about what's been going on in our lives, what's new, our feelings and, from there, come up with ideas for the episode.

Which is your favourite podcast episode, so far, and why?

Gael: There is one that I think fully encompasses what we do and why, which is about being as authentic as possible. In this episode, we started arguing – it was an explosion of resentment and feelings that came up during the recording. You can hear us trying to communicate effectively and then fail. We had to end early because tensions were so high. For me, that episode is one of my favourites, not because it was enjoyable but because it is so unique.

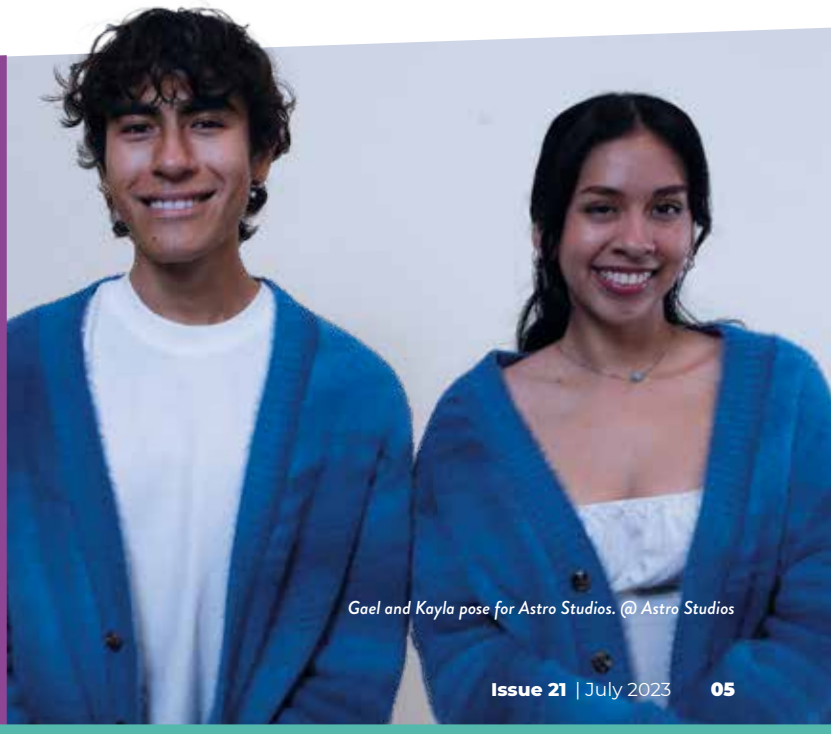
Kayla: One of the more recent episodes that stands out to me was about the issues and emotions we face as first-generation students. I was transitioning into college and it was affecting me a lot. We uploaded some clips to TikTok, and they got a lot more views than usual. I remember feeling relieved, because it meant other people are going through this, too, because, at the time, it didn't feel like I, as a first-gen student, was relating to many people at school.

Is there a concern that keeps cropping up among teens?

Kayla: The way I view it is that there is a jumble of emotions in all areas of one's life that ultimately result in loneliness. It's hard to feel like other people understand what you're going through or that they fully recognise you as you are, which then makes it harder to connect with people. Social media is a double-edged sword in the sense that it can bring people together, and serve as a sense of community, but it's all digital. You don't have that face-to-face connection and interaction, and this is isolating. Social anxiety is also a lot more common. There are many things to battle when you finally do decide, okay, I want to put myself out there. If you do want to overcome loneliness, you have to have the confidence in yourself to take a chance. You never know what connections are out there.

Gael: It almost feels like talking to people in person isn't allowed anymore, and the constant patrolling on the internet is making it worse. Before the internet, people approached people and asked them whether they wanted to go out. Now, people are overthinking even the smallest of interactions. What if the person doesn't want to be bothered? What if this is considered harassment? I think this is driving the loneliness epidemic because we're unable to bring our online connections into the real world; we're unable to establish real-world connections because we're scared of approaching people.

> ***"AS TEENAGERS, WE GO THROUGH UNIVERSAL ISSUES, EVEN THOUGH WE MIGHT EXPERIENCE THEM IN DIFFERENT WAYS. THAT WAS WHAT WAS RESONATING WITH OUR LISTENERS."***
> ***GAEL***



Gael and Kayla pose for Astro Studios. @ Astro Studios

Gael and Kayla speaking at the Aspen Ideas Festival in 2022. @ Teenager Therapy

> ***IT BEGINS WITH A MINDSET SHIFT. YOU CAN TALK TO ANYONE. IT'S FLATTERING TO BE APPROACHED. YOU MAY EXPERIENCE REJECTION, BUT REJECTION IS PART OF LIFE AND THE MORE YOU GO THROUGH LIFE BEING OKAY WITH REJECTION, THE MORE FULFILLING YOUR LIFE WILL BE.***
> ***GAEL***

What is your advice for young people who are feeling lonely and disconnected?

Gael: It begins with a mindset shift. You can talk to anyone. It's flattering to be approached. You may experience rejection, but rejection is part of life, and the more you go through life being okay with rejection, the more fulfilling your life will be. You'll stumble across some really cool people if you put yourself in situations where you might be rejected.

What's next for Teenager Therapy?

Gael: Teenager Therapy is coming to an end in September 2023, coinciding with its five-year anniversary. We're all going to be 20 years old and we feel we've outgrown the brand. We want to go out with a big bang, so who knows what we'll do for our final episode!

> ***SOCIAL MEDIA IS A DOUBLE-EDGED SWORD IN THE SENSE THAT IT CAN BRING PEOPLE TOGETHER, AND SERVE AS A SENSE OF COMMUNITY, BUT IT'S ALL DIGITAL.***
> ***KAYLA***

Kayla picnicking in a park. @ Teenager Therapy

Kayla eats pizza on her first trip to New York with the team. @ Teenager Therapy

You have recently launched Astro Studios. Are there personal reasons for your interest in mental health?

Gael: A lot of the work I do is mission-driven. I've never been profit-driven. When I think about what I'm going to make, I don't think about how much money it's going to create, I think about what kind of impact I want to have. I've realised that what has made Teenager Therapy so fulfilling is the impact it's having. It's the same for Astro Studios. I want to create a space for teenagers to turn to when they're dealing with overwhelming emotions. I went through an emotional crisis at one point in my life, and I didn't know how to handle it, or how I was supposed to feel. I remember thinking, how are others dealing with this? I wanted to hear about the experiences of other young people and that's the driving force behind the shows we make at Astro Studios.

Kayla: When I was a kid in middle school, I didn't know that the term 'mental health' existed, and this is particularly true for underrepresented people. My nephews are teens, and I think about how they'll be needing help at some points in their lives, but they won't be asking for or talking about it. When I think about this on a much larger scale, affecting thousands and thousands of people, I recognise that teens need an outlet, somewhere to go. Astro Studios will become that place.

Do you have an idea of where you want your studies or career to take you?

Kayla: I don't know if this sounds bad or not, but I'm not actively trying to excel academically. I'm majoring in business, so it feels right to be gaining experience, rather than focusing on theory, which is why I'm so excited to see where Astro takes us.

I want to finish my studies because, for me, school is a personal accomplishment. My family doesn't come from educational or college background. I also recognise that if Astro doesn't take off and I need to redirect my attention, I may have to consider different routes.

Gael at an art gallery in New York. @ Teenager Therapy

Gael records for a Spotify Podcast Masterclass in New York. @ Teenager Therapy

> ***I WANTED TO HEAR ABOUT THE EXPERIENCES OF OTHER YOUNG PEOPLE AND THAT'S THE DRIVING FORCE BEHIND THE SHOWS WE MAKE AT ASTRO STUDIOS.***
> ***GAEL***

Gael: I've been an entrepreneur since I was 12 years old. I created my first e-commerce clothing company at 13 and grew that to $100,000 in sales by the time I was 14. I was born in Mexico and emigrated to the US when I was 6. I didn't speak English and lived with my single mom and sister. My mom didn't finish college either. For me, my focus is on growing Astro Studios to hopefully become a successful company and retire after that.

About Astro Studios

As the five friends prepare for perhaps 'the final' big bang for Teenager Therapy, Gael and Kayla have been working on a new project. Launched in May 2023, Astro Studios is a teen mental health start-up providing on-demand access to professional and specialised therapists. At present, it works as a podcast network, which teens can access through a single subscription, but Gael and Kayla have much bigger plans for its development. "This is step one of a hundred steps to where we want to go with Astro Studios," says Gael. "We're reimagining the mental healthcare system and how social media and software can be a supporting pillar." Although Astro Studios is separate from Teenager Therapy, Gael and Kayla describe it as a more mature and scaled-up version of it. "For example, we'll focus on love, and how to deal with a breakup, but instead of covering this in one episode, we'll have a full podcast series dedicated to love and each episode will focus on one person's perspective." The aim is for listeners to be able to select from a wide range of experiences and perspectives, with each interview being between 10 and 15 minutes long.

According to the UK National Health Service (NHS), one in six young people aged between 5 and 16 in England experienced a mental health problem in 2020, up from 1 in 9 in 2017. In the US, young adults aged from 18 to 25 are reported to have experienced more mental health concerns (30.6%), compared to adults aged 26 to 49 years, and the highest rate of serious mental illness (9.7%). "There is a mental health crisis and we're in a loneliness epidemic," says Gael. "A lot of the traditional approaches don't consider all the varying factors that need to come together for there to be an effective solution. I think modern teens think about their mental health in a different way, and that means encompassing media. Astro Studios will use media to provide a community for young people."

@astrostudios
teenagertherapy.com

ABOUT

Can you trust what you see online?

A world leader gives a rousing speech, stirring up anger and resentment among their followers and opponents alike. A viral video shows a celebrity doing a hilarious dance routine. But is any of this real? Today, deepfake technology is so advanced that it is hard to know if you can trust what you see online. At the **University of Illinois Urbana-Champaign**, USA, **Dr Gang Wang** and **Jaron Mink** are investigating how we interact with artificially generated content and how to protect us from its harmful effects.

Dr Gang Wang

Assistant Professor

Jaron Mink

PhD Candidate

Department of Computer Science, University of Illinois Urbana-Champaign, USA

PROFILE

Field of research
Computer Science

Research project
Examining how people interact with phishing attacks and deepfakes, and protecting users from their harmful effects

Funder
US National Science Foundation (NSF)

TALK LIKE A ...

COMPUTER SCIENTIST

Artifact — in computer science, an error

Cybersecurity — the protection of computer systems and networks

Deepfake — any apparently authentic image, audio, video or text that is actually artificially generated

Machine learning — the development of computer systems to learn and adapt based on data, without following explicit instructions

Phishing — a type of social engineering attack in which attackers deceive users into revealing sensitive information or taking harmful actions

Social engineering — psychologically manipulating human users to compromise a computer system

URL (Uniform Resource Locator) — a link or website address

'Congratulations! You have won our top prize!'

'Unusual activity has been detected on your TikTok account. Please click the link below and enter your login details to verify your identity.'

'We understand you have recently been in an accident that wasn't your fault. We can help you claim $10,000 in compensation!'

Have you ever received messages like these? They are examples of phishing, in which cybercriminals trick people into revealing sensitive information, such as passwords or bank details, or taking harmful action, such as installing malicious software. "In phishing attacks, attackers may gain the victim's trust by impersonating friends, co-workers, authorities or official sites," explains Dr Gang Wang, a computer scientist at the University of Illinois Urbana-Champaign. "These impersonations can occur through any communication channel, including emails, social media platforms, text messages and phone calls."

Deepfakes are another method that cybercriminals are increasingly using to trick people into believing information that is not true. "A deepfake is any content (e.g., video, image, audio or text) that appears to be authentic but has actually either been partially manipulated or fully generated by artificial intelligence," explains Jaron Mink, a PhD candidate working with Gang. While deepfakes can be used to create light-hearted entertainment (the internet is awash with fake videos of celebrities supposedly doing or saying funny or silly things), they can also be used maliciously to deliberately hurt people or spread false information.

"If deepfakes are being used for beneficial purposes, such as to enhance artistic projects by creating photorealistic scenes or for comedy entertainment, it should be made clear that viewers are interacting with artificially produced content," says Jaron. "Misuse arises when the technology is used to deceive others intentionally." Malicious deepfakes can harm the individuals who feature in them and they can threaten

national security. For example, in 2019, a deepfake social media profile successfully infiltrated Washington DC's political circle and connected with top government officials. It is, therefore, extremely important that deepfakes can be recognised and removed.

Gang and Jaron hope to not only improve cybersecurity by developing computer methods to detect phishing and deepfakes, but they also want to understand how we, as humans, interact with these phishing attempts and deepfake content.

How can we recognise phishing and deepfakes?

"There are signs that can help you identify phishing attempts," says Gang. These include requests for sensitive information (e.g., login details), urgent demands (e.g., 'Your account is about to expire. Update your details now.') and the presence of suspicious URLs. However, as artificial intelligence advances, it is becoming harder to distinguish deepfakes from authentic content. "There are still a few tell-tale signs," says Jaron. "Deepfake images of people may have distorted or asymmetric accessories or hands, while deepfake texts may contain repeated phrases or incoherent trains of thought."

How do computers protect us from phishing and deepfakes?

Does your spam inbox contain dodgy phishing emails as well as commercial advertising spam? Have you ever had a warning message when you tried to interact with an online account or website? If so, your computer has automatically detected these attack attempts and protected you from them. "Computers can be trained to detect phishing attacks by learning the differences between phishing attempts and genuine communications," explains Gang. "This can be done using machine learning algorithms, which statistically examine different features in the email or social media profile, such as keywords, URLs and images."

Unfortunately, it is still very difficult for computers to recognise deepfake content. "Both deepfake-generated content and the models used to detect them rely on very similar machine learning methods," explains Jaron. "This results in a cat-and-mouse game between cybercriminals generating new deepfake methods and cybersecurity experts developing new detection methods."

Therefore, while it is helpful for computers and social media platforms to detect phishing and deepfake content, computer scientists are trying to find more sustainable solutions. "We are developing machine learning explanation methods to help users recognise why messages and social media profiles may be suspicious," says Gang. Jaron believes we need to rethink how we view online content: "Perhaps we should focus on presenting content that we know is trustworthy, instead of focusing on removing content we think may be artificial."

How do people interact with deepfakes?

Gang and Jaron conducted a study to test people's responses to deepfake social media profiles, by creating fake profiles on the professional social network, LinkedIn, and asking whether people would accept a friend request from them. Some of these profiles contained artifacts, or small errors, in the artificially generated profile photo (e.g., a distorted background) or biography text (e.g., grammatical errors), or inconsistencies between the two (e.g., the biography states the person graduated in 1982 but the photo is of someone in their 20s).

Gang and Jaron discovered that while the presence of deepfake artifacts in a profile decreased the acceptance rate of friend requests compared to profiles without artifacts, 43% of participants accepted requests from the fake profiles they were presented with. "We asked participants why they accepted or rejected each friend request," says Jaron. "We discovered many people found it difficult to attribute certain artifacts to deepfake technology and not genuine human error." For example, incorrect grammar and inconsistent ideas in the biography text were commonly assumed to be due to poor communication and writing skills and so were not considered suspicious by participants.

What happens when people are warned about deepfakes?

Gang and Jaron also investigated whether people could be trained to detect deepfake artifacts. Of the 286 study participants, one third were not told that the LinkedIn profiles may contain deepfake content, one third were told, and one third were told and given in-depth training on how to recognise deepfake artifacts.

"When warned about deepfake content, we find significant decreases in friend request acceptances by participants," says Jaron. "However, even in such conditions, participants still accept friend requests from artifact-laden profiles." The deepfake recognition training did appear to help participants, as this group was better able to recognise poorly generated images as being artificial, while untrained participants were more likely to be confused, but unworried, by strange image artifacts.

However, Gang and Jaron discovered that warning people about fake profiles had some unintended negative consequences. "Trained participants may overcompensate in their search for deepfake artifacts, interpreting real profile characteristics as deepfake artifacts, and so decline genuine friend requests," explains Gang. Most worryingly, some wrongly-perceived artifacts stemmed from racial and gender stereotyping. "One participant became suspicious as they perceived that the name and image in a profile were stereotypically held by people of different gender and racial identities," says Jaron. "Encouraging users to try to differentiate real from fake profiles may instead cause them to differentiate between individuals that do and do not follow their held perceptions of what is 'normal'."

This highlights the need to ensure that deepfake training does not disproportionally harm marginalised and underrepresented communities. The future of cybersecurity, therefore, relies not only on computer scientists, but also social scientists, to create an inclusive and accessible internet.

About *cybersecurity*

As computer scientists, Gang and Jaron work in the field of cybersecurity, which involves protecting computer systems and the people who use them. They are especially interested in combatting social engineering and using machine learning to improve cybersecurity. Social engineering is the tactic of psychologically manipulating people into falling for cyber scams. "For example, social engineering may involve an attacker writing phishing messages in a way that creates a sense of urgency, fear or curiosity in the target user, luring them into giving away sensitive information," says Gang.

Cybersecurity experts are in a constant battle with cybercriminals, as new methods to attack and defend computers are continually being developed. As computer technology advances, there are many challenges for cybersecurity experts to solve. "These include improving security defences to handle increasingly complex and large-scale attacks, making security tools accessible for all users, and improving computers' abilities to respond to new and constantly changing attack tactics," says Gang. Machine learning can address some of these challenges. For example, it can enable computers to recognise patterns in large datasets and can automate key steps in the security defence process.

How can you stay safe online?

"Avoid over-sharing personal information (such as your name, address, phone number, birthday, etc.) and don't share sexually explicit images with anyone," advises Gang. "Such information may be used against you by abusers, for scams or harassment purposes." He also recommends verifying the privacy settings on all your social media accounts to ensure any personal information is only shared with your intended audience.

"Before engaging with information you find online, consider where it has come from," advises Jaron. If it is not from a well-known trustworthy source, he recommends remaining sceptical and not engaging with it. It is also important not to click on links with suspicious URLs, as these could take you to fake or malicious websites. Jaron advises taking care when connecting with people through social media. "Before accepting a friend request, make sure you've talked to that person in real life," he suggests. "And remember, even if the profile contains photos and details of a person you know, it might not actually be them sitting behind the computer communicating with you."

"It is very important to have a support system," finishes Gang. "Talk to trusted adults (such as parents, teachers or the police) if you believe you have encountered scams, phishing or other abusive behaviour online."

Pathway from school to *cybersecurity*

- At school, take any available computer-related courses. Mathematics is also important as computer science is very mathematical.
- You can learn computer coding and programming by exploring the many free websites and online tutorials available, such as Code Academy (**www.codecademy.com**). Once you know how to program, you can then learn about security and hacking (e.g., **www.pwn.college**).
- Jaron recommends joining your school or local computer club, and Gang recommends taking part in Capture the Flag (**www.ctftime.org/ctf-wtf**) events, where competitors solve cybersecurity challenges and attempt to (ethically) hack into systems to test cybersecurity defences.
- At university, degrees in cybersecurity, computer science, computer engineering or information technology will teach you the skills needed for a career in cybersecurity.
- "While in university, take courses that teach you about networking, operating systems, cryptography and security," says Gang. Explaining your work to others and educating the public about cybersecurity is also important, so it is a good idea to take classes in science communication and writing.

Explore careers in *cybersecurity*

- There is a wide range of career paths in cybersecurity. For example, security engineers build security infrastructure, security analysts monitor security systems, penetration testers (also known as ethical hackers) hack into computer systems to test security defences, and security consultants advise companies about cybersecurity.
- "Working in cybersecurity is intellectually stimulating and fun because the field is constantly evolving as attackers adopt new technologies and tactics," says Gang. "To defend against hackers, security professionals need to become better hackers themselves!"
- This article from Forbes explains how to get started on a career in cybersecurity: **www.forbes.com/advisor/education/how-to-get-into-cyber-security-field**
- Best Colleges has some useful information about degrees in the wider field of computer science and the careers these could lead to: **www.bestcolleges.com/computer-science/is-a-computer-science-degree-worth-it**

Meet *Gang*

As a teenager, I was primarily interested in computers because I enjoyed playing computer games. During college, my interests shifted to computer networks (the technology that enables the internet), then, during my PhD, I began to specialise in the security and privacy problems in networked systems.

As a student, I undertook internships at the Microsoft Research Lab, where I worked with researchers to tackle different security problems. I had the opportunity to interact with different production teams at Microsoft to understand the considerations and concerns from practitioners' perspectives. These experiences allowed me to test research ideas in practical scenarios. Personally, the internships helped me to better understand different roles in industrial research labs, which was very useful when it came to choosing a career path.

> ***AS A COMPUTER SCIENTIST, I ENJOY THE FREEDOM OF CHOOSING TO WORK ON EXCITING PROBLEMS.***

Computer science is a fast-moving field. Emerging technologies are changing almost every aspect of our lives, introducing new problems with respect to security and privacy.

As a computer scientist, I enjoy the freedom of choosing to work on exciting problems. I think can make a positive difference in the world. I also enjoy working with students. It is a rewarding experience to witness their growth and help them to become the next generation of computer engineers and scientists.

I am currently teaching my own kids how to program – computing skills are important life skills these days. And, in my free time, I still enjoy playing computer games!

Gang's *top tips*

1. Stay curious.
2. Learn how to program and start building things.
3. You will learn just as much by trying to break something as you did when building it. This is especially true for computer programming and security, so once you have programmed something, try to break it!

Meet *Jaron*

I enjoyed playing video games and board games when I was a teenager, as well as hanging out with friends. Don't discount how important goofing around with friends is to a healthy life!

My love for STEM came from a wonderful set of biology and physics high school teachers. These people were truly excited about teaching their subjects. While in their classes, it felt like what learning ought to be: curious, exciting and perspective-widening!

My high school didn't teach computer science, so I didn't realise that was my passion until later in life. In college, I spent the first year debating whether I wanted to study microbiology, chemistry or electrical engineering. By chance, I took a computer science course and immediately fell in love with the subject.

I love working in computer science because computers are embedded in nearly every scientific discipline and throughout society. With a skillset in computer science, you can improve algorithms for healthcare, discover novel ways to render graphics for video games, or work on theoretical mathematics about computing. Working with computers means being at the cutting edge of many problems the world is facing.

While most work in computer science is about building new systems, I love the human aspect of cybersecurity because it focuses on understanding the psychology of people, and how and why they act. Compared to theoretical work, human-centred computer science provides more immediate solutions to real-life problems.

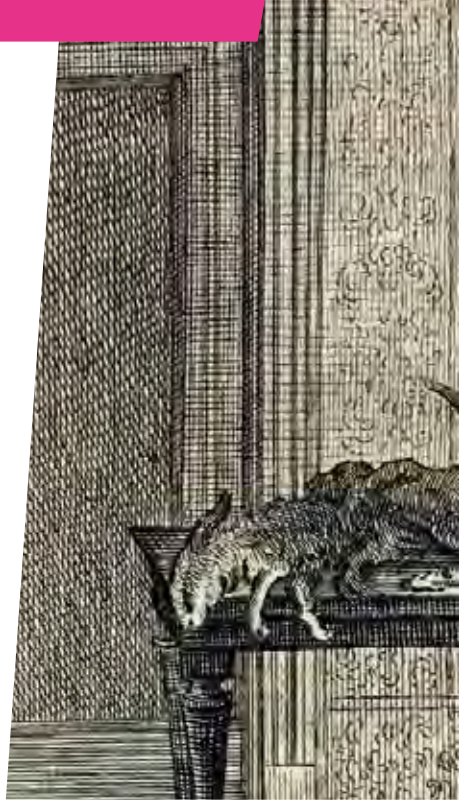
For example, during an internship, I worked on developing an autism therapy app that allowed trained clinicians to remotely interact with parents of autistic children and provide treatment from afar. During the COVID-19 lockdowns, I worked with computer security researchers to ensure the university's contact tracing app was secure and protected the privacy of its users.

In my free time, I enjoy swing dancing, playing board games, hiking with friends and weight training. One day, I hope to learn to play jazz piano!

Jaron's *top tips*

1. Keep an open mind and don't just stay on a fixed path. It's extremely valuable to explore beyond that path.
2. Follow your interests. Pursue things because you're interested in them, not just because other people tell you to.
3. Make time for your friends, loved ones and hobbies. This is just as important as a successful career as they will support you and bring you joy on your journey through life.

How philosophers have influenced the way you think about race



Problematic perceptions about race damage our society. These attitudes can seem impossible to overcome, but philosophers **Dr Jennifer Mensch**, at **Western Sydney University** in Australia, and **Dr Michael Olson**, at **Marquette University** in the US, beg to differ. They are compiling a collection of 18th-century philosophical and scientific texts that helped shape the way people saw race across the Western world, and were used to justify colonisation. They believe that by exposing these historical roots of racism, opportunities to improve societal attitudes to race will become easier to identify.

Associate Professor Jennifer Mensch

School of Humanities and Communication Arts, Western Sydney University, Australia

Dr Michael Olson

Department of Philosophy, Marquette University, USA

PROFILE

Fields of research
Philosophy, History and Philosophy of Science

Research project
Creating an anthology of key texts from 18th-century life sciences and philosophy to assess the history of the concept of race

Funders
Australian Research Council (ARC; Discovery Project DP1903769), Journal of the History of Philosophy, Western Sydney University, Marquette University

TALK LIKE A ...

HISTORIAN AND PHILOSOPHER OF SCIENCE

Biological racism — prejudice against people based on the mistaken belief that 'race' is a part of a person's biology and indicates race-specific traits like intelligence or work ethic

Heredity — genetically passing on characteristics from biological parent to child. In the 18th century, where a person came from was thought to determine some of the features they inherited and passed on to their children

Implicit bias — to be unaware of negative attitudes you might hold toward others, especially if you got these ideas from everyday cultural products, like films or television

Philosophy — the study of the nature of knowledge, reality, ethics, history and politics

Racialised groups — a modern term for what used to be called 'race', that highlights the ways in which racial identities are socially-imposed rather than natural

Structural racism — policies and rules that contribute to the inequality of racialised groups

"Race is one of the most important concepts in modern social life," says Dr Michael Olson, a philosopher at Marquette University. "It's also among the most poorly understood, at least in part because it can be so uncomfortable to talk about it." We all have a rough understanding of the roots of racial inequality, including the huge injustices of colonisation and slavery, and their impacts today. However, what is less well-understood is why, and how, such ideas about race arose in the first place. "We are bringing our expertise, as philosophers interested in the history and philosophy of science, to help understand these origins," says Dr Jennifer Mensch at Western Sydney University, explaining the research she and Michael are conducting.

Throughout history, philosophers have paved the way for shifts in societal thought, but nowadays their works and ideas are typically analysed apart from the context in which they were written. "This is a mistake, because these philosophers were heavily influenced by the economic and political realities of their day," explains Jennifer. Correcting this oversight is the key focus of Jennifer and Michael's project: creating an anthology (or collection) of 18th-century philosophical and scientific works. Their research will consider cultural context to assess how the works influenced, and were influenced by, societal attitudes to race.

The European Age of Enlightenment

Jennifer and Michael's anthology will focus on philosophers and scientists working in Germany between 1745 and 1845. Sometimes referred to as the 'Age of Enlightenment', this period in the 18th and 19th centuries marks a time when European thinkers promoted the pursuit of knowledge through reason and evidence

Enlightenment scientists use an early microscope to investigate tissue from a dissected animal, by François-Antoine Aveline, 1749

– this was the beginning of what we now call the scientific method.

One of the aims of the Enlightenment was to organise information in a rational way. For example, many dictionaries and encyclopaedias were written during this period to classify and sort information about animals, plants, minerals, diseases and medicines. At the same time, European powers (especially England, France and Spain) were exploring the world in search of resources and new places to establish colonies. As a result, Europeans were suddenly aware of the many different cultures and peoples living very different lives far away from the shores of Europe. This created a desire to classify what was called, at the time, 'the varieties of mankind'. Classification in this area laid the basis for the creation of a scientific theory of human differences, eventually referred to as 'race'.

Kant's views on race

Jennifer and Michael's anthology will pay special attention to the works of German Enlightenment philosopher Immanuel Kant (1724-1804). Kant is often described as the most important philosopher of the 18th century, and his ideas about morality continue to be admired and followed in Western society. However, he also used Enlightenment thinking to put forward his own account of the 'scientific' basis for racial differences. "Kant focused on skin colour as the primary way to categorise race, and he linked different races to certain characteristics," says Jennifer. "For example, Kant thought that Europeans were the most capable of industry and self-improvement, while he considered races found closer to the equator to be 'lazy'."

For Kant, rationality combined with responsibility was the hallmark of human life. Races considered less rational were deemed 'inferior' – and, according to Kant's theory, were easily identified by skin colour. "This approach supported colonisation as a project aimed at advancing human progress and as requiring, therefore, that colonisers should 'civilise' the 'less advanced races," explains Michael. "Kant's attempt to link skin colour to other characteristics, such as intelligence, motivation and the ability to govern one's own society, influenced many other studies from that time onwards."

The beginnings of ideas

While Kant's ideas about race have been scientifically disproven and are heavily criticised today, their influence persists. To understand both why this is, and how to combat it, Jennifer and Michael believe it is vital to understand the context in which these ideas arose. Their anthology will consist of three parts. The first will focus on the work of scientists and philosophers to understand the processes of generation and inheritance. The second part will consist of the attempts at the time, including by Kant, to understand and categorise racial differences. The third part will focus on the social and historical context: most importantly, the effects of empires, colonisation and slavery, as well as the 'evidence' gathered by 18th-century scientists, such as skulls, from other parts of the world.

The first part, focusing on the history of science, is crucial to understanding the attempts of 18th-century scientists and philosophers to fit things into neat categories. "At the time, it was still not well understood how the sperm and egg contributed to the generation of offspring," explains Michael. "The children of parents of different races provided key evidence that both sperm and egg contributed, given these children's skin colour typically demonstrates inheritance from both biological parents." This led to a different debate regarding the degree to which skin colour is determined by the environment. During this time-period of colonisation and slavery, people wondered if Europeans moving to Australia or Africans moving to the Americas would eventually produce descendants who looked like the peoples native to the land. "Though biologists have now definitively rejected the idea of race as a scientific category for classifying people, questions around inherited and cultural differences between racialised groups endure in politics across the world," says Jennifer.

Racism today

"Examples of structural racism in modern history are easy to find," says Jennifer. "For instance, the US's post-World War II social security scheme guaranteed pensions, but not for agricultural labourers or domestic servants. At the time, these were the two main professions of non-white people." Generations later, such prejudiced policies continue to have an impact. "In the 1950s, US banks were reluctant to give mortgages to Black buyers, which has directly led to today's wealth gap in the US," Jennifer explains. "White families continue to be richer, on average, than Black families, typically with money inherited through the sale of the houses owned by their grandparents and parents."

It is not just policies, but also internalised prejudices, that carry forward such inequalities. Though few people would describe themselves as racist, there is compelling evidence that racism is often unconscious, and that this kind of prejudice, or 'implicit bias', is widespread. Implicit bias occurs because life is full of cultural messages telling us how to think about ourselves (e.g., 'This is what girls do') and about other people (e.g., 'Foreigners eat strange food'). As a result, we generate and act upon stereotypes without realising it. This is problematic and damaging, as stereotypes are not accurate representations of individuals.

While people might know that structural racism and implicit bias exist, their historical and philosophical roots are less thoroughly understood, which is one reason why Jennifer and Michael believe they persist. "When people are educated about how these socio-cultural categories have come into being, they can be released from identities that can seem biologically determined," says Jennifer. "In fact, this categorisation only occurred in fairly recent history, and this release is a good thing."

About *philosophy*

The word 'philosophy' comes from Ancient Greek and means 'the love of wisdom'. For thousands of years, philosophers have reflected on the nature of reality, the organisation of society, and the best way to live a good life, introducing new ideas which have influenced, and been influenced by, cultural context.

Philosophy is a wide-ranging discipline that challenges our fundamental ideas about the world and our own place within it. "Philosophy makes you think about things in new and surprising ways," says Jennifer. Simple questions become incredibly in-depth and interesting when addressed from a philosophical point of view. "For instance, what defines our ideas of self and individuality? Is it our body, our mind, our collection of memories? Do you remain 'you' if you develop amnesia or a personality disorder, for instance? Spend time with a philosopher and you will soon be questioning all sorts of things you thought you knew for certain!"

The history and philosophy of science

Jennifer and Michael specialise in the history and philosophy of science. This typically involves looking at what philosophers had to say about a scientific topic, then analysing those conversations in the context of the history of science and their impact on the philosophers' own philosophies. "For example, Kant had a theory of racial diversity," says Jennifer. "We are investigating how Kant's theory fits into the history of scientific discussions of this topic at the time, and how it affected Kant's own philosophy."

What skills do philosophers need?

"To study philosophy, it's important to be open-minded and a patient reader," says Michael. So, if you are interested in philosophy, get reading! "There are plenty of literary philosophers out there," says Jennifer, who recommends the plays and short stories written by Jean-Paul Sartre and the works of 'existentialist' writers such as Dostoevsky, Camus and Kafka. "Even works of science fiction, from authors such as Philip K. Dick and Ursula Le Guin, have really valuable philosophical insights that help stretch our minds."

Studying philosophy means reading philosophical works written hundreds or even thousands of years ago. "It's important to remember the period of history these were written in and give the authors a chance to communicate what was important to them," Jennifer says. "That unlocks great possibilities: now you can discover what Plato thought about the soul, what Locke thought would happen when money was invented, or why Kant thought we couldn't rule out the possibility of life on other planets."

We live in a world full of information, where people make unfounded claims about anything and everything. Philosophy teaches you to think and ask questions, preparing you to join the debate in this world of claims and counter-claims. "Our students graduate knowing how to read carefully and think deeply, and most of all to remain intellectually curious," says Michael. "They learn to write and communicate with great clarity and can engage in creative problem solving. These are precisely the kind of 'transferable skills' that employers look for."

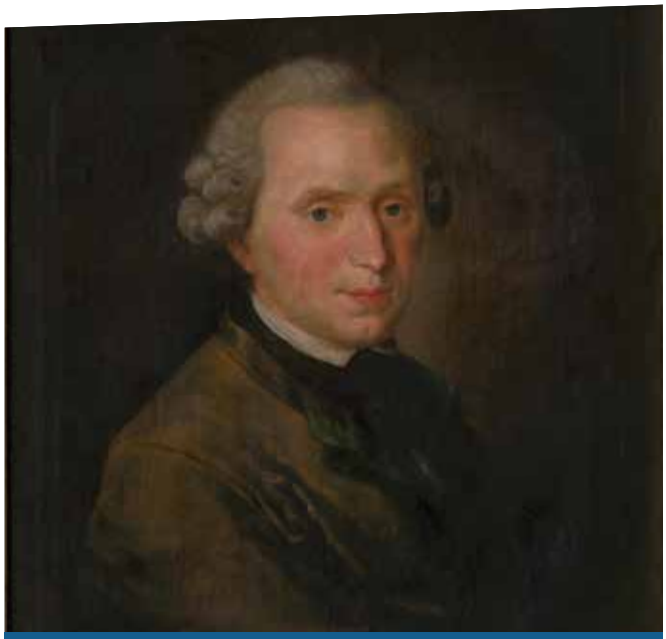
Pathway from school to *philosophy*

- It would be useful to study English or history at school to build your critical reading and writing skills.
- Many universities offer undergraduate degrees in philosophy. Requirements for getting onto these courses vary but are usually flexible about what subjects they look for.
- Philosophical thinking can open a deeper understanding of every field of study, so whatever your interests, taking a class or two in philosophy alongside your other studies will enhance your view of the world.

Explore careers in *philosophy*

- You can use the transferable skills you will gain during a philosophy degree in a huge range of careers. For example, journalism, advertising and public relations all require people who can think analytically and communicate clearly. If you are passionate about ethics and justice, you could use your philosophy knowledge in a career in law or politics.
- Marquette University's Department of Philosophy has information about the value of a philosophy degree, as well as spotlights on work from undergraduates and faculty: **www.marquette.edu/philosophy**
- Western Sydney University aims to make university accessible for students from all backgrounds. Their Year 12 Student Info Hub provides detailed information about how university works, how to apply, and a range of study materials and opportunities to visit: **www.westernsydney.edu.au/future/study/info-for-year-12-students**
- Times Higher Education provides information about what you could do with a philosophy degree: **www.timeshighereducation.com/student/subjects/what-can-you-do-philosophy-degree**
- Jennifer notes that, while salaries for recent philosophy graduates may not initially be the highest, ten years after graduation an average philosophy graduate is earning close to US$100,000 year.

Photo caption: Characters and caricatures drawn by W. Hogarth, 1743



Immanuel Kant (1724-1804) was a German Enlightenment philosopher who proposed theories about racial differences. Painting by Johann Christoph Frisch, c.1770

Meet *Michael*

Growing up, I wanted to be a neurosurgeon or a filmmaker. But that was just because I hadn't discovered philosophy yet!

My introduction to philosophy was an accident. I enrolled in a philosophy course as an undergraduate because my preferred courses were fully subscribed. However, when I discovered how philosophy encouraged intellectual curiosity and established connections between different disciplines, I was hooked.

There are ideas in the history of philosophy that seem strange or absurd when first encountered. I enjoy the challenge of working out why these unfamiliar ways of thinking seemed right to thoughtful people in the past. It's an exercise in understanding how other people make sense of the world. Learning to see things as others see them is enormously helpful in clarifying the value of our own views and in appreciating the complexity and nuance of thought.

In a rapidly changing world, we often overlook how our lives and thoughts are often based on very old ideas. This connects us to ancient traditions and gives us a relationship with the past. More than that, we can understand the origins of our values, preconceptions and prejudices, which helps us understand which are useful and which should be discarded.

Everything is interesting and puzzling if you examine it closely enough. Once I realised how rewarding it can be to pay attention to the everyday things, I stopped thinking about how much better my life could be if I did something different or lived somewhere else. Finding value in philosophical reflection gives me a satisfaction that helps counteract the impulses of envy and ambition.

Meet *Jennifer*

As a kid, I liked animals and being outside, so I thought I might become a veterinarian. I was also a big reader and loved to find out the 'why' of things. That's how I fell in love with the history of ideas, which is focused on understanding how people have approached the world and its processes at different times through history. This includes how we have thought about animals and their place in nature, so it combines my interests perfectly.

My own father was a philosophy professor, which naturally meant that I wanted nothing to do with the subject! However, my undergraduate degree required me to take a philosophy class. The first lesson involved Zeno's paradoxes, which lit up something in my mind. After that, I never looked back and took every philosophy class I could.

> **PHILOSOPHY REQUIRES ASKING HARD QUESTIONS.**

I like studying 18th-century thinkers, especially because people didn't have firm disciplinary boundaries back then. This meant that philosophers could cover everything from the fundamentals of knowledge, to ethics and logic, to geography and physics. Many were interested in new scientific technologies, like the microscope, and how these new devices caused us to radically change our ideas about reality and to ask questions about how our minds can come to know it.

The 18th century was also the 'Age of Empire', which has in the past been dismissed as irrelevant when considering philosophers of the time. However, this means you miss important facets of the philosopher's perception of the world. I think it's important to consider all cultural context, and not just pretend the bad stuff doesn't exist. Philosophy requires asking hard questions.

I try to remain open-minded and intellectually curious. As well as being important skills for my profession, this has also helped me see the good in the world. I try to err on the side of generosity, and assume that most people are trying to do their best to navigate through a complex and confusing world with kindness.

Jennifer's *top tip*

Create an 'ideas journal'. If you hear or read something interesting, take a minute to write it down and think about it. Every time you hear a surprising way of approaching an issue, write it down. I've been keeping journals like these for decades, and they help me collect my thoughts and try out ideas. Philosophers have been doing similar things for hundreds of years!

Social science for social change: the story of marriage equality in the US

For centuries, gay people have suffered discrimination, prejudice and persecution. However, since the 1990s, public attitudes towards gay rights in the US have undergone a monumental shift. **Professor Michael Rosenfeld**, a sociologist at **Stanford University**, has studied this dramatic change in public opinion. Not only has Michael investigated why it occurred, he also played an important role in achieving marriage equality in the US.

Professor Michael Rosenfeld

Department of Sociology, Stanford University, USA

PROFILE

Field of research
Sociology

Research project
Investigating changing attitudes towards marriage equality in the US

TALK LIKE A ...

SOCIAL SCIENTIST

AIDS (acquired immunodeficiency syndrome) — an infectious disease caused when the human immunodeficiency virus (HIV) weakens a person's immune system

Discrimination — treating people differently based on certain characteristics, such as their gender, sexuality or race

Gay — a person attracted to someone of the same sex. In this article, the term is used to refer to both men and women

Marriage equality — when same-sex couples have the same right to marry as different-sex couples

Public opinion — the collective opinion on a particular topic

Social change — changes to how a society behaves

Sue — to take legal action against a person or organisation

Supreme Court — the highest court in the US that has the ultimate say on legal matters at a national level

In 2015, the Supreme Court legalised same-sex marriage in the US, giving same-sex couples the same right to marry as different-sex couples. This landmark ruling was the result of the tireless work of gay rights activists over several decades, who campaigned for marriage equality to be enshrined in US law.

In 1988, less than 30 years earlier, only 12% of Americans supported the idea of marriage equality (while 88% opposed it or had no opinion) and 77% believed that gay sex was always wrong (while 23% believed it was not always wrong). Yet, in just a few short decades, these attitudes had dramatically changed. By 2016, 59% of Americans thought same-sex couples should have the right to marry and the proportion of the population opposed to gay sex had decreased to 40%. According to Professor Michael Rosenfeld, a sociologist at Stanford University, "This is the story of the greatest transformation of public opinion in US history."

Most public attitudes remain relatively stable over time and social change is a slow process. The fight for racial equality, for example, began centuries ago and is still in progress. As social change goes, the shift in public opinion about marriage equality was unprecedented. So, why did public attitudes to gay rights change so significantly?

The recent history of gay rights in the US

1969: the Stonewall riots

From the outside, the Stonewall Inn did not look very impressive. Its drab exterior disguised it as just another New York bar. The inside was dark and dingy, the air hot, stuffy and reeking of stale cigarette smoke. The bar had no running water. But, if you pushed through a set of double doors at the back of the bar, you could enter a world of dance music and rainbow colours. The Stonewall Inn was one of the few places in New York City where gay people felt safe and accepted. The danceroom behind the bar was a haven for people to dance with same-sex partners, dress in drag and express themselves freely, without judgement or hostility.

In June 1969, police raided the Stonewall Inn, as the discriminatory laws of the time meant gay bars were illegal. This raid sparked three nights of violent rioting throughout the neighbourhood, acting as a catalyst for the gay community to fight against oppression. "The Stonewall riots became a rallying cry for gay rights activists to organise politically and fight back against police harassment," explains Michael. Now, every June in cities all over the world, people march and celebrate Gay Pride in commemoration of the 1969 Stonewall riots.

1980s: the AIDS crisis

AIDS is a serious viral disease that was first recognised in 1981. Before effective treatments were developed, the death toll from AIDS was severe, and it particularly affected gay men. The

US government initially ignored the problem, so gay men had to find ways of supporting each other. They set up support groups to care for those suffering from AIDS and created organisations that campaigned for increased AIDS awareness.

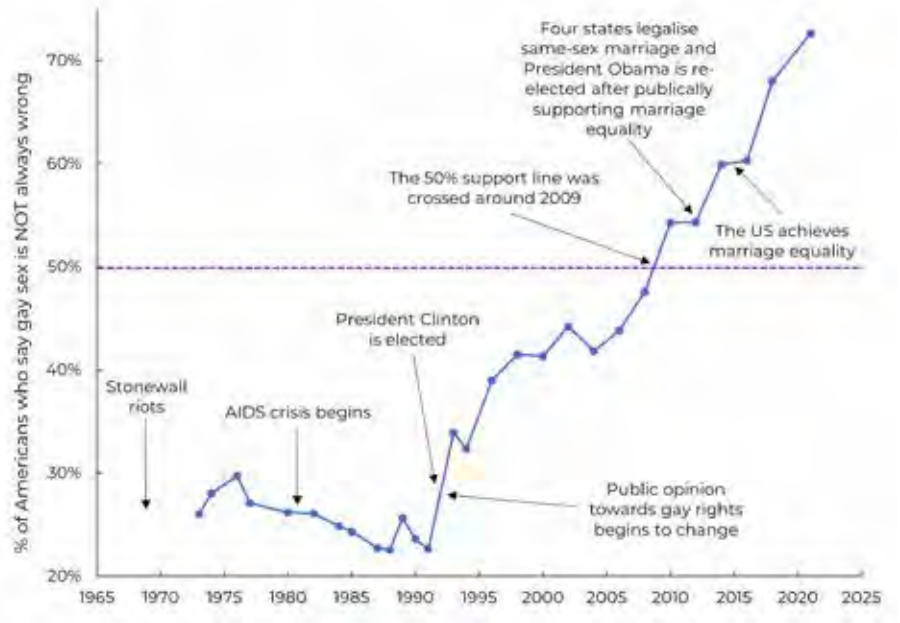
The activism born from the Stonewall riots and AIDS crisis could only be organised when gay people declared their sexuality; they had to 'come out' and let other people know they were gay. "Coming out to friends and family turned out to be a very effective way to influence other people to support gay rights," explains Michael.

1990s: public opinion begins to change

During his presidential campaign in 1992, Bill Clinton said he wanted to lift the ban on gay people serving in the US military. Before this, no presidential candidate had ever said anything positive about gay rights. "Words matter!" says Michael. "The President of the United States is the most powerful person in the country, so the president's words matter even more." Unfortunately, Clinton's ambitions never came to fruition. In the early 1990s, public and political opinion was still against gay rights, and he was instead forced by Congress to implement a 'Don't ask, don't tell' policy, which made the situation even worse for gay people in the US military by making them hide their sexual identities. As a result, Clinton is often vilified by gay rights activists. "However, he started the public and political conversation about gay rights," says Michael.

Public acceptance of gay people and support for gay rights began to rise rapidly after 1992. This was primarily due to the increase in people coming out as gay. For a long time, gay people had been forced to live in secrecy, so most straight Americans thought they had never met a gay person before. "Once straight people knew there were gay people in their family and friendship circles, they realised there was no reason to fear them as gay people were just like themselves," explains Michael. "We tend to trust and respect the people we are closest to (our friends, families, school mates and colleagues), so knowing gay people meant that respect for gay rights rapidly increased."

This figure is derived from General Social Survey data. Respondents were asked 'What is your opinion about sexual relations between two adults of the same sex?' Answer options were 'Always wrong', 'Almost always wrong', 'Sometimes wrong' and 'Not wrong at all'. This question was first asked in 1973, when gay rights were almost universally opposed in the US, hence the anti-gay emphasis in the answer options.



The 21st century: marriage equality is achieved

As acceptance grew, so did the hopes of achieving marriage equality. By 2010, support for gay rights had crossed over the 50% threshold. Now, with the majority of the population onside, it was easier for gay rights to win in court cases and elections. In 2012, four US states legalised same-sex marriage and President Barack Obama made a statement in support of marriage equality. Later that year, he was re-elected, indicating the majority of voters were in favour of marriage equality.

Over the next few years, many same-sex couples living in states that still did not recognise same-sex marriage sued their state for the right to marry. Then, in 2015, a ruling by the Supreme Court made same-sex marriage legal in all 50 US states, finally achieving marriage equality.

Today, gay rights activists are still fighting to ensure that gay people in the US and across the world can live their lives free from discrimination, prejudice and persecution. However, in less than three decades, the memory of the Stonewall riots, the gay community's response to the AIDS crisis and the bravery of millions of gay people who have come out over the ensuing years have helped change the attitude of an entire nation. "Social change happens slowly, so you don't notice it from one day to the next," says Michael. "You can't change opinions overnight, but it is important to know that, over the years, you can change the world."

Social science *for social change*

Societies and the social networks that exist within them can be incredibly complex. With so many interrelated parts, trying to understand how they interact can be a difficult task. To understand how public opinions and attitudes have changed over time, Michael analyses data from the US General Social Survey (GSS) and the US census. The GSS is a semi-annual survey that asks Americans their opinion on a huge variety of different topics, from whether they support marriage equality to whether they like jazz music. In addition to his data analysis, Michael also reads books on relevant topics, studies history, interviews people who sued their states for the right to marry and learns about the US legal system.

How did social science influence the fight for marriage equality?

In 2010, Michael published an academic paper showing that children who were raised by same-sex couples performed just as well at school as those raised by different-sex couples. "Most academic papers are only read by the handful of other academics interested in the same research topic," says Michael. "I didn't expect my paper to have any public impact." Little did he know that his seemingly insignificant contribution to academia would advance the cause of marriage equality.

In 2012, April DeBoer and Jayne Rowse sued the state of Michigan for the right to marry, leading to a trial in a federal courtroom in 2014. Some anti-gay rights scholars had disputed the findings of Michael's 2010 research paper, and Michigan's lawyers called them as witnesses for the case against April and Jayne. In response, April and Jayne's lawyers called Michael as a witness for their side of the argument. "I was delighted to oblige!" he says.

As an 'expert witness', Michael's role in court was to explain his social science research to the judge and highlight why the opponents' arguments were misleading. While public opinion can be influenced by personal prejudices, there is no space for dogma or prejudice in the court room. Instead, trials are based on objective truth, facts and the law.

© Jose Luis Carrascosa/Shutterstock.com

> ***"THE FIGHT FOR GAY RIGHTS ENDURED DECADES OF LOSSES AND SETBACKS BEFORE THEY STARTED TO WIN. SO, TRY NOT TO BE DISCOURAGED BY SETBACKS IN THE CHANGES YOU HOPE TO SEE."***

In proving that children fared no differently at school, regardless of the sex of their parents, Michael used social science as evidence that April and Jayne should be allowed to marry. As a result, the judge ruled in April and Jayne's favour. The state of Michigan appealed the judge's decision, so, along with three similar cases of same-sex couples suing their states, the case was passed on to the Supreme Court. In 2015, the Supreme Court agreed that all four same-sex couples had the right to marry, and marriage equality was made the law across the whole country. "Most social science does not change policy right away," says Michael. "I was lucky to have the opportunity to make a real difference in a case that turned out to have national significance."

Why is marriage equality important for everyone?

The right to marry the person you love is a basic adult human right. Therefore, marriage equality is important for everyone in society, regardless of sexuality and whether or not they have a desire to get married. "When same-sex couples were denied the right to marry, it symbolised a second-class status and encouraged discrimination against them," explains Michael. "While this discrimination has not gone away, it has lessened."

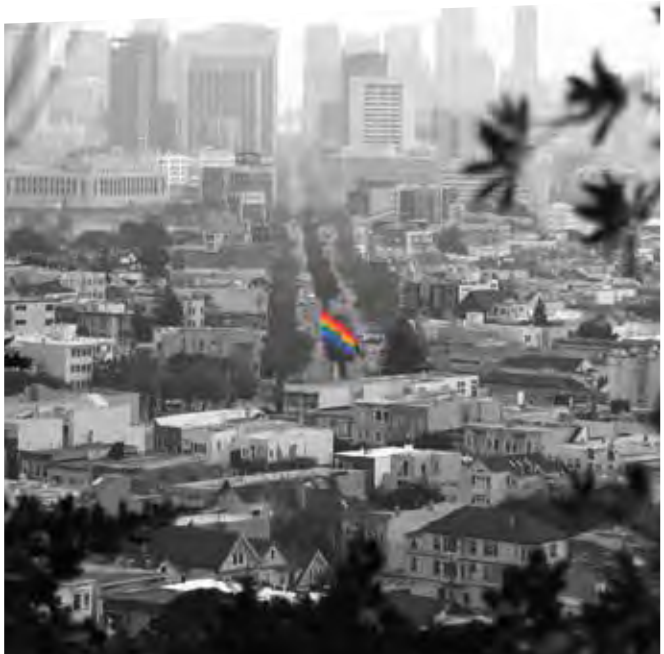
Why should we be encouraged by the story of marriage equality?

For a long time, marriage equality was so unpopular in public opinion that even gay rights activists thought it could never be achieved. And yet, in just a few decades, it became law across the country. The story of marriage equality teaches us that social change is possible, no matter how impossible it may seem. "It takes a long time to make social change," says Michael. "The fight for gay rights endured decades of losses and setbacks before they started to win. So, try not to be discouraged by setbacks in the changes you hope to see."

There are many issues on which the youth and older generations disagree. For young people, it can seem as though adults hold all the power. "But remember, by the time you are 30 or 40, many of the people who oppose your views will be retired," says Michael. This will leave room for a new generation of more tolerant public figures.

How can you initiate social change?

As soon as you are eligible, ensure you vote to make your voice heard. And you can start initiating change now, whatever your age. Get involved with issues you care about. Learn how to be persuasive about your views but also respectful to those who disagree with you. Don't let their opinions discourage you; with time, they may come round to your way of thinking. In the same way that gay people changed the opinions of their families and friends, leading to a dramatic change in public opinion towards gay rights in the 1990s, remember that you can influence the people around you. As Michael says, "You have more power than you know."



A pride flag flies over San Fransisco © Michael Rosenfeld

People have fought for marriage equality for decades and, in many countries, continue to do so. © Rawpixel.com/shutterstock.com

Explore careers in *sociology*

- Studying sociology will open many career possibilities, such as teaching, social work, marketing, public relations and law. "A lot of sociologists work for big internet companies, as these companies are built on the sociological theory of social networking," says Michael.
- Prospects provides information about the range of careers available for people with a sociology degree: **www.prospects.ac.uk/careers-advice/what-can-i-do-with-my-degree/sociology**

Pathway from school to *sociology*

- "If you care about the world and are interested in both people and data, then sociology is a great field to study!" says Michael.
- There is a lot of overlap between the social sciences: sociology, psychology, economics, anthropology and political science, as well as history and law. Knowledge from all these fields will be useful if you are interested in sociology, so a degree in any of these subjects could lead to a career in sociology.
- Sociology research often relies on applied statistics and data manipulation, so a solid understanding of mathematics is also useful.
- Find social science books and articles that address aspects of the world that interest you. Be curious and learn about the things you are passionate about. For examples, *Contexts* is an online magazine about sociology and social science research, full of interesting articles written for a general audience: **www.contexts.org**
- Michael's website contains free versions of his published academic papers, resources for the sociology classes he teaches and information about the court case he participated in: **www.web.stanford.edu/~mrosenfe**

Social solutions for socio-economic issues

Extreme poverty is a global issue that affects hundreds of millions of people. Even in developed countries, many people struggle to make ends meet. In New England, a region in Northeastern USA, many rural communities face high levels of poverty. In large part, this is due to high unemployment rates and a lack of suitable education and training programmes. **Dr Nathan Fiala** from the **University of Connecticut** is working with these rural communities to help solve this problem and reduce poverty rates.

Dr Nathan Fiala

Department of Agricultural and Resource Economics, University of Connecticut, USA

PROFILE

Field of research
Agriculture and Resource Economics

Research project
Identifying existing employment gaps faced by rural New England employers

Funder
US Department of Agriculture's National Institute of Food and Agriculture (USDA NIFA)

TALK LIKE AN ...

AGRICULTURE AND RESOURCE ECONOMIST

Causality — the concept of cause and effect

Extreme poverty — severe lack of access to basic human needs such as food, water, shelter, healthcare and education

Poverty line — the minimum level of income a person needs to afford necessities (which will vary depending on country)

Randomised control trial — a study in which an intervention is randomly assigned to people within a population. A control group is also randomly selected, and the two groups are studied over time to determine the effect of the intervention

Rural communities — small villages or settlements that are located in the countryside

Skills gap — a disparity between the skills that employers are searching for and the skills that potential employees have

Over 700 million people around the world are currently living in extreme poverty, surviving on an income of less than $2.15 a day – about the price of a tube of Pringles. For people trying to get by on such a small amount, life can become a real fight for survival.

Extreme poverty is a global problem. Even in wealthy countries, millions of people live below the poverty line. In the US, for example, almost 40 million people are living in extreme poverty. How is it that America, the home of Hollywood, Wall Street and The American Dream, is also the home of so many people who are struggling to survive?

The answer is not a simple one. The causes of extreme poverty, and extreme inequality, in the US are numerous, varied and complex, and many people have dedicated their careers to studying them. Even so, studying the causes of extreme poverty is just the first step on a long journey to eradicating the problem.

The next step involves implementing schemes and programmes that can support people living in poverty and help them to achieve financial security. Dr Nathan Fiala, an agriculture and resource economist from the University of Connecticut, is leading a new programme in the region of New England, where his university is based. He hopes that this programme will help to encourage economic growth in the poverty-stricken communities of rural New England, so that the people who live there can attain a better quality of life.

Life in New England

"Extreme poverty is common across the US," says Nathan. "New England is no different." Poverty is particularly prevalent in rural communities in the north of the region. Big cities, like Boston in Massachusetts, tend to be the economic heartbeat of a region. In them, it can be much easier to find well-paying jobs, affordable housing and educational opportunities. In rural communities, on the other hand, access to these basic needs can be harder to come by.

Rural communities are often cut off from much of the money that moves around in the big cities. As well as a lack of jobs, housing and education, these communities also tend to lack good quality infrastructure, such as roads and public transport, access to health care, and support from government programmes. Many such programmes are designed to tackle poverty in urban environments, and they are not always appropriate for these rural communities.


© bbernard/Shutterstock.com

How is Nathan hoping to fight extreme poverty in rural communities?

One of the biggest causes of poverty in rural New England is unemployment. Many people in rural communities have less access to quality education and there are fewer job opportunities in their local areas. On top of this, many of the jobs that are available require skills and expertise that many people in these communities do not have. This is known as a skills gap – an imbalance between the skills than an employer needs and the skills that potential employees have.

Nathan's project involves trying to get a clearer picture of these skills gaps so that he can identify exactly which kinds of skills local employers are looking for, and which kinds of skills local people are lacking. Nathan hopes that by identifying and narrowing these skills gaps, he will be able to help these rural communities lift themselves out of poverty.

How will Nathan identify these skills gaps?

Nathan will work with local business groups and associations to understand which jobs they are struggling to fill and pinpoint which skills the applicants for these jobs are lacking. He will also work with these associations to determine what their employment needs will be in the future, and which skills their workforces will need to cultivate.

Another way in which Nathan is collecting data for his project is via an online job postings website called Burning Glass. By analysing the job adverts on this site, Nathan will be able to understand which skills are needed in which places, and which skills are not being developed enough by local education and training programmes.

How can the skills gaps be closed?

Nathan will work to catalogue the existing training programmes within the region, at both high schools and higher education institutions like universities and colleges. There are also training opportunities within the business and industry communities themselves, so Nathan will talk members of these communities to get a full picture of all the training that is available to potential employees.

> **"RURAL COMMUNITIES ARE OFTEN CUT OFF FROM MUCH OF THE MONEY THAT MOVES AROUND IN THE BIG CITIES."**

Once these training opportunities have been identified, Nathan will be able to identify which sought after skills are not being supported by training programmes. He can then work with educational institutions and business groups to encourage them to develop the necessary training.

Nathan will also communicate the findings of his projects to people in the local area who are unemployed or looking for new, higher-skilled jobs. He will be able to point these people in the right direction and help them find the training programmes that will help them gain the skills that they need. Nathan will also work with local high schools to help students understand which skills they might need to develop to begin their journey along their chosen career path.

How will Nathan know whether the programme is working?

Once Nathan has finished collecting data on the local skills gaps and training opportunities, he will share his findings with schools and young people in the local area. His plan is to conduct a randomised control trial to determine whether having access to this information will influence what types of further education young people pursue.

A randomised control trial is a type of experiment that aims to evaluate the impact of a particular intervention. In this case, giving young people access to information about the skills gaps and training in their local area. The study group (those who are given access to the intervention) and a control group (those who are not) are chosen randomly from a wider population – in Nathan's investigation, young people in rural New England. The two groups are then studied over a period of time to understand the impact of the intervention on the study group.

The feature that separates randomised control trials from other types of experiment is the random assignment of the study and control groups. This makes them particularly robust and allows them to provide powerful insights into questions of causality. Through these trials, researchers can confirm whether any changes to the study population are being caused by the intervention, as opposed to other variables.

What will the long-term impacts of Nathan's programme be?

Nathan hopes that his project will help to create sustainable economic growth by increasing access and availability to training, and by upskilling local people to fill employers' needs. In doing so, the project will help rural communities to climb out of the poverty that they are currently experiencing.

Living in poverty can have an enormous impact on a person's health and well-being. Without a stable income, it can be hard to lead a healthy lifestyle, eat nutritious food and look after your mental health. If Nathan can help people in these rural communities find better jobs and escape poverty, he will also be helping them to live longer, healthier lives.

About *agriculture and resources economics*

In its broadest sense, the field of agriculture and resource economics looks at how agricultural lands and natural resources are managed, and how this management can be improved. For example, a researcher in this field might investigate how farms can increase the amount of food they produce, whilst also minimising their contributions to climate change. Other researchers might study mining, energy production (including renewable energy) or water management.

Much of Nathan's research has been focused on the social impacts of economics and resource management. He has worked with impoverished communities all over the world, investigating different ways of helping them lead healthier, more prosperous lives.

For example, in Zambia, he conducted an experimental study that provided free bicycles to primary school girls. Two major challenges for young girls attending school in Zambia are the distances that they have to travel to get to school, and their safety as they make these journeys. Nathan found that providing these girls with bicycles made it much easier for them to attend school, leading to higher levels of aspiration and self-esteem.

Other projects that Nathan is currently working on include studies looking at trust within homeless communities in Connecticut, how better cooking stoves can help communities in Rwanda, and the effect of private e-savings accounts on women in Tanzania.

Nathan's research spans countries and includes a whole range of social resources and interventions. The common thread throughout all of Nathan's work is his desire to help people in poverty-stricken communities to lead better lives.

Pathway from school to *agriculture and resource economist*

- Studying mathematics and statistics in school is particularly important. It is also useful to understand how people behave and interact with their environments, so subjects like human geography and sociology could be useful.
- Read books on related issues to ensure that you have a good grasp of the field. Nathan recommends *Off the Books: The Underground Economy of the Urban Poor* by Sudhir Venkatesh, *Not in My Neighbourhood: How Bigotry Shaped a Great American City* by Antero Pietila and *Pedigree: How Elite Students Get Elite Jobs* by Lauren A. Rivera.
- Agriculture and resource economics is usually offered as a postgraduate degree. For your undergraduate degree, you should choose a course in a related field such as geography, sociology or economics.

Explore careers in *agriculture and resource economics*

- Work as an agriculture and resource economist can be highly varied. You might want to work in farming, fisheries, mining, forest management, renewable energy, water management or many other areas. Getting a degree in agriculture and resource economics can open the door to many career opportunities including: farm management, economic consultancy, policy analysis and loan officiating.
- Nathan's work focuses on community action and the social aspects of growth and development. As an agriculture and resource economist, you will get the opportunity to meet and work with all kinds of people and communities.
- There are many journals that are dedicated to research in agriculture and resource economics. Through these journals, you can explore the latest developments in the field. Some journals include: The Journal of Agricultural and Resource Economics (**www.jstor.org/journal/jagriresoecon**) and the Australian Journal of Agricultural and Resource Economics (**onlinelibrary.wiley.com/journal/14678489**)

Q&A

Meet *Nathan*

What inspired you to pursue a career in this field?

I have been interested in economic development since I was 14. I grew up in Saudi Arabia and had the opportunity visit many countries as a child. My trip to Kenya at the age of 5 has stuck with me my entire life. I remember very vividly the poverty that I saw, along with the hard work people were doing to keep going.

What does your work as a consultant involve?

Alongside my academic research, I also work as a consultant, supporting organisations to help them to understand the impact of the programming that they do. It is often hard to determine if the things that an organisation does have the positive effects on individuals they are aiming for.

What do you enjoy about conducting research abroad?

I enjoy trying to understand what types of programming are best to improve the lives of people living in poverty around the world. I have been lucky enough to conduct research all over the world in places like Uganda, Tanzania, Kenya, Zambia, Swaziland, Zimbabwe, Ghana, Myanmar, India and Paraguay.

How do you decide which issues to work on?

I go where the need is. For example, a team at Harvard University reached out to me about working in New York on housing evictions. Generally, organisations reach out to me to help them better understand the effects of what they're doing.

What are your proudest career achievements so far?

My work in Uganda, which has helped to show that people living in poverty can make good use of cash grants. There was concern that they would waste the money, but they do not.

Nathan's *top tips*

1. It is important to get to know the people you are trying to help, so you can really understand them and their needs.
2. Working on your mathematics skills will set you up well for a career in advanced economics.
3. Data analysis skills are often in high demand, so working on these is a good idea.

Ways of knowing: how can traditional knowledge enrich geoscience education?

Indigenous communities have inhabited their lands for tens of thousands of years and developed unique connections with their environments, which are passed down through stories containing a deep and intricate understanding of the world. However, western science often ignores this traditional knowledge, marginalising Indigenous scientists and discouraging Indigenous students from pursuing careers in STEM. **Dr Judith Brown Clarke**, from **Stony Brook University,** and **Dr Wendy K'ah Skaahluwaa Todd**, from the **University of Minnesota Duluth**, USA, hope to increase the participation and retention of Indigenous students in geoscience, by incorporating traditional knowledge in geoscience education and research.

Dr Judith Brown Clarke

Vice President for Equity and Inclusion, Chief Diversity Officer, Stony Brook University, USA

Field of research
Inclusive Education

Dr Wendy K'ah Skaahluwaa Todd

Howard Highholt Endowed Professor, Department of American Indian Studies, Department of Earth and Environmental Sciences, University of Minnesota Duluth, USA

Fields of research
Traditional Knowledge in Geoscience, Microbial Diversity, Metal Chemistry

Research project
Increasing participation and retention of Indigenous students in geoscience education

Funder
US National Science Foundation (NSF)

This work was supported by the US National Science Foundation (NSF; #2022931) under the Division of Research, Innovation, Synergies, and Education (RISE)

PROFILES

TALK LIKE A ... GEOSCIENTIST

Indigenous community — a community native to a particular place that has inhabited a region for millennia

Reciprocity — the act of exchanging things with others, based on mutual benefit

Traditional knowledge — a body of observations, practices and beliefs passed down through generations over thousands of years. Traditional knowledge is developed using local knowledge embedded in cultural traditions. It may be shared through language, art, dance, music, names, medicines, stories and songs

STEM — an umbrella term used to group western science into distinct technical disciplines of science, technology, engineering and mathematics

Many years ago, a young man wandered alone through a frozen forest. He had been lazy, and was not prepared for the long, hard winter. One night, in a snowy clearing, he caught a partridge, cooked it on a fire and ate it, leaving only the feet, which he tossed into the snow.

A few days later, the young man had caught nothing more. He found himself back at the clearing and sat down to make a fire. As the snow melted, he found the discarded partridge feet and ate them hungrily. That night as he slept, a partridge came to him in a dream. "You were too proud to eat my feet as other people do, but now you want to have them," it said. "You are at death's door, but from now on you will be alright. Tomorrow night, you will have plenty to eat."

The next day, the man sauntered around the forest, daydreaming about all the food he was sure to find. But, as night fell, he grew weary and his stomach remained empty. He felt cheated by the partridge who, he felt sure, had deceived him. Feeling deflated, he sat down by a snow drift and lit a fire for warmth. Soon, the smell of cooking fat rose into his nostrils. The fire was melting the snow that had been covering a moose, which had died in the autumn when it was fat. The man let the fire cook the moose, then ate until he fell into a contented slumber.

This story has been passed from generation to generation by the Dunne-Za, a group of First Nations People in Canada. For thousands of years, the Dunne-Za have used stories like this to teach their children. In the depths of a freezing winter, survival depends on an intimate knowledge of your environment: of knowing that partridges do not migrate or hibernate, that their feet are edible, that frozen carcasses may be safe to eat, and that moose are fattest in the autumn. These details can be the difference between life or death.


© Russ Heinl/Shutterstock.com

This story is an example of traditional knowledge. Indigenous communities all over the world have formed deep, reciprocal relationships with their lands over hundreds of generations and thousands of years. Each community has developed its own unique body of knowledge and its own systems for sharing it through stories, songs, paintings, sculptures and dances.

Dr Judith (Judi) Brown Clarke and Dr Wendy K'ah Skaahluwaa Todd want traditional knowledge to be used in geoscience education and research. The use of these two knowledge systems, traditional knowledge and western science, not only provides scientists with a deeper worldview, greater cultural appreciation and improved critical thinking skills, but also allows Indigenous students and researchers to maintain their identity as Native scientists.

How does traditional knowledge inform western science?

"Traditional knowledge is dynamic and varies between Indigenous communities," says Wendy, a Haida geoscientist. Hundreds of Indigenous tribes live in the US alone, each with their own knowledge, culture and language. "The practice of combining the identities and experiences of individuals from distinct tribal communities into a single monolithic group, and treating traditional knowledge as a single entity, is harmful and neglectful," she says.

Traditional knowledge is its own independent knowledge system, informed by local natural phenomena. Unlike western science, which tends to look at parts of a whole, like cells in an organism or animals in an ecosystem, traditional knowledge explores how all parts interact and impact the whole system.

For example, a geochemist might study the elemental composition of water in a river, a physical geographer might examine the river's flow rate and an engineer might investigate the river's likelihood of flooding. "Traditional knowledge of that river demonstrates how the water impacts the entire ecosystem," explains Wendy. "The water impacts microbes, plants and animals, and the river's interactions with ecosystems affect human health and the wider environment."

Why is traditional knowledge undervalued by western science?

"Western science is steeped in institutional, structural and systemic bias, intolerance and racism," explains Judi. "It is a product of the Doctrine of Discovery that was established 600 years ago." The Doctrine of Discovery was the idea that European people and their belief systems were more sophisticated than those from other parts of the world. As a result, Europeans colonised other regions and replaced local beliefs and traditions with Christianity and western science.

As western science spread around the globe, it became the dominant mindset for viewing the world. To this day, schools of thought not rooted in western society are discredited as unscientific or rudimentary. "It becomes easy to dismiss what is unfamiliar, unknown and different," says Judi, "especially when in a position of power."

What are the problems with current geoscience teaching and research methods?

It is not uncommon for western researchers to 'discover' things about a place that local tribes have known for thousands of years. "Claiming these as new discoveries undermines Indigenous peoples and their knowledge systems," says Judi. "Ignoring the ancestral and cultural contexts of each Indigenous community is disrespectful, unethical and theft of intellectual property, just as if a discovery from a research lab was taken and used without permission."

As a discipline, geoscience relies heavily on fieldwork, which is commonly conducted on Indigenous lands by western researchers who fail to learn and acknowledge the history and sacredness of these places. Educational field trips are often not inclusive of Indigenous students, as they usually take place during the summer when students may have cultural responsibilities at home. Indigenous people are underrepresented in geoscience departments at all levels, from students to professors to administrators. This can leave Indigenous students feeling isolated, without role models to mentor and advocate for them through their journey to a career in geoscience.

How can geoscience become inclusive to Indigenous students and communities?

Geoscience researchers should learn the culture and history of the lands on which they work. "It is important for researchers to build long-term, meaningful relationships with Indigenous communities," says Wendy. These relationships should be based on reciprocity, on giving and receiving, rather than one-sided transactions in which researchers take knowledge and resources from a field site but give nothing back to the community. "Fieldwork should be seen as an opportunity for cross-cultural knowledge exchange. It should address the needs of tribal communities as well as the researcher."

'Two-eyed seeing', the coupling of traditional knowledge and western science, in education and research will sharpen the critical thinking skills of all students and researchers, leading to the development of scientists who are better-equipped to deal with the challenges facing our planet and societies.

Judi and Wendy are developing a culturally aligned STEM curriculum, to incorporate traditional knowledge into STEM teaching at all educational levels. Only when Indigenous knowledge is taught and treated with respect will Indigenous students feel seen, included and validated in scientific disciplines. Judi and Wendy have also established a mentorship programme, providing Indigenous students with role models to support them in their identity as Native scientists as they navigate western education systems.

"We hope Indigenous communities will take control of their education systems," says Judi. "Our goal is that people become teachers in their own communities, incorporating their culture, language, stories and traditional knowledge, not only into geoscience lessons and the wider STEM curriculum, but into all aspects of teaching and learning."

© Susan Colby/Shutterstock.com

About *traditional knowledge in geoscience*

Geoscience is the interdisciplinary study of the Earth. It covers all aspects of our planet, from rivers and oceans to rocks and minerals, from the tectonic forces that shape landscapes to the interactions of microbial communities in hot springs. As traditional knowledge shows us how all aspects of Earth are interrelated, it can teach us a lot about geoscience.

Teaching geoscience using Haida knowledge

Wendy and Judi have created educational modules for elementary and high schools in Hydaburg, a Haida community in Alaska, that teach STEM topics using traditional Haida stories. For example, the Haida Creation Story is the basis of a module on environmental science that examines water quality, anatomy, physiology and evolution. The Haida Frog Story was used to teach climate history by linking culture and dendrochronology (dating a tree by counting its rings). "When Hydaburg redid its totem poles, we used the old poles to teach dendrochronology," says Wendy. "From these trees, students could construct a 500-year climate history of the region by studying the tree rings persevered in the totem poles."

High school students also assessed the water quality in Hydaburg's marina by lowering pieces of wood to different depths in the water column and leaving them for a year to see if they would be colonised by shipworms, a type of clam that burrows into wood and is very sensitive to pollution. Over five years, students discovered the surface water in the marina was polluted, as shipworms never colonised the higher-level pieces of wood. They collated the five years' worth of data and gave it to the tribe in a report, which the tribe used as evidence to secure a grant to clean up the marina. The following year, shipworms colonised the wood at all levels in the water column, indicating the water quality had improved. "This was a great example of a project that enabled students to have a direct positive impact on their own community," says Wendy. And, as Judi points out, "The community could see their students as critical thinkers who are contributing to environmental stewardship."

How can geoscience careers empower Indigenous communities?

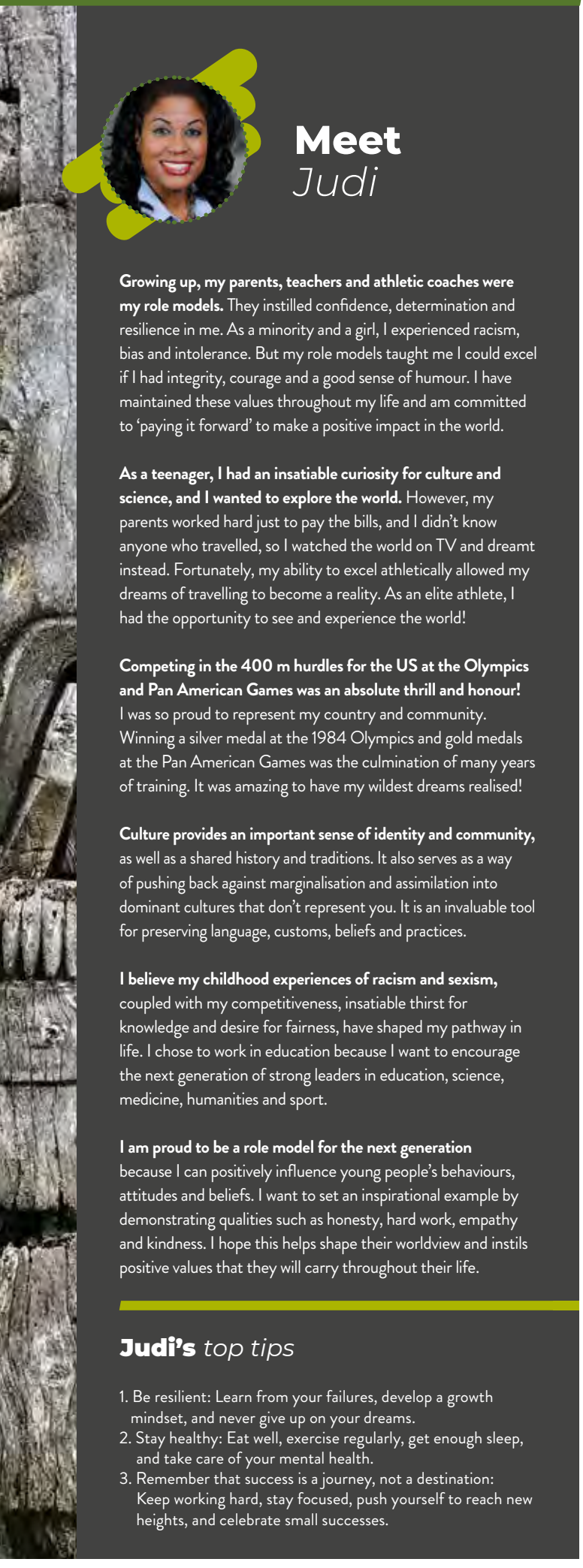
The Native lands of many Indigenous communities are rich in natural resources such as timber, oil, minerals and fish. Extractive industries, such as mining, forestry and fishing, commonly operate on Indigenous lands without consideration of local communities or ecosystems. As these industries are geoscience-based, training the next generation of Indigenous geoscientists is essential for preserving lands and resources. "It is vital that tribal members, who have a connection to the land and understand how to treat it with respect, act as caretakers to assess the use and extraction of resources in a responsible and culturally respectful manner," says Wendy. By pursuing a career in geoscience, Indigenous students and researchers can empower their communities to advocate for greater protection of lands and ecosystems. "We also want to encourage students interested in geoscience to pursue non-scientific careers, in education, policy, law, consulting, journalism and advocacy," says Judi. Geoscience and traditional knowledge show us that, as humans, we are a part of our environment, not separate from it.

Pathway from school to *geoscience*

- Studying geography, chemistry, biology, physics and mathematics at school, followed by geology, Earth science, geography or environmental science at university, will set you on a path to become a geoscientist. However, remember that while western science treats these disciplines as distinct fields, geoscience is a holistic way of looking at the world.
- Take courses that combine traditional knowledge with STEM education to gain a deeper view of the world and of how all aspects of geoscience are interrelated.
- Talk to community members, elders and Indigenous researchers to learn more about traditional knowledge and how it can be applied to the world around you.
- Popular science books can give you an insight into how traditional knowledge informs western science. Wendy and Judi recommend *Braiding Sweetgrass*, by Robin Wall Kimmerer, *Research is Ceremony*, by Shawn Wilson, *Knowing Home*, by Gloria Snively, and *Native Science*, by Gregory Cajete.

Explore careers in *geoscience*

- The American and Indigenous Science and Engineering Society (AISES) is a wonderful organisation that provides support for Indigenous students. Visit their website to explore their careers hub and educational resources: **www.aises.org**
- Wendy founded the Indigenous Geoscience Community, which is a great place to explore how traditional knowledge is used in geoscience: **www.sites.google.com/d.umn.edu/wfsmythe/home/indigenous-geoscience-community**
- The American Geophysical Union (**www.agu.org**) and the Geological Society of America (**www.geosociety.org**) both have sections dedicated to Indigenous knowledge and careers in geoscience.



Meet *Judi*

Growing up, my parents, teachers and athletic coaches were my role models. They instilled confidence, determination and resilience in me. As a minority and a girl, I experienced racism, bias and intolerance. But my role models taught me I could excel if I had integrity, courage and a good sense of humour. I have maintained these values throughout my life and am committed to 'paying it forward' to make a positive impact in the world.

As a teenager, I had an insatiable curiosity for culture and science, and I wanted to explore the world. However, my parents worked hard just to pay the bills, and I didn't know anyone who travelled, so I watched the world on TV and dreamt instead. Fortunately, my ability to excel athletically allowed my dreams of travelling to become a reality. As an elite athlete, I had the opportunity to see and experience the world!

Competing in the 400 m hurdles for the US at the Olympics and Pan American Games was an absolute thrill and honour! I was so proud to represent my country and community. Winning a silver medal at the 1984 Olympics and gold medals at the Pan American Games was the culmination of many years of training. It was amazing to have my wildest dreams realised!

Culture provides an important sense of identity and community, as well as a shared history and traditions. It also serves as a way of pushing back against marginalisation and assimilation into dominant cultures that don't represent you. It is an invaluable tool for preserving language, customs, beliefs and practices.

I believe my childhood experiences of racism and sexism, coupled with my competitiveness, insatiable thirst for knowledge and desire for fairness, have shaped my pathway in life. I chose to work in education because I want to encourage the next generation of strong leaders in education, science, medicine, humanities and sport.

I am proud to be a role model for the next generation because I can positively influence young people's behaviours, attitudes and beliefs. I want to set an inspirational example by demonstrating qualities such as honesty, hard work, empathy and kindness. I hope this helps shape their worldview and instils positive values that they will carry throughout their life.

Judi's *top tips*

1. Be resilient: Learn from your failures, develop a growth mindset, and never give up on your dreams.
2. Stay healthy: Eat well, exercise regularly, get enough sleep, and take care of your mental health.
3. Remember that success is a journey, not a destination: Keep working hard, stay focused, push yourself to reach new heights, and celebrate small successes.

Meet *Wendy*

My 6th grade science teacher, Mr Price, was my role model when I was younger. He fostered my interest in science, specifically marine science, as he had a marine fish tank in class and each week there would be a different and unusual animal in the tank.

I am the first generation of my community not forced to attend state boarding school. My mom attended boarding school, where she was forced to speak English and forbidden from speaking Haida. I am now reclaiming my culture and learning the Haida language.

> ***I HAVE LEARNT TO LISTEN AND ALLOW MYSELF TO BE GUIDED ON A JOURNEY OF A LIFETIME.***

It is important to know who you are and to own your indigeneity. Never let anyone take it away from you, or make you feel ashamed of your identity, culture or language. When you reclaim your language and culture, you are honouring the sacrifices of your ancestors.

My culture means everything to me! As I learn and reclaim more of my Haida culture, I learn more about my responsibility as a Haida woman. It keeps me grounded and guides me through this world and through this life. I have learnt to listen and allow myself to be guided on a journey of a lifetime.

Every time I experience racism and sexism, it makes me more determined to bring awareness of these negative behaviours and change the system for other diverse scholars. Having to stand my ground when using traditional knowledge or working with Indigenous communities in academia motivates me in my work.

As a Haida geoscientist studying the geochemistry of rivers and hot springs, I work with my tribal community and elders to gain knowledge about my research. As a university professor, I include traditional knowledge in the science courses I teach. I also mentor Haida high school and university students, and am always proud when they succeed. Our cultural responsibility requires that we guide and support our youth. All that we have is not really ours – it belongs to future generations.

Wendy's *top tips*

1. Know that you are where you are supposed to be. You belong.
2. Trust that your path will reveal itself to you when you are ready.
3. Always remember that you are important and cherished.

How does the Southern Ocean help protect our planet?

The Southern Ocean circulation system is vital for redistributing heat, carbon and nutrients around the world. It also plays a significant role in absorbing carbon dioxide from the atmosphere, having sequestered ~40% of anthropogenic CO_2 absorbed by the oceans. **Associate Professor Julie Trotter** and **Professor Malcolm McCulloch** from **The University of Western Australia**, and **Dr Paolo Montagna** from the **Institute of Polar Sciences** in Bologna, Italy, are working to understand the complex interactions between the Southern Ocean and global climate.

Associate Professor Julie Trotter

The University of Western Australia

Professor Malcolm McCulloch

The University of Western Australia

Dr Paolo Montagna

The Institute of Polar Sciences, Bologna, Italy

PROFILES

Field of research
Marine Geochemistry

Research focus
Investigating environmental changes and ocean-atmosphere interactions in the Southern Ocean

Funders
Australian Research Council (ARC), Schmidt Ocean Institute, National Research Council of Italy

TALK LIKE A ...

MARINE GEOCHEMIST

Anthropogenic — describing the influence of human activity on the natural world

Biota — the plants and animals living in a particular place

Calibration equation — used to convert geochemical proxy data to a specific environmental parameter

Cryosphere — the frozen parts of the planet, including ice caps and sea ice

Ecosystem — the living organisms and physical environment of a specific area

Geochemical proxy — a chemical method that measures specific compositions of a natural archive, that reflect particular environmental conditions when the organism grew. For example, the ratio of trace elements, such as lithium/magnesium, in a coral skeleton can tell us about the temperature of the seawater in which the coral grew

Isotope — different atomic forms of the same element that have the same number of protons, but a different number of neutrons, and so have different atomic masses

Ocean acidification — a reduction in the pH of the ocean resulting, largely, from the absorption of increased atmospheric carbon dioxide

Phytoplankton — microscopic marine algae that form the basis of most marine food webs

Sequester — to store away

The Southern Ocean is one of the windiest places on earth. Encircling the continent of Antarctica and uninterrupted by land, the polar winds drive the world's strongest ocean current system, the Antarctic Circumpolar Current (ACC). The ACC directly links the Pacific, Atlantic and Indian oceans, giving it a pivotal role in the circulation of water through the world's oceans.
The ACC draws cold, nutrient-rich waters up from the deep ocean, some of which flows southwards where it eventually sinks, but most overturns to flow northwards and into the world's upper oceans, redistributing heat, carbon and nutrients. These northward flowing waters are responsible for nearly three-quarters of global marine biological production, with one of their first stopovers being the mid-latitude submarine canyons off southwest Australia.

These previously unexplored canyons, within the Bremer Marine Park and

Collecting Desmophyllum cup corals and Acesta bivalves with vacuum suction using ROV SuBastian. Hood Canyon, 866 m.
© Schmidt Ocean Institute

Perth Canyon Marine Park, as well as sites in the Ross Sea, are being studied by Julie Trotter and Malcolm McCulloch from the University of Western Australia and Paolo Montagna from the Institute of Polar Sciences. They use the chemical compositions from live and fossil coral skeletons, collected from shallow water reefs to deepwater habitats, to better understand both human-induced and long-term natural changes occurring in our oceans. One important question that the team is addressing is whether the role that the Southern Ocean plays in absorbing carbon dioxide (CO_2) is changing. This occurs as the upwelling of deep, nutrient-rich waters fuel blooms of phytoplankton, which consume carbon from the water. When the phytoplankton die, they sink into the depths, taking the carbon with them and sequestering it in the deep ocean.

With warming of the Southern Ocean and overturning circulation now occurring closer to the Antarctic margin, climate change may be short-circuiting the ability of the Southern Ocean to absorb large amounts of CO_2 from the atmosphere. The Ross Sea and the SW Australian canyons are ideal places to study how Southern Ocean overturning circulation and CO_2 uptake change through time. The canyons, being more easily accessible than the distant and harsh environments nearer Antarctica, are sourced by waters traversing the critical Southern Ocean zone of high phytoplankton productivity, which now mainly drives high CO_2 uptake. Studying ancient fossil corals from the canyons is also important because during the ice-ages, the opposite may have occurred when the northwards flowing waters were stronger.

What is the team hoping to discover?

Despite its global importance, the Southern Ocean is the least studied ocean in the world, largely due to the logistical and practical challenges of working in such an isolated, hostile environment. One of the team's main focuses is to collect and interpret new environmental data to increase our knowledge of the ecosystems, biodiversity and changes that have occurred at different depths and sites in the Southern Ocean. Julie, Malcolm and Paolo collect live and fossilised corals, and analyse their skeletons to reconstruct what the Southern Ocean was like in the past, and how it has changed between then and today. Understanding these changes can help researchers make predictions about how the Southern Ocean will change in the future, and how that might affect other regions. As the amount of CO_2 in the atmosphere continues to increase at an alarming rate, the Southern Ocean could change dramatically, potentially disrupting the distribution of nutrients, heat and oxygen, and threatening ecosystems all over the globe.

What are geochemical proxies?

Geochemical proxy data are specific chemical compositions measured from natural physical archives that tell us about the environmental conditions when the organisms grew. For example, the relative amounts of certain elements that a coral takes into its skeleton (archive), such as lithium/magnesium, magnesium/calcium, and strontium/calcium (proxies), are largely dependent on the temperature of the surrounding seawater. If researchers measure some of these ratios in coral skeletons, they can learn about the temperature of the surrounding seawater when the coral grew its skeleton. Similarly, barium/calcium ratios can be used as a proxy for river runoff or nutrients in seawater.

How are samples collected?

In shallow tropical waters, large, long-lived coral heads are cored using underwater drilling equipment while SCUBA diving. However, to collect deep-water corals (100s to 1,000s of metres deep), the team needs to use remotely operated vehicles (ROVs), which are like mini remote-controlled submarines, tethered to the ship and controlled by joysticks. When collecting samples from the deep canyon systems off SW Australia, the team launched an ROV from the oceanographic research vessel called *Falkor*. The not-for-profit Schmidt Ocean Institute provides its ship and ROV to oceanographers all over the world through a competitive process. This is especially important for marine scientists conducting research in Australia where, despite having one of the longest coastlines, there are no locally available research ROVs.

As well as corals, the team collects samples of seawater that the corals grow in. They deploy a large instrument called a CTD-Rosette system, which collects water when triggered at specific depths while also measuring properties, such as temperature, salinity and oxygen. Much of their analyses of seawater samples and coral skeletons happens back in the lab where they use expensive, sophisticated equipment, such as mass spectrometers (which measure the concentration of elements or their isotopic ratios). Julie, Malcolm and Paolo can compare the CTD readings and chemical analyses of seawater to the measurements of specific proxies in the skeletons from live corals. These allow them to derive calibration equations that are applied to older specimens to reconstruct past changes in seawater conditions.

What have proxy data revealed?

In addition to using temperature proxies to track climate change in modern and fossil corals, the team has studied another type of proxy that is only dependent on the isotopic composition of the element measured, for example, the stable isotopes of boron that depend on the seawater pH. Another is the radioactive isotope of carbon (radiocarbon), best known for dating carbon formed at the Earth's surface from processes involving atmospheric CO_2.

Their studies of boron isotopes in corals from shallow water reefs, temperate environments, and deep waters led Julie, Malcolm and Paolo to discover that certain types of corals can increase the pH of their calcifying fluid, which they use to build their carbonate skeletons. This is important because the pH of the seawater is decreasing as

the oceans absorb more of the CO_2 that human activity produces, which is making it more acidic (ocean acidification). This makes it harder for corals to build their skeletons, and even more so for some deep-water corals that already live in low pH environments. However, the team's discovery provides some hope that some coral species may be able to adapt to the increasingly acidic conditions.

By combining measurements of radiocarbon and uranium-thorium ages from ancient coral skeletons, the team has been able to track changes in the uptake and storage of atmospheric carbon in the deep waters in the SW Australian canyons. The deep-water corals living in the canyons during the last glacial period, about 20,000 to 25,000-years ago, recorded major changes in the Southern Ocean's circulation, which resulted in the storage of higher amounts of CO_2 in the deep ocean. The team is also reconstructing ocean temperatures and nutrients from this period of major changes in climate and ocean dynamics.

Ocean circulation is vital for the sequestration of CO_2. Changes in ocean dynamics have direct implications for carbon uptake and storage, which in turn influences the chemistry and productivity of ocean waters and, consequently, the entire climate system.

How does the melting of Antarctic ice affect circulation in the Southern Ocean?

As Antarctic ice melts, it increases the amount of freshwater flowing into the Southern Ocean. This decreases the salinity of the seawater, making it less dense and preventing it from sinking down to the deep ocean. This has the potential to disrupt the Southern Ocean's circulation system, as well as its ability to sequester carbon to the deep. As a result, in addition to increasing sea levels, the melting of Antarctic ice could have global implications for distributing heat, oxygen and nutrients throughout the world's oceans.

What's next for the team's research?

Julie, Malcolm and Paolo are hoping to learn more about the effects of meltwater in the Southern Ocean. To do this, they will have to use ice breakers (specialised ships) and ROVs to collect deep-water coral samples from the very cold waters near the Antarctic continent. These samples could reveal how melting ice affected Antarctic waters in the past, and the team is also hoping to learn more about how different water masses contribute to the ice melt.

The team is continually collecting new samples and searching for new geochemical proxies to help understand these complex processes. In the face of global climate change, it is more important than ever that we understand how ocean systems work and interact with the atmosphere and cryosphere. With carbon emissions continuing to rise, changes to the Southern Ocean are inevitable, which will impact the world's oceans, their ecosystems and global climate.

About *marine geochemistry*

Marine geochemistry is the study of the chemical composition of seawater, the sediments that sit at the bottom of the ocean and the marine biota. Many different factors can affect the chemistry of seawater including temperature, ocean circulation, biological and hydrothermal activity and ice melt.

Human activities can also affect the chemical make-up of seawater. For example, fertiliser run-off from farming can wreak havoc on coastal ecosystems. The excessive amounts of CO_2 being released into the atmosphere from human activities have begun to significantly alter the chemistry of the world's oceans as they continue to rapidly absorb atmospheric carbon. Scientists from many different disciplines are devoting their careers to investigating these impacts.

How important is collaboration in marine geochemistry?

Cross-disciplinary collaboration is essential due to the complexities of our oceans and their interactions with the atmosphere, cryosphere and biosphere. An holistic and integrated approach is needed to obtain a clearer understanding of these complex data, so collaboration between geologists, geochemists, oceanographers, biologists and modellers is important.

For Julie, Malcolm and Paolo, collaboration has been vital. Most of the geochemical analyses have been done in the state-of-the-art labs at The University of Western Australia, whilst the Institute of Polar Sciences has provided many important coral specimens and complementary expertise needed to study them. Following a competitive assessment of their research proposal, the Schmidt Ocean Institute partnered with the team, generously providing its research vessel, remotely operated vehicle (ROV), and the crews needed to pilot them.

Co-ordinating work with colleagues can prove to be challenging, especially when they are living halfway across the world in a different time zone. Although technology allows meetings to take place online, working side-by-side is usually more productive and enjoyable.

Despite the challenges of cross-disciplinary research, the rewards make it worthwhile. Researchers are exposed to new approaches and perspectives which allows problems to be tackled with innovation and creativity. Beyond this, travelling overseas can be an inspiring experience, and researchers often make life-long friends when they are involved in this kind of work.

Where do marine geochemists work?

Marine geochemists spend much of their time in laboratories or on research ships. One of the first jobs on board is to collect bathymetry data using multibeam echosounder systems, which shows researchers how the depth of the ocean changes below the ship and provides 3D reconstructions of the seafloor. This helps them find suitable locations to collect their samples.

Work on a research ship also involves collecting samples of seawater, sediments and, in the case of this research, coral specimens. Some initial analyses can be conducted on the ship. However, more in-depth geochemical analyses are conducted back on shore in labs, for example, using high-tech mass spectrometers to analyse the chemical compositions of coral skeletons and seawater samples.

What research opportunities will be open to the next generation of marine geochemists?

Technological advancements will open a lot of doors for future marine geochemists. Some of these advancements may make it easier to conduct in-depth chemical analyses whilst still on the research vessel. These advancements, as well as improvements to ROVs and fully autonomous underwater vehicles will allow researchers to get more information about their samples whilst at sea. This will allow them to make real-time decisions and work more efficiently, and will also open up new research directions.

Collecting black coral, Leiopathes, using ROV SuBastian. Hood Canyon, 717 m. © Schmidt Ocean Institute

Explore careers in *marine geochemistry*

- Marine geochemists of the future will need an extensive skill set. You will need cross-disciplinary knowledge with a background in chemistry, statistics, geology and oceanography, good communication skills, networking abilities and good technical skills to operate lab equipment.
- As a marine geochemist, you will be working with a wide range of scientists from many different disciplines. You should have a basic understanding of these disciplines so that you can communicate with other researchers and share ideas.
- There are many societies related to marine science, which you can explore to keep up to date with the latest research. Some of these societies include The Challenger Society for Marine Science (**challenger-society.org.uk**), The Australian Marine Science Association (**amsa.asn.au**), the European Marine Board (**www.marineboard.eu**), the EuroMarine Network (**euromarinenetwork.eu**), International Council for the Exploration of the Sea (**ices.dk**) and the Intergovernmental Oceanographic Commission (**ioc.unesco.org**).

Pathway from school to *marine geochemistry*

- Studying STEM subjects at school is important. Chemistry, biology, physics, geology and statistics could all prove very useful.
- Attend summer schools when possible and contact your local university or college to see if they have any internship opportunities.
- Studying oceanography, geology, chemistry or environmental sciences as a bachelor's degree is a good place to start.
- Spending part of your educational career abroad at reputable institutions with specialist labs can be very beneficial.
- Volunteering on oceanographic research cruises is a great way of getting practical experience and can be very exciting!

"MY CAREER HAS ALSO BEEN SHAPED BY WORKING FOR EXTENDED PERIODS IN WORLD-CLASS RESEARCH INSTITUTES"
PAOLO

Meet *Paolo*

I think I became a traveller first and then a scientist. When I was a kid, I used to travel to remote places with my parents. I visited Tanzania when I was six, then the US national parks, the Baltoro Glacier in Pakistan, Papua New Guinea and Borneo. One of my professors at college was a geologist and he introduced me to the main geological theories and periods. After college, I studied geology at university and, during summer holidays, I worked as a geological guide for small to medium-sized travel groups in isolated geographical areas, such as the Himalayan region (Kashmir and Ladakh), South America (Chile and Bolivia) and Iceland. This gave me the opportunity to discover unique places, where geology is the undisputed protagonist, with high mountains, massive glaciers, volcanos and salt lakes. Since I was a kid, I have been fascinated by nature, fossil remains and rocks, and I have always enjoyed the sense of freedom and curiosity of the world. I think all this shaped my character and my passion for science and research.

My career has also been shaped by working for extended periods in world-class research institutes in Australia, USA, Spain and France. Having the opportunity to meet world renowned geochemists and paleoceanographers helped build my scientific knowledge and improve my analytical skills.

As a PhD student, post-doctoral fellow and visiting research scientist (~6.5 years abroad for research training), I have worked in six of the best equipped laboratories in the world (Australian Institute of Marine Science, Australian National University, University of Barcelona, Lamont-Doherty Earth Observatory, Laboratoire des Sciences du Climat et de l'Environnement, Paris-Sud University and The University of Western Australia), with state-of-the-art laboratory facilities, including experimental tanks for coral cultures, ultra clean labs and mass spectrometers used to analyse trace elements, stable and radiogenic isotopes.

I have participated in 20 oceanographic missions to the Mediterranean Sea, Atlantic, Indian and Pacific Oceans, as well as the Ross Sea off Antarctica, and I have also been involved in several SCUBA diving expeditions worldwide.

I always try to have a few options (plan A, B and C) in case something goes wrong, and I try to organise things (lab and field work) by checking all the details.

My proudest achievement has been the discovery that phosphorus concentration within the skeleton of corals is directly proportional to the ambient seawater phosphorus and can be used as a paleo-nutrient proxy. This finding was published in *Science*. In the future, I want to continue to follow my passion for research, making the most of new challenges and opportunities and helping students and young researchers to path their careers.

Life as a paleoceanographer in three words:
Curiosity-driven, experimental, adventurous.

Meet *Julie*

I've always been interested in the natural world, it's diversity, breadth and complexity. My high school science teacher's passion for geology and palaeontology was particularly inspiring. At university, my focus was mostly on geology and palaeontology, so I spent my early career as a palaeontologist. Later, when I had the opportunity to work on joint geochemistry and palaeontology projects, I discovered the importance of geochemistry and how it can be used to advance almost any science discipline.

I have been lucky to have worked in many different field settings: such as the Australian outback, SCUBA diving in the Great Barrier Reef, geological field work in Morocco, Siberia and Argentina, and exploring the ocean depths in the southwest canyons offshore Western Australia. These experiences fuelled my interests in Earth sciences and have drawn me to work with skilled and enthusiastic colleagues from different countries.

I was exposed to the world of geochemistry while working at The Commonwealth Scientific and Industrial Research Organisation (CSIRO) with some wonderful mentors. Those mentors encouraged me to pursue a geochemistry-based PhD at the Australian National University (ANU), that would also use my palaeontological expertise. This unusual combination of skills allowed me to bridge knowledge and communication gaps between these disciplines, and to develop new approaches to better understand environmental changes that occurred over geological and modern timescales.

> ***"I DISCOVERED THE IMPORTANCE OF GEOCHEMISTRY AND HOW IT CAN BE USED TO ADVANCE ALMOST ANY SCIENCE DISCIPLINE."***

I have been very fortunate to have worked in state-of-the-art facilities at ANU and UWA, with world-leading researchers at the cutting edge of science. At ANU, I developed expertise in high resolution in-situ mass spectrometry analyses (laser; ion microprobe) to extract environmental records from tiny marine microfossils (conodonts). At UWA, I helped establish a state-of-the-art Clean Laboratory and Mass Spectrometry geochemistry facility, and expanded my research into recent and modern coral geochemistry, especially deepwater corals.

Perseverance, breaking down the issues, thinking laterally and talking to colleagues, including those with different skills, experience and perspectives, helps with overcoming obstacles. Working through problems with colleagues is extremely rewarding. Looking for different ways to solve a problem and thinking 'outside the box' invariably delivers. If not, take a break, refresh and return with a clear mind. Keeping thorough and accurate records allows you to backtrack easily when troubleshooting unexpected results.

My proudest achievements in science are having contributed new approaches to extract and interpret environmental records from different biogenic archives. Oxygen isotope records determined from single conodont specimens for the first time, using an ion microprobe, showed that major global cooling spurred one of the greatest biodiversification events in Earth's history. Its now widespread application is greatly expanding our knowledge of Palaeozoic and Mesozoic climates and ecosystem.* In the modern realm, revealing that some corals upregulate the pH of their calcifying fluid has significantly enhanced our understanding of their susceptibility to ocean acidification. Most recently, leading an international team to research SW Australia's previously unexplored submarine canyons has been a great privilege, not only as the first to see these incredible deep-sea environments but, most importantly, to reveal them to the world.

Life as a geochemist in three words:
Complex, cross-disciplinary, rewarding

** Visit the British Geological Survey's website for a geological timechart: **www.bgs.ac.uk/discovering-geology/fossils-and-geological-time/geological-timechart***

ROV SuBastian being launched from the RV Falkor to explore the SW Australian canyons © Schmidt Ocean Institute

The team's *top tips*

- Develop and apply your own critical thinking and skill sets to address what you think are important meaningful questions.
- Do not stop studying.
- Visit, live and work in other countries, explore other research environments and directions, take all the opportunities that present themselves.
- Establish a positive, engaging and supportive network of colleagues.
- Hard-work, perseverance and a critical mind are key attributes.
- Don't follow 'the pack' – explore new things or different approaches.
- Have an open mind and get involved in different research areas to expand your skill-base and knowledge. Having diverse skillsets and undertaking cross-disciplinary research is invaluable.
- Take (or make) any opportunity to work in state-of-the-art laboratories with engaging scientists to learn as much as you can.
- Most importantly, select interesting research projects that inspire you.

Meet *Malcolm*

I grew up in a modest sized coastal city called Busselton, located in Geographe Bay in Western Australia. The name 'Geographe' comes from a ship that was part of one of most important scientific expeditions of its time. In addition to its interesting 'scientific' origins, Busselton has relatively calm waters and the longest jetty in the southern hemisphere. These all contributed to my 'natural interest' in the marine realm.

Because of my interest in the physical world, I decided to study STEM subjects. After completing my undergraduate studies, I undertook a Master of Science thesis under the guidance of Professor John deLaeter. John, and later my PhD supervisor, Jerry Wasserburg at the California Institute of Technology, were my most influential mentors.

I've been fortunate to have had a number of 'eureka' moments. Several occurred at The California Institute of Technology where, under Jerry's tutelage, we discovered the first clear evidence for distinctive heavy-element isotopic signatures of ancient nucleosynthetic processes that ultimately led to the formation of the early Solar System.

I was also keen to work in the marine realm, so at the Australian National University I commenced working on dating fossil coral reefs and sea levels changes, and then proxies for ocean temperature changes. These interests then focused on the present-day Great Barrier Reef (GBR) examining both its temperature and bleaching history, as well as providing the first geochemical record of much increased terrestrial runoff into the reef, which could be clearly attributed to 'European' style land-uses (especially cattle grazing). I'm very proud of this work as it provided some of the most definitive scientific rationale for improved land use practices in the GBR and elsewhere.

Here at UWA, the most exciting development, and my proudest achievement to date, was the discovery of how corals up-regulate the pH of their calcifying fluid and the role of symbionts (organisms living in symbiosis with another) in suppling additional dissolved inorganic carbon to the fluid. This now provides a more fundamental level of understanding of the limitations of coral resilience to climate change and especially their 'Achille's heel', coral bleaching, due to greenhouse warming of the oceans.

I overcome obstacles with persistence and some measure of patience, but with the realisation that you also need to take responsibility for developing the essential capabilities needed to undertake novel research. Also, working as a team with people who have complementary skills and genuine interests always helps.

I've been fortunate to have had the opportunity to make significant science contributions, initially in cosmochemistry, then isotopic tracing of geologic processes in the solid Earth sciences, and most recently in environmental geochemistry, the latter with respect to coral reefs. Not only has it given me the chance to work in what is unquestionably one of the most awe-inspiring environments, but also to make meaningful contributions to understanding the ever-increasing risks and challenges that this unique environment now faces.

My aim for the future is to better understand and promote a sustainable future for our marine environment.

Life as a geochemist in three words:
Challenging, rewarding, enlightening.

Making sense of science with a podcast

After being bombarded with health-related questions about the COVID-19 pandemic, immunologist **Dr Aimee Pugh Bernard** and physician **Dr Toni Eyssallenne** decided to host a podcast called **Help! Make it Make Sense**. As they celebrate their one-year anniversary, we ask them why it's so important for scientists to reach out to the general public.

HELP! MAKE IT MAKE SENSE

Why did you decide to produce a podcast?

We kept getting asked questions about the pandemic from people in all aspects of our lives – friends, family, neighbours, students (Aimee), patients and staff (Toni). Even people we didn't know would reach out to us with questions on Facebook and through emails! So, we decided to join forces and maximise our time by answering FAQs via a podcast and then sending people the link. In addition, misinformation about COVID-19 and vaccinations was gaining momentum and we wanted to address it clearly so that people wouldn't be confused.

How easy was it to set up a podcast?

It was far too easy! It seems like anyone – even us – can start a podcast! Since we are an immunology professor (Aimee) and physician (Toni), we didn't need to learn new skills in the realms of science or communicating to students or the public. The biggest hurdles we've faced have been technical ones, such as figuring out how to post podcasts to different platforms because we're doing it all ourselves.

What do you hope to achieve with 'Help! Make it Make Sense'?

We want to be a trusted source for facts surrounding all things pandemic-, science- and medicine-related. Our aim is to reach people who are a little skeptical, or who have questions but don't know who to ask. We strive to be relatable and respectful, and to explain the information in ways that are easy to understand so that people can feel empowered to make decisions based on this information. There is uncertainty in science, so we clearly state what we know and what we don't know, and explain how to be critical about the information people receive.

How do you decide what to talk about in each episode?

We typically build our episodes around what is happening in the news right now. Sometimes, one of us might get sent a confusing video or article, or we select a topic that needs to be examined in greater detail.

As an example, in one episode, we talked about the United States Vaccine Adverse Event Reporting System (VAERS), explaining what it is and how information can be extracted from it. VAERS is a website that allows people to report any health issues they think are connected to getting a vaccine. While this tool can be used to help the Centers for Disease Control (CDC) and Federal Drug Administration (FDA), co-sponsors of the website, rapidly detect unusual or unexpected results, the health issues (or 'events' as they are officially known) added to VAERS may be inaccurate, coincidental or unverified. We chose to discuss this topic because many anti-vaxxers use this website in dishonest ways or as a point of reference to encourage others not to vaccinate. We wanted to set the record straight!

How many listeners do you have and do you engage with them?

We have a solid 40-50 downloads per episode with 100+ downloads for our more popular episodes. We also have an email address (DrToniandDrAimee@gmail.com), which we

Toni at work at her clinic

© Andrei_Diachenko/shutterstock.com

promote after every episode. If you have a health-, medicine- or science-related question, we would love to hear from you!

What has been your favourite podcast episode so far, and why?

It has to be 'Don't Cough on My Baby!' That episode includes one of our favourite quotes of all time, when Aimee talked about "freshly coughed pockets of air". It was in reference to the air we breathe, which we might believe is fresh and pristine but it's also possible that one minute before, someone was hacking up a lung and releasing a "freshly coughed pocket of air" full of pathogens that you can't see!

Do you think it's important for scientists and academics to reach out to the public through podcasts?

Yes! We need to add more accurate information to the noise. Further, scientists really need to work on learning how to communicate with the public and leave the jargon aside. We try our best to explain the science in ways that make it easy to understand, so that people can make evidence-based decisions for their health and well-being.

What are your top tips for starting a podcast?

First, find a topic you are passionate about, love to talk about and want to spread to the world. Second, find a fun co-host that makes you laugh and have fun.

Other than your own, which podcasts would you recommend, and why?

Aimee: I love so many podcasts! For younger students, I would recommend 'WOW in the World', 'Brains On', and 'Goodnight Stories for Rebel Girls'. For older students (high school and beyond), I would recommend 'Short Wave', 'Science Vs', 'Ologies' and 'This Podcast Will Kill You'.

Toni: I love 'Science Vs' and certain episodes of 'Short Wave'. I also love 'Beyond the Scenes' with Roy Wood Jr., which takes a deeper look at the topics they present on the Daily Show, which are often about misinformation and the propaganda machine.

Listen to 'Help! Make it Make Sense'

www.buzzsprout.com/1912655
helpmakeitmakesense6769

You can also find Aimee and Toni's podcast on Google Podcasts.

If you have a question you would like answered on 'Help! Make it Make Sense', email: DrToniandDrAimee@gmail.com

> **"WE WANT TO BE A TRUSTED SOURCE FOR FACTS SURROUNDING ALL THINGS PANDEMIC-, SCIENCE- AND MEDICINE-RELATED."**

Aimee gives the 'thumbs up' after receiving her annual flu vaccine: "Let the training of the immuninjas begin!"

> **REPEATING THE PHRASE, "WE LEARN MORE FROM OUR MISTAKES" IS THE MANTRA OF ANY SCIENTIST. EMBRACE THE FAILURE AND LEARN TO CELEBRATE THE TINY WINS!**

Meet Aimee

Executive Director, Human Immunology and Immunotherapy Initiative (HI3)

Assistant Professor, Department of Immunology and Microbiology, Anschutz School of Medicine, University of Colorado, USA

When I was younger, I thought about becoming a veterinarian until I realised I feel faint when I see blood. I still have to lie down when giving blood!

I always knew I loved science. I really liked my general biology course in high school but then I took an immunology course in college and totally fell in love with the subject. I knew that I wanted to dedicate my life to learning about the immune system. While in graduate school, I decided to focus on a career in education and teaching, aiming to become a professor so that I could teach others about immunology.... And here I am!

I don't think education and experience can be separated – they are intimately intertwined. Part of a PhD involves hands-on experience designing experiments and answering scientific questions in a lab. After a PhD, you continue to design experiments and answer questions in a postdoctoral position under the guidance of the principal investigator (a.k.a. the boss) of the lab. All along the way, you're being educated about the science and how to successfully contribute to research in your realm.

You must have grit and determination to succeed in science. Be sure you're ready to persevere through immense failure. The life of a scientist is all about the little successes and wins amongst a lab notebook littered with failure. Repeating the phrase, "We learn more from our mistakes" is the mantra of any scientist. Embrace the failure and learn to celebrate the tiny wins!

Enjoy what you choose to do as your profession. Life is too short and too precious to waste your time doing something that doesn't bring you joy. The most common feedback I get from the students I teach on the medical campus is how much they can tell I love immunology. This is a quote from one of my first-year medical students: "Dr. Bernard's love for immunology is contagious. It is so fun to learn from her. She explains complex topics in simple, digestible ways. I love learning from her!"

Connect with Aimee

- **@apbSCIENCE**
- **aimeebernard-phd-sheher-50190426**
- **@apbscience**
- **@immuninja**

Toni, Aimee and Tim (Aimee's husband) held a strategy session on Zoom in January 2022, just before the launch of Help! Make it Make Sense. Tim was a fellow classmate in Toni's medical school class at the University of Rochester, which is where all three of them met and became friends.

Aimee speaking at the 2023 Colorado Regional Immunization Summit

Meet Toni

Physician and Operations Consultant, Strong Children Wellness

Senior Medical Advisor, New York City Department of Health and Mental Hygiene, USA

Like Aimee, I also wanted to be a vet when I was younger. Then, when I was 12, my dad said that my talents would be better served to help people and that changed my whole life.

I basically let the wind take me where it wants to go. I learned in college that you can have a plan but you also have to be flexible. There will be unexpected events and it's important to not let them deter you from your ultimate goal, but to use them to give you more experience and become a better and wiser person.

> ***"MY PHILOSOPHY IN LIFE IS TO ASK MYSELF EVERY DAY WHETHER WHAT I'M DOING CONTRIBUTES TO MAKING THE WORLD A BETTER PLACE."***

Being a first generation Haitian-American, I have always wanted to be a physician in Haiti. I wanted to help build capacity for healthcare together with the brilliant minds that already live and work there, and I got the chance to do that. I still help support a Haitian residency in paediatrics that I helped set up and I do my best to participate in advocacy for Haiti and Haitian people as much as I can.

Education and experience have both been valuable to me. My education has enhanced my experience and career, my career has enhanced my experience and education, and my experience has enhanced my education and career. You need it all to shape the human being that you strive to become.

One piece of advice I wish someone had given me at the beginning of my career is that you don't have to stay where you begin. Long gone is the age of dying at your desk or having to show that you have been at a place for 10 years before you move on. If a place doesn't serve you, leave – even if it is the place that gave you your start in life. You can appreciate the opportunity without having to sacrifice yourself because no one is irreplaceable – literally, NO ONE! So, don't believe the hype. Stay if you feel valued and fulfilled but don't stay because you're worried that you won't find a comparable job or salary. You have worked too hard not to have options, so don't be afraid to seek alternatives even if you have only been somewhere for a year.

My philosophy in life is to ask myself every day whether what I'm doing contributes to making the world a better place. Every activity, every emotion, every effort has to bring me somewhere that I feel goes towards changing or affecting in some way shape or form the injustices that pervade our society. So, if I'm mindlessly watching TV and I'm not clear as to why I'm doing that, I'll stop. If I'm mindlessly watching TV and I know I'm doing it to give my brain a break so that I can recharge, then I'm happy to continue until I feel recharged to continue the fight towards equity in the world.

Toni recording Help! Make it Make Sense

Connect with Toni

- **@sln_pwr**
- **tonieyssallenne-05816181**
- **@haititoni**

How do the head, neck, and heart develop?

Birth defects affect one in every 33 babies born in the United States each year. A developmental biologist at **Howard University** in the US, **Dr Janine M. Ziermann** is studying the head, neck, and heart to find out how head and heart birth defects form.

Dr Janine M. Ziermann

HeadHeartEvoDevo-Lab, Department of Anatomy, College of Medicine, Howard University, Washington DC, USA

PROFILE

Fields of research
Anatomy, Developmental Biology

Research project
Understanding cephalic and cardiac development in vertebrates

Funders
Currently, US National Science Foundation (NSF) (previously, Howard University Bridge funding)

This work is/was supported by the NSF, under award number #2000005. The contents are solely the responsibility of the authors and do not necessarily represent the official views of NSF.

TALK LIKE A ...

DEVELOPMENTAL BIOLOGIST

Cardiac — relating to the heart

Cardiopharyngeal — relating to the heart and the pharyngeal arches

Cephalic — relating to the head

Congenital — present from birth

Cranial — relating to the cranium

Craniofacial — relating to the skull and the face

Cranium — the skull, especially the part surrounding the brain

Gastrulation — a process during week three of human development, where the embryo transforms from a two-dimensional layer into a three-dimensional structure

Mesoderm — the middle of three layers of an embryo which are the source of many tissues and structures

Palate — the roof of the mouth

Pharyngeal arches — pocket like structures in the embryo that will form most of the head and neck structures

Vertebrates — the group of animals that have a backbone or spinal column, including fish, amphibians, reptiles and birds, and mammals

Despite being in different regions of the body, the muscles of both our heart and our head originate from the same cell group – a group called the cardiopharyngeal mesoderm.

"During embryonic development, the expression of specific genes at precise times and locations ensures that almost all the different head and heart muscles differentiate from this common mesoderm," says Dr Janine M. Ziermann, who is studying this group of cells for her research at Howard University.

Another cell group, called the cranial neural crest cells, also contributes to the development of the head and heart. During embryonic development, both the neural crest cells and the mesodermal cells create multiple other cell types in the body. Neural crest cells give rise to cells of the nervous system and connective tissue cells. They also generate cells called odontoblasts, chondroblasts and osteoblasts, which eventually help create our teeth and form cartilage and bones in the head.

"The mesoderm forms skeletal structures and muscles," says Janine. It leads to the creation of the notochord (a rod-like structure that coordinates the backbone development), our urinary and genital systems, and even our axial skeleton (the 80 bones within the central core of our bodies). As well as this, the mesoderm gives rise to cells that differentiate into the heart musculature, blood vessels, muscles and some bones of the head!

By studying both the cardiopharyngeal mesoderm and the cranial neural crest cells, Janine has much of the information necessary to investigate which genes are responsible for causing birth defects in the head and the heart.

What are birth defects?

Structures that are present at birth are called congenital. The terms 'anomalies' and 'defects' are often used interchangeably and describe something

Mouse embryo at stage E9.5 © JMZiermann

that is different from the expected condition or feature. "Both congenital heart defects and craniofacial anomalies are very common," says Janine.

Craniofacial anomalies are deformities which affect the head and facial structure. The most common type of craniofacial anomalies are facial clefts – such as cleft lip or cleft palate – where someone has a separation in their lip or in the roof of their mouth.

Congenital heart defects affect the structure and function of the heart. They can range from mild conditions, such as having a small hole in the heart, to severe conditions, such as poorly formed or missing parts of the heart.

Due to the achievements of modern science, researchers know so much more about the development of these defects now compared to a few decades ago. "However, it is still not clear how even minor changes in the gene regulatory network can have severe effects on the development of head and heart," Janine explains.

What is Janine's research?

Janine studies tissue interactions needed for the normal development of head and heart musculature, and there are many elements to her research. One of Janine's research projects focuses specifically on one of the gastrulation-brain-homeobox genes, Gbx2, which is essential for the development of the brain and the spinal cord.

Gbx2 is first expressed during gastrulation. "It is responsible for several important processes and is essential for the movement and survival of neural crest cells," says Janine. "If Gbx2 is misregulated, the neural crest cells that would usually ensure proper heart development are also likely to be abnormal."

To carry out this research project, Janine is collaborating with Dr Samuel Waters, a professor at the University of the District of Colombia. Together, they study mouse models that have

> ***"DURING EMBRYONIC DEVELOPMENT, THE EXPRESSION OF SPECIFIC GENES AT PRECISE TIMES AND LOCATIONS ENSURES THAT ALMOST ALL THE DIFFERENT HEAD AND HEART MUSCLES DIFFERENTIATE FROM THIS COMMON MESODERM."***

been genetically modified to have a very low expression of Gbx2.

What have they learnt from the mice?

In order to understand Janine's results, we first have to know more about the anatomy of the head. On the bottom of our brains, there are 12 nerves called the cranial nerves. The most prominent is the trigeminal nerve, which is responsible for providing sensation to the face and motor function to several muscles. There are three main branches of the trigeminal nerve. One of these is the mandibular branch, which controls the sensations in the jaw, lower lip, gum and, importantly, the motor function of the muscles used for chewing.

"We always learn and teach that the final stage of a muscle to become functional and look normal is the interaction with its nerve," says Janine. In this case, this means that scientists always thought that the muscles we use for chewing could only be functional and normal once they interacted with the mandibular branch.

When Sam started studying mice with a very low expression of Gbx2, he saw that these mice did not have the mandibular branch of the trigeminal nerve. However, even though the mice did not have a mandibular nerve, they still had seemingly normal looking, but not functional, chewing muscles. This mystery has brought Sam and Janine together as researchers. "This was most fascinating to me!" says Janine. "We are currently looking into the developmental mechanisms that would help us to understand this phenomenon."

How can mice models teach Janine about human heart defects?

Mice are vertebrates and mammals – just like humans – which means there are many mechanisms and pathways that are very similar, if not the same, between the two. "A mouse heart even looks like a miniature human heart," says Janine.

Genetic modification techniques allow scientists to manipulate or delete specific genes in mice. "This can tell us the role that the manipulated gene plays in development, which tissues and organs are affected by a misregulation of that gene, and which other genes are changed in their quantity of expression and therefore regulated by the manipulated gene," explains Janine.

By closely observing the anatomy of a mouse with a specific gene defect, scientists can make educated guesses and investigate potential defects in humans who are missing the same gene. "This process can help future family planning by discussing the risk of the same genetic abnormality happening in the next generation," Janine adds.

Where might this research go next?

Janine is interested in studying another cell group called the endoderm. "The endoderm sends signals to the developing head and heart," says Janine. If successful in getting funding for this new project, she will be able to start studying the effect that endodermal cells have on the development of our muscles.

About *developmental biology*

Have you ever wondered how all the organs in your body developed and how they all manage to work together? Have you thought about the shapes of your limbs and how they ended up in the positions they are in? These are the areas that developmental biologists explore.

Developmental biologists investigate how animals or plants develop from a single cell to a complex group of cells that all perform separate tasks. They could be studying any process that occurs over the lifetime of an animal or plant, from the very beginning of the reproductive cells, to how the embryo develops and how the body is formed, what the effect of age is, or even what happens within the organism during or after death. To be able to investigate all these processes, developmental biologists must be highly interdisciplinary thinkers who have a good understanding of genetics, biophysics, biochemistry, cell biology, physiology and anatomy.

Scientific advances in this field can have massive impacts on people's lives. Birth defects, for example, are the reason for one in every five deaths of children who are less than 12 months old. Birth defects can be caused by random chance, inherited gene mutations, complications during pregnancy or birth, or even toxic substances (e.g., fumes, alcohol and medication) that a mother and, hence, the foetus have come into contact with. Developmental biologists, who work to understand how and why these defects happen, distribute the knowledge to health care professionals, who advise families on inherited risks and contribute to developing public policy that allows us to live in healthy, toxin-free environments.

Developmental biology is a very exciting and dynamic field. "The next generation of researchers will have the chance to make organs in a petri dish," says Janine. Amazingly, this is already being done with cartilage cells and with beating muscle cells! "Perhaps, in the future, we might be able to raise a new heart out of the body cells of the same person, and therefore eradicate organ transplant rejection reactions," says Janine. "This is still in the future, but not as far as some might think."

Pathway from school to *developmental biology*

- During high school and post-16 studies, study STEM subjects such as biology, chemistry, mathematics and physics.
- To work in this field, you should complete a biology-related undergraduate degree such as anatomy, biology, biochemistry, microbiology, or molecular and cellular biology. If you are aiming to work in human anatomy, Janine recommends studying an anatomy degree. However, Janine and many of her colleagues studied biology and ended up working in anatomy.
- Janine recommends taking statistics or comparative anatomy courses during your degree if they are available.
- If you live near Washington DC, see if you can visit Janine's university (**medicine.howard.edu**). "The Department of Anatomy at Howard University regularly welcomes high school students to visit our anatomy lab and to see first-hand some real human anatomy," says Janine. "These are usually two-hour sessions with several stations (where students can learn about the skull and other bones, brain, heart, lungs, muscles of the body) and a Q&A session."

Explore careers in *developmental biology*

- Developmental biology and anatomy are diverse fields that have a wide range of career opportunities. You might find yourself working in academia or industry as a teacher or researcher or a combination of both, often alongside other scientists and students from different fields.
- Janine recommends visiting the American Association for Anatomy's website to read about the latest news within the fields of anatomy and developmental biology (**www.anatomy.org**). It also provides an introduction to anatomy which explains more about what the field covers: **www.anatomy.org/AAA/About-AAA/What-Is-Anatomy.aspx**
- Best Accredited Colleges has some helpful information on what a career in developmental biology involves and what the job opportunities are: **bestaccreditedcolleges.org/articles/careers-in-developmental-biology-job-options-and-requirements.html**
- According to Salary Expert, the average annual salary for a developmental biologist in the US is $72,000.

Mouse embryo at stage E13.5 © JMZiermann

Q&A

Meet *Janine*

Who or what inspired you to become a scientist?

I first wanted to be a veterinary doctor. After visiting an introduction session to the veterinary course in Leipzig, Germany, I realised that it might not be for me. I went home and looked for another option. Biology was it.

I wanted to specialise in zoology and I did, but not in the way I thought in the beginning. Halfway through my education, Dr Lennart Olsson joined our university. He is a great scientist studying the evolution and development of head structures. I did my research rotation with him and fell in love with the subject. I ended up doing both my diploma and PhD in his lab.

As a scientist, it is possible to meet people from all over the world. As long as one keeps an open mind, this brings lots of learning experiences and new friendships. It also provides the opportunity to see different approaches to the same problem.

What is the worst piece of advice you have been given, and how did you 'unlearn' it?

'Figure it out yourself'. This is utter nonsense! I never wanted to bother my professors and lost lots of opportunities because of it. I still think it is not advisable to bother professors with small talk after each lecture; however, if you are interested in a topic and want to learn more, talk to them. They are all human and most actually enjoy talking with students about their lectures and research. If you have a goal and don't know how to reach it, ask a professor who you trust if they can help outline the next steps. Some say no, and that's okay, but more will say yes!

Last but not least, it is always okay to say, "I don't know". This will be important for your whole career and life. No one knows everything and it is much more respectable to say "Let me look into it" or "Let's figure that out together" rather than making stuff up.

Janine and her research assistant, Paola Correa-Alfonzo (© JMZiermann)

What are your proudest career achievements, so far?

I got a poster presentation award for my diploma (thesis) and a publication award in 2014 for a paper in my second postdoctoral position. Most recently, I was awarded a US National Science Foundation grant that is supporting the research related to Gbx2.

My favourite achievement was that I got to publish two manuscripts with my academic 'hero', Dr Drew Noden. Not only did we publish together, but we are still in touch. I was able to visit him before his retirement, and he recently gave a talk at Howard University. I took advantage of him visiting and had long and fascinating conversations with him.

What are your ambitions for the future?

I'm currently trying to stabilise my lab. I recently hired a research assistant/lab manager, Ms Paola Correa-Alfonzo. Getting more funding to keep her and hire MS/PhD students and postdoctoral researchers is next on my plan. With a larger group, I hope to get faster results relevant to the tissue interaction during head and heart muscle development. I also want to establish more collaborations where several people research different aspects on the same model organism. That would reduce not only the number of animals needed in research, but also put changes in gene expression in a larger, more global picture.

Janine's *top tips*

1. Find something you are really passionate about, and don't be afraid to change fields for it!
2. Be flexible. Adding new technologies, new questions and new aspects has its risks but makes things more exciting, not only for yourself but also for funding agencies and the future research and job market.

What causes problems with the lower urinary tract?

Our bodies are fascinatingly interconnected. Did you know that urinating a lot at night might be due to a heart problem? Or that a condition such as diabetes might affect urination? In the US, a team of doctors and researchers, including **Professor Cindy L. Amundsen** from **Duke University School of Medicine,** have come together to study lower urinary tract dysfunction, which affects almost 70% of people over 60 years old. The scientists' aim is to understand what causes lower urinary tract symptoms and how treatment outcomes for these conditions can be improved.

Professor Cindy L. Amundsen, MD

Roy T. Parker Endowed Professor of Obstetrics and Gynecology, Division of Urogynecology, and Professor, Department of Surgery, Division of Urology, Duke University School of Medicine, USA

PROFILE

Fields of research
Obstetrics and Gynaecology, Urogynaecology

Research project
Improving treatment outcomes for lower urinary tract dysfunction

Funders
US National Institute of Diabetes and Digestive and Kidney Diseases, US National Institutes of Health's National Center for Advancing Translational Sciences
Funder of Futurum Careers project: Roy T. Parker Endowed Professorship, Duke University School of Medicine

TALK LIKE A ...

UROGYNAECOLOGIST

Bladder — the organ that stores urine

Gynaecology — the area of medicine focused on treating female diseases, especially those that affect the reproductive organs

Obstetrics — the area of medicine focused on pregnancy, childbirth and female health immediately after delivery

Pelvic — related to the pelvis, the space between the hips where several organs and structures are located

Urethra — the tube through which urine leaves the body

Urinary tract — the organs that make urine and remove it from the body, including the kidneys, ureters, bladder and urethra

Urogynaecology — a specialised field of gynaecology and urology that focuses on female pelvic medicine

Urology — the area of medicine focused on diseases of the male and female urinary tract

Our urinary tract involves all the organs that work together to make urine and remove it from our bodies. This includes the kidneys, where urine is made; the ureters, which carries urine to the bladder; the bladder, where urine is stored; and the urethra, through which urine exits the body. The urinary tract is divided into two parts. The upper urinary tract includes the kidneys and ureters, and the lower urinary tract includes the bladder and urethra.

When the lower urinary tract is not working properly, someone might have lower urinary tract dysfunction (LUTD). Both males and females can experience LUTD, as can children of any age. LUTD encompasses a broad range of different problems, and symptoms can include leaking urine, having sudden urges to pee, urinating at night, having a slow stream or feeling as if your bladder is not empty after urinating.

As you can imagine, the symptoms of LUTD can greatly impact an individual's day-to-day life. At Duke University School of Medicine, Professor Cindy L. Amundsen is studying LUTD with the goal of developing better treatment options for people struggling with this condition. "Symptoms can limit activities people enjoy doing outside the home, reduce their social interactions, disrupt sleep, and decrease their feeling of mental and physical wellness," says Cindy.

Can lower urinary tract dysfunction be treated?

Luckily, there are many therapies that already exist which can treat the symptoms of LUTD. Sometimes, patients can improve their symptoms by decreasing the amount of caffeine they drink, reducing the amount of fluid they drink, or limiting drinking fluid before going to bed. Other patients might do exercises to strengthen the muscles around the urethra and bladder or undergo surgery to support the urethra. "Additional treatments involve placing an electrode near nerves that control the bladder or injecting medicine into the bladder to decrease the muscle spasms," explains Cindy.

However, there are limitations to these treatments. The first limitation is that urinary symptoms are often attributed to the lower urinary tract when the symptoms may not be related to problems with the lower urinary tract at all. Symptoms of LUTD can occur due to poor sleep, the amount of fluid being consumed, childbearing, previous surgeries, ageing or certain medications. "They can also be caused by non-urological organs and diseases or conditions such as diabetes, anxiety or depression," explains Cindy. It can be difficult to diagnose exactly why someone is experiencing symptoms, which can reduce the effectiveness of the treatment.

"Another limiting factor is that many patients experience a combination of symptoms, so treatment that focuses on a single symptom may result in suboptimal care," explains Cindy.

To improve these treatment outcomes, Cindy has received grant funding from the US National Institute of Health (NIH) to support research to help understand the different subtypes of lower urinary tract symptoms and the causes for each group.

How is Cindy studying LUTD?

Cindy is part of a team of surgeons, biological scientists, computational scientists and medical research professionals who have come together from six different universities across the US to study the lower urinary tract and improve treatments for LUTD. The network was formed in 2012 and named 'LURN: the Symptoms of Lower Urinary Tract Dysfunction Research Network'. It is supported by grants from the US National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK) and the National Institutes of Health's National Center for Advancing Translational Sciences 5U01-DK097780-09.

Crucially, the project involves people from various backgrounds who are all experts in different areas. Since lower urinary tract symptoms (LUTS) can have multiple causes, the research project needs to have a diverse team whose members can share their knowledge on various areas.

The scientists within LURN work with patients struggling with urinary symptoms. "We gather information through questionnaires, physical examinations, and urine and blood samples," says Cindy.

The goal is to be able to group patients with similar symptoms together into subtypes and analyse the differences between these groups. To do this, the team created a new questionnaire called LURN SI-29 and a shortened version, LURN SI-10. "While there are several questionnaires available to clinicians, none capture the full spectrum of LUTS in both men and women which could then be used as a tool for both clinical use and research," explains Cindy.

How does a country-wide research programme like LURN work?

The two main challenges of having a collaboration across the US are logistics and expense. The whole group of scientists meets virtually twice a month and in person in Washington, DC, four times a year to discuss their findings. The varying time zones across the country mean that organising virtual meeting times can be difficult and enabling the whole team to travel is expensive.

So, why has LURN decided that a country-wide research project is worth it? The main reason is that it allows the team to recruit a large and diverse group of patients. "This makes the findings of our study more generalisable to others across the country and even to those in other countries who have similar symptoms," explains Cindy.

What has the project found?

The initial research that has come out of LURN shows that not only are there different symptoms among patients, but also differences in demographics, medical conditions and biological variables between patients.

Cindy and the rest of LURN used advanced statistics to group individuals together into subtypes according to the similarity of their symptoms. Interestingly, they found that symptom improvement varied by subtype, meaning that some subtypes responded better to therapies than others.

What is next for LURN?

The LURN team aims to understand which specific treatments work best for each subtype. In order to do this, the researchers need to recruit more patients with LUTS and perform more studies to understand the underlying causes of symptoms. "By incorporating more data that include diagnostic information and possibly cellular or molecular factors, more meaningful differences among patients may be identified," says Cindy.

The LURN team also plans to use computer modelling techniques to estimate the risk of individuals developing LUTS later in life, with the goal of preventing more cases. The team hopes its results can be used to develop better, personalised treatment plans, so that more people struggling with lower urinary tract symptoms will be able to get the help they need.

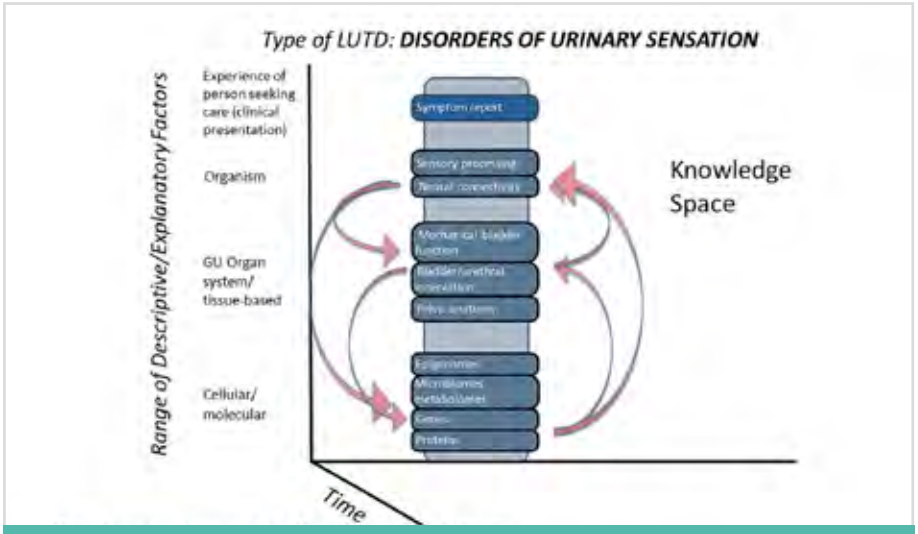


Figure Conceptual representation of lower urinary tract dysfunction. Reference: Symptons of Lower Urinary Tract Dysfunction Research Network. Yang CC, Weinfurt KP, Merion RM, Kirkali Z; LURN Study Group. J Urol. 2016 Jul;196(1):146-52. doi:10.1016/j.juro.2016.01.007. Epub 2016 Jan 16.PMID: 26784647

About *urogynaecology*

If you enjoy learning about women's issues and think you will enjoy a medical career, then working in gynaecology could be for you. Gynaecology is often combined with obstetrics to create the field of obstetrics and gynaecology, referred to by the acronym OB/GYN. Having a strong knowledge of both areas will make you more able to solve problems related to women's health.

Gynaecologists are medical doctors who perform surgery and who have undergone specialised training to become experts in the female reproductive system. They might work in a clinical environment, engaging daily with patients experiencing health problems and/or work in a research setting, conducting experiments or surveys to better understand medical problems and develop new, innovative treatments.

You must be curious about women's health issues to work in this field, as there is still so much to be discovered. "We still don't understand why women get many of the gynaecologic conditions such as endometriosis, recurrent urinary tract infections, chronic pelvic pain, fibroids, infertility, gynaecologic cancer, menstrual irregularities, pelvic support problems, urinary incontinence, and many more conditions," explains Cindy.

Future gynaecologists will pursue research questions to understand what contributes to the onsets of these conditions and diseases, as well as how they progress and what treatments might be possible. Gynaecologists also need to be able to disseminate their findings to the wider scientific community and use their results to improve advice for patients.

Cindy wears multiple professional 'hats'. As a researcher, surgeon, clinician and educator, she highlights the different aspects to careers in this field: investigating issues and aiming to find clinical solutions, working directly with patients, and helping to train and support the next generation of gynaecologists.

How are new technologies aiding Cindy's work as a surgeon?

"Robotic surgery allows for very complicated surgery to be done with more precision, flexibility and control than open surgery as it is performed through very small incisions," says Cindy. "Additionally, technologic advances with medical devices allow surgically implanted devices to be placed with less anaesthesia and through smaller incisions. Finally, the accuracy of radiographic and other diagnostic technologies has improved so much that we are detecting earlier stages of medical conditions which allows for minimally invasive treatments to be performed."

Pathway from school to *gynaecology*

- During high school and post-16-years, study biology, chemistry, physics and mathematics. Working in OB/GYN also involves having strong interpersonal and communication skills, so taking language courses can be very useful too.
- To work in gynaecology, you must complete a medical degree before undergoing specialised training in obstetrics and gynaecology. If you are attending university in the US, you will need to do a pre-med degree before you start studying medicine.
- If you have the option to choose courses during your university degree, Cindy recommends studying deductive reasoning, psychology, communication, epidemiology, ethics, anatomy, biochemistry, pathophysiology, pharmacology, pathology and immunology. "In addition, math skills that will help would be algebra, geometry, statistics and probability," she adds.
- Cindy recommends the website Career Girls, which has a fantastic page on working in obstetrics and gynaecology, details of what an average day might involve, and interviews with various obstetrics and gynaecology role models: **www.careergirls.org/careers/ob-gyn**

Explore careers in *gynaecology*

- "Working in gynaecology is very rewarding, but it is a demanding career and, thus, you must be passionate about the field," says Cindy. "Gynaecologists will see patients in the clinic and operate at the hospital, so every day will be different. Skills that would be useful are dexterity, patience, communication, problem solving, flexibility, resilience, organisational skills and physical stamina."
- If you are interested in working with women's health issues but do not want to be a gynaecologist, then there are lots of other options too. Nurses, midwives, general practitioners and psychologists, as well as jobs within non-profit organisations and women's centres, all play important roles in improving women's health.
- Indeed.com has some useful information on working in obstetrics and gynaecology, including which skills you need to develop to be successful in this career: **www.indeed.com/career-advice/finding-a-job/how-to-become-obgyn**
- According to the US Bureau of Labour Statistics, the average annual salary for obstetricians and gynaecologists in the US is $277,000
- Cindy recommends watching this 15-minute video by Med School Insiders about what it is like to work in OB/GYN: **So You Want to Be an OB/GYN [Ep. 22]**. There is also an accompanying blog post to the video here: **medschoolinsiders.com/medical-student/so-you-want-to-be-an-ob-gyn**

Meet *Cindy*

scholars.duke.edu/person/amund002

I was first inspired to pursue a career in gynaecology because I grew up sewing my own clothes with my mother and sister; I always enjoyed working with my hands. Sewing, in many respects, is like performing a surgery. You must understand the anatomy or material you are working with, know the techniques necessary to perform the task, and have the creativity and skill to finish the procedure/product. In medical school, I was drawn to the specialty of surgery and wanted to improve women's health conditions that require surgery. I did additional training to become a urogynaecologist, one who specifically performs reconstructive pelvic surgery involving the lower urinary tract organs and gynaecologic organs.

Three major experiences of my childhood led me to be a researcher, surgeon and educator. As expressed above, my mother taught me to sew at a very young age – cutting out the patterns and sewing with my hands. My father taught me to be a good researcher as I would watch him read dental manuals and journals. Lastly, when I was a teenager, I learned how to become a dance instructor. Teaching others gave me much satisfaction, so I wanted a profession where I could also teach what I know.

Balancing research, surgery and education during my work is not easy, and it can get very busy. There are times I need to prioritise tasks, so staying organised and preparing ahead of time to meet specific deadlines is very important. I am passionate about all three areas and strive to do my best in each of them.

Gynecologic trainees in the suture laboratory practice to suturing (sewing biologcal tissue)

Cindy teaching in the operating room (OR)

They all interconnect. When I am performing surgery, I have several trainees in the operating room and educate them on the surgical techniques and other clinical aspects. My research often involves clinical trials that involve the recruitment of patients, so I get them involved and educate my patients on the advances and improvements in patient care discovered through research.

I find it very gratifying to pass on knowledge, skills and wisdom to the next generation, and I enjoy helping my mentees achieve more than they could do alone. Mentees also challenge me, helping me stay abreast of newest developments!

The worst piece of advice I was ever given was that I was told there was no need for me to work hard when I first came on faculty, since I had a very successful and world-renowned surgeon as a husband. This did not fit my personality and so I disregarded it, worked hard, and became successful in my own right.

Outside of work, I enjoy training for sprint triathlons and playing golf. To relax, I love doing puzzles and playing mah-jong and bridge.

I feel very grateful that over the past 24 years, my involvement in research, patient care and trainee education has enabled me to make contributions that have significantly impacted the quality of patient care. In 2017, I was awarded the Rodney Appell Continence Care Champion, one of the most prestigious recognitions in the field of continence care. In addition, in 2021, I received the Duke School of Medicine Career Mentoring Award in Clinical Research/Population Health which recognised excellence in research mentoring.

Cindy's *top tips*

1. Be curious and open to the opportunities that are presented to you, no matter how small they may seem.
2. Follow the 4 Ps:
   - When given an opportunity – PERFORM. Do the best that you can.
   - Nothing that is worth something is easy, so be PATIENT and learn from any mistakes that you make.
   - PERSEVERENCE is very important to achieve your goals.
   - Lastly, follow your PASSION, even if someone says you should pursue something else.

KURe – the K12 Urologic Research Career Development Program

As part of her commitment to education and mentoring other scientists, **Cindy** leads **Duke University School of Medicine's KURe Program *** which supports researchers to build independent research careers. We meet three programme participants.

** funded by the NIH/National Institute of Diabetes, Digestive and Kidney Diseases (NIDDK) K12-DK100024-11*

Meet *Cassandra*

Dr Cassandra Kisby, MD

Duke Division of Urogynecology, Assistant Professor of Obstetrics and Gynecology, Duke University School of Medicine

Fields of research: Obstetrics and Gynaecology, Urogynaecology

Funder: K12 Urologic Research Career Development Program K12-DK100024-11 NIH/NIDDK

The most impactful thing that has changed my career path has been mentor relationships. There are people who will tell you it can't be done; find the people that believe in you and will help you navigate the unbeaten path. I am from a very small town in North Carolina and am the first in my family to go to college. A very special high school physics teacher believed in me and sponsored me for a full tuition scholarship to Duke and it changed my life.

Because I am a clinician-scientist, my research covers both basic science and clinical research. I am a urogynaecologist, meaning I treat women with bladder and pelvic issues, so my research is aimed at improving care for women with these issues. For my current research, I am using regenerative medicine technologies (such as stem cells) to help women who have pelvic floor disorders or were born with differences in bladder and gynaecologic anatomy. As a clinician-scientist, I have a diverse research profile – I even do some work that involves 3D printing. The key is to find a meaningful question or problem and think creatively.

Cassandra performing pelvic surgery

Success requires persistence. A hypothesis is an educated guess and, statistically, hypotheses cannot all be correct. If you are following your passions and doing work that is meaningful to you, you will be more resilient when you are faced with negative results (when your hypothesis was wrong).

Like many things in life, the most challenging part of research is finding funding. The great idea is just the start – you have to write well-written grants to be able to fund the research projects. The writing and planning is worth it when you have a research breakthrough. It's great to synthesise your results and present them to your peers at national meetings and publish your results in an academic journal.

The KURe Program has given me time and funding to develop my research career. I have time to prepare and conduct my research studies and meet with a career coach, and the ability to network with other young researchers at Duke. It has been a remarkable programme, and I am very thankful to have such support from mentors like Dr Amundsen.

As part of my clinical training, I did fellowship in urogynaecology. During fellowship, I decided I had a special interest in urogenital congenital anomalies, meaning anatomic differences of the bladder and genitals in women. For example, some women can be born with a double uterus. Over the last two years at Duke, I've created a Congenital Anomaly Program, which has grown into a multi-disciplinary treatment programme. It was featured in the Duke OB/GYN magazine: **issuu.com/dukeobgyn/docs/digital_020623__duke_obgyn_magazine_winter_2023?fr=sNzg4MTQ3MDc3NTg**

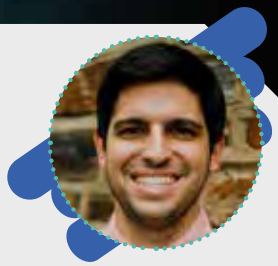
My hope is to share my research and clinical skills with the next generation of clinician-scientists; the future is very bright.

Cassandra's *top tips*

1. Learn about the differences between mentors, sponsors and career coaches. At each stage of your career, I would find a few with whom you can form formal relationships.
2. Sometimes the cost of education can be a barrier. Seek out local and national scholarships to prevent debt from driving your career decisions.
3. Look into summer programmes at local colleges and universities. These are a great way to network and get exposed to science and research.

© Suttha Burawonk/Shutterstock.com

Meet *Eric*



Dr Eric Gonzalez, PhD

Department of Biomedical Engineering, Duke University, USA

Field of research: Neuroscience

Funders: K12 Urologic Research Career Development Program, and K01 Research Scientist Development Award K12-DK100024-11 NIH/NIDDK

The Duke KURe Program and Dr Amundsen helped kick start my translational research programme. Making my research objectives relevant to human conditions made me stand out compared to having only pre-clinical studies.

My research is currently focused on developing a peripheral nerve stimulation device to manage LUTS and improve bladder emptying in underactive bladder (UAB). I hope to increase our understanding of the muscular and neural alterations in the lower urinary tract that may accompany UAB and provide a foundation for clinicians to develop innovative therapeutics to improve patient outcomes.

We began a clinical pilot study, mentored by Dr Amundsen, to determine the influence of bladder and urethral electrical stimulation on bothersome symptoms and bladder function in adult women with UAB. This is the first step in developing alternative therapeutics.

It is challenging navigating your career and differentiating your research enough to receive funding. It is rewarding working on solutions to problems that many older adults face.

The Duke KURe Program provided an opportunity to collaborate with clinicians and develop mentorship in clinical research. It also provided protected time to support collecting preliminary data for my next awarded grant.

I am proud of being awarded an NIH Mentored Research Scientist Development Award to support four years of my research. For the future, I plan to continue pursuing a career in clinical research.

Eric's *top tip*

You can get your foot in the door by volunteering to help in a laboratory.

Meet *Byron*

Dr Byron Hayes, PhD

Department of Pathology, Duke University School of Medicine, USA

Field of research: Pathology

Funder: K12 Urologic Research Career Development Program K12-DK100024-11 NIH/NIDDK

Around halfway through my time in graduate school, my research shifted focus to my current studies involving the nervous system, which was a new field of interest for the lab in which I currently work. This has been particularly enjoyable since I like having the opportunity to drive a new research interest forward.

Currently, my research focuses on discovering better treatment options for patients that suffer from frequent urinary tract infections (UTIs) by using mice. I am specifically interested in treating pain and other symptoms that relate to the nervous system.

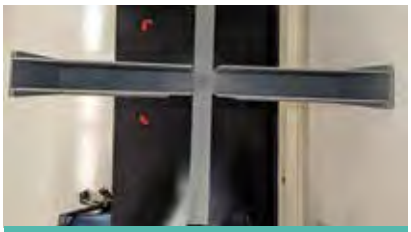
My key successes include developing a mouse model of UTI induced pain and urinary frequency, which enabled me to discover what goes on in the bladder after a UTI. The next step is to use this mouse model to study anxiety and depression, since these are other symptoms experienced by patients.

A lot of my time is spent designing experiments and going through trial-and-error as these are unanswered research questions. Fortunately, when discoveries are made, it gives you a strong sense of accomplishment, knowing that you have contributed to your field of research.

The KURe Program has enabled me to interact with several clinicians; these interactions are very important in ensuring that my research is directed at areas that are relevant to UTI patients.

I was vital in expanding my lab into neuroscience during graduate school. My work also awarded us research funds (~$1.5 million) to further support our studies. These are two achievements I am very proud of.

I plan to start my own research lab in the future, studying interactions between the nervous system and bladder after infection. I will focus on the bladder and brain/spinal cord, since the bladder is regulated by the brain.



The 'Elevated Plus Maze' is a common behaviour test used to check if rodents are showing signs of anxiety based on whether they avoid going onto the exposed arms of the maze. (© Byron Hayes)

Byron's *top tip*

Start working in a lab early. This is important so you can truly learn whether it's the right path for you. If it is, you will be able to start getting the right guidance to make your path forward clearer.

Can scientists prevent kidney disease?

At **Duke University Medical Center** in the US, **Dr Jamie Privratsky** divides his time between treating critically ill patients on the hospital wards and uncovering the biological causes of their conditions. In his most recent research project, Jamie has been using mouse models to shed light on the mechanisms behind acute kidney injury (AKI), a serious problem that can occur in the organ that makes urine and manages fluid and blood pressure, and to determine how to prevent AKI progressing to chronic kidney disease.

Dr Jamie Privratsky

Associate Professor of Anesthesiology,
Duke University Medical Center, USA

PROFILE

Fields of research
Nephrology, Critical Care Medicine

Research project
Investigating the mechanisms behind acute kidney injury (AKI)

Funders
US National Institutes of Health (NIH): National Institute of Diabetes and Digestive and Kidney Diseases (NIDDK), National Institute of General Medical Sciences (NIGMS); International Anesthesia Research Society; Duke Department of Anesthesiology

TALK LIKE A ...

PHYSICIAN SCIENTIST

Cytokine — a small protein that plays a role in cellular signalling

Dialysis — a medical treatment in which the blood is artificially filtered by a machine when the kidneys have failed and cannot filter the blood

Endothelial cell — a cell lining a blood vessel

Inflammation — the immune system's response to harmful stimuli

Macrophage — a type of immune cell

Pathogen — any organism that can cause disease

Sepsis — the immune system's extreme reaction to an infection

"Acute kidney injury (AKI) occurs in up to 50% of critically ill patients," says Dr Jamie Privratsky, a physician scientist at Duke University Medical Center. In his dual role as a physician scientist, Jamie not only treats patients with AKI, but is also conducting research to uncover the molecular causes of the disease.

What is acute kidney injury (AKI)?

Our kidneys play a crucial role in our body. They filter half a cup of blood every minute, removing waste products and any extra fluid from our body by producing urine. AKI occurs when kidneys cannot perform their normal functions, causing waste products to build up in the blood, which can then cause problems for other organs such as the brain, heart and lungs. "AKI can lead to the need for dialysis, the injury of other organs and death," says Jamie.

AKI can occur if the kidneys are damaged, for example by a severe infection or traumatic accident, and blood flow to the kidneys is restricted. This means AKI is a common problem among people who are in an intensive care unit in a hospital. If AKI is limited or prevented early enough, kidney function can be restored. If not, the kidneys can become irreversibly damaged, resulting in chronic kidney disease (CKD). CKD and its end result, end-stage renal disease (ESRD), can be fatal unless the patient receives a kidney transplant or regularly undergoes dialysis for the rest of their life.

In critically ill patients, sepsis is the most common cause of AKI. Sepsis occurs when the immune system overreacts to an infection, damaging the body's tissues and organs. It can be extremely serious and life-threatening. "When AKI occurs as a complication of sepsis, the mortality rate climbs to greater than 50%," says Jamie. "Despite this, the processes of septic AKI are still poorly understood." He therefore hopes to increase understanding of AKI to improve the outcomes for patients.

What role do macrophages play?

Jamie's research involves studying macrophages, important cells in the immune system. Macrophages are specialised cells that detect harmful organisms in our bodies. They circulate in almost every tissue, searching for pathogens and removing dead cells. "Macrophages can have protective or detrimental effects on kidney injury,

depending on their location within the kidney, the disease causing the injury, and the length of time after injury," says Jamie. During septic AKI, macrophages have been shown to be protective, but scientists do not understand which macrophages have these protective effects.

Macrophages release cytokines, small protein molecules that help with communication between cells during immune responses, by signalling to other immune cells to cause inflammation. Like macrophages, cytokines play a vital role in helping the body fight disease. "Inflammation is needed for healing, but in kidney injury, it can also cause damage," explains Jamie. "The key is to regulate the immune response so the cells cause inflammation without inducing significant injury."

How is Jamie studying AKI?

Jamie is using mouse models and human studies to investigate macrophages and cytokines in the kidneys during septic AKI. "In mouse kidneys, macrophages consist of two main subpopulations, F4/80^{hi} macrophages and CD11b^{hi} macrophages," he says. Jamie is focused on F4/80^{hi} macrophages, as these seem to be important in the kidney, but scientists do not yet understand why.

Two major cytokines released during sepsis are interleukin-6 (IL-6) and interleukin-1 (IL-1). "IL-6 is a major proinflammatory cytokine that is released at sites of injury and following sepsis," says Jamie. "IL-1 is known to induce IL-6 and, inversely, anti-IL-1 therapy can limit IL-6 generation." Jamie discovered that IL-6 levels were higher in subjects who have both severe sepsis and AKI, implicating IL-6 as a possible mediator of septic AKI. He decided to see if limiting the amount of IL-6 in the body would reduce the severity of AKI.

How did Jamie create mouse models?

"To study this, we used a genetic mouse model that specifically depletes F4/80^{hi} macrophages," says Jamie. These mice had their genes engineered to express a receptor for the diphtheria toxin receptor. In humans, diphtheria is a serious infection, so we get vaccinated against it, however mice are completely unharmed by diphtheria and its toxin. "We use this to our advantage by expressing the receptor in specific cells in the mice, in this case in the F4/80^{hi} macrophages," Jamie explains. "By giving these mice the diphtheria toxin, their F4/80^{hi} macrophages are deleted."

> **"WHEN AKI OCCURS AS A COMPLICATION OF SEPSIS, THE MORTALITY RATE CLIMBS TO GREATER THAN 50%. DESPITE THIS, THE PROCESSES OF SEPTIC AKI ARE STILL POORLY UNDERSTOOD."**

Jamie and his research team then infected mice that were missing F4/80^{hi} macrophages to induce sepsis, to determine what level of kidney injury they developed as a result. They observed the mice's kidneys under the microscope to analyse the immune cells they contained and measured markers of kidney injury in the blood.

What has Jamie discovered?

Jamie and his team found that F4/80^{hi} macrophages produce an inhibitor of IL-1, known as IL-1 receptor antagonist, which represses IL-6 production in kidney endothelial cells. They further found that limiting IL-6 appears to decrease inflammation and the severity of AKI. "F4/80^{hi} macrophages clearly play prominent but complex roles in kidney disease," Jamie adds. "Our study provides a rationale to target macrophage–endothelial cell interactions to protect the kidney during sepsis."

What next?

Jamie's next steps will be to look for ways that his research can improve therapies for people with AKI and prevent its transition to CKD. "While inhibitors of both IL-1 and IL-6 have been tried in patients with sepsis, these drugs have not always worked well due to other side effects, such as the fact that they supress the immune system," he explains. Jamie hopes his research leads to more targeting of these treatment options, to limit side effects and improve the outcomes for people with kidney injury.

Our kidneys filter half a cup of blood every minute, removing waste products and any extra fluid from our body by producing urine
© H_Ko/Shutterstock.com

About *physician scientists*

By working both as medical doctors and research scientists, physician scientists are a crucial bridge between medicine and science. They represent less than 2% of physicians, yet they have contributed so much to our knowledge of medicine and ability to provide healthcare. Historical achievements of physician scientists include the polio vaccine (which has improved the lives of millions of children), reductions in coronary artery disease, treatments for patients with failing organs, and pioneering steps towards the eradication of smallpox. In fact, more than half of the Nobel prizes in medicine and physiology have been awarded to physicians working in scientific research.

Their in-depth clinical knowledge as doctors, combined with their skills in scientific investigation, make physician scientists incredibly useful and important. By working with patients as well as conducting research, they are uniquely placed to recognise the challenges in medicine, discover the underlying biological mechanisms behind health conditions and test new therapies to prevent and treat diseases.

What does Jamie's job as a physician scientist involve?

Alongside studying kidneys in a scientific lab, Jamie also works as an anaesthesiologist and intensive care doctor. "As an anaesthesiologist, I anesthetise patients (make them unconscious) for surgery," explains Jamie. This involves inserting intravenous (IV) drips so the anaesthesia drugs can be released directly into their blood, inserting breathing tubes in their throats so they can still breathe while unconscious, and closely monitoring their condition throughout the surgery to ensure they are safe. "When I work in the intensive care unit, I am looking after the sickest patients in the hospital," Jamie says. "I make the medical decisions that will hopefully get them through their severe illness."

In contrast, a typical research day for Jamie involves conducting experiments in the lab, analysing data, writing up results and applying for research funding. "I love being in the lab because I get to learn about science and design experiments to test our hypotheses," he says.

What are the joys and challenges of this dual role?

"The hardest thing about having a dual role is that both jobs are very challenging, and I have to do well in both of them," says Jamie. Despite these challenges, many people are drawn towards a career as a physician scientist due to the variety and satisfaction of the work. "Being a researcher involves many days where experiments do not work, so some days I can feel like I didn't accomplish anything," says Jamie. "It is therefore very rewarding to go into the hospital where I can help people directly. On the other hand, clinical work can be overwhelming and tedious, so it is nice to have a change of pace by working in the lab to design experiments and analyse data. Being a physician scientist means I get the best of both worlds!"

Pathway from school to *physician scientist*

- Studying biology, chemistry and physics at school and post-16 will be useful for becoming a physician scientist, and may be a requirement for getting into medical school.
- "Physician scientists also need to be good at writing and presenting their work, so taking writing and English classes is also useful," says Jamie.
- Physician scientists are medical doctors as well as research scientists, so you will need to complete a medical degree to qualify as a medical doctor.
- Typical degrees to study before attending medical school include biology, biochemistry and biomedical science. "I majored in clinical laboratory science," says Jamie. "This gave me a strong background in science and medicine."
- Some universities offer dual degrees specifically for physician scientists, which combine a degree in medicine with a PhD. The Association of American Medical Colleges has a useful webpage about dual degrees: **students-residents.aamc.org/applying-medical-school/considering-combined-degree-md-phd-md-mba-md-mph-md-jd**

Explore careers as a *physician scientist*

- "Physician scientists need to be naturally curious, be good at taking in a lot of information, enjoy working with and helping people, and want to understand how things work at a deep level," says Jamie. "As well as that, you need to have a strong work ethic and a love of science and medicine."
- To pursue a career as a physician scientist, Jamie recommends exploring the resources from the American Physician Scientist Association (**www.physicianscientists.org**) and the American Society of Clinical Investigation (**www.the-asci.org**).
- This article, by Dr Karuna Ganesh, explains the joys and challenges of being a physician scientist: **www.nature.com/articles/s41575-021-00443-3**
- This article, by Dr David Schwartz, explains the importance of physician scientists for bridging the gap between medicine and science: **www.atsjournals.org/doi/full/10.1164/rccm.201110-1806ED**

© Hananeko_Studio/shutterstock.com

Meet *Jamie*

I have wanted to be a doctor since early high school. I always enjoyed science, I was pretty good at math and I really just enjoyed learning. I still wanted to understand things even when I was studying subjects that weren't my favourite.

Despite my early interest in medicine, I didn't consider a career as a physician scientist until later. My interest in research didn't start until I did research in college. After that, I realised that research would help fulfil the intellectual curiosity I had. I also knew that being a physician would give me a great understanding of human health and disease. It helped that, in the US, there are programmes that pay for your medical school tuition if you do a dual degree and graduate with both a PhD and a medical degree. As I enjoyed both medicine and research, this seemed like a great option.

> ***I REALISED THAT RESEARCH WOULD HELP FULFIL THE INTELLECTUAL CURIOSITY I HAD.***

My favourite fact about the kidneys is that they coordinate many of the physiological processes in the body. For example, the kidneys are responsible for maintaining blood pressure, blood volume, electrolytes, acids and bases in the body. They truly do it all!

I enjoy spending my free time with my family, especially going skiing or to the beach. My wife and I are foodies, so we enjoy eating out and trying new foods. I also love watching sports, playing golf and helping with activities at my church.

Jamie's *top tips*

1. Follow your passion and go for it. Do what you love, and it will never feel like work! I love my job and can't imagine doing anything else.
2. Work hard at whatever you do.
3. Make sure you have a good support system around you and value your family and friends above your work.

How can diabetes lead to vision loss, and how can this be prevented?

Diabetic retinopathy is the leading cause of blindness among working-age adults in the developed world. **Dr David Antonetti**, a molecular and cell biologist at the **University of Michigan**, USA, works in the field of ophthalmology to investigate how diabetes causes eye issues. He hopes his research will lead to the development of new treatments for diabetes-related vision loss.

Dr David Antonetti

Department of Ophthalmology and Visual Sciences, Kellogg Eye Center, University of Michigan, USA

PROFILE

Fields of research
Ophthalmology, Molecular and Cell Biology

Research project
Investigating factors that affect the blood-retinal barrier during diabetic retinopathy

Funders
US National Institutes of Health (NIH), Research to Prevent Blindness (RPB)

TALK LIKE AN ...

OPHTHALMOLOGIST

Blood-retinal barrier — a physiological barrier that regulates the flow of nutrients, ions and molecules between the bloodstream and retina

Cultured cell — a cell grown in a laboratory

Cytokine — a small protein molecule released from one cell that signals a cell response in another cell, usually by binding to a specific receptor

Neuron — a nerve cell that conveys a signal by electrical response

Ophthalmology — the branch of medicine focused on the eye and vision

Permeability — the ability of a material to allow substances to pass through it. A material with high permeability allows substances to pass through easily

Phosphorylation — the addition of a phosphate group (PO_4^{3-}) to a molecule

Physiological — relating to the normal functioning of an organism

Retina — the thin layer of light-detecting cells at the back of the eye

Signalling — the process of a cell emitting, receiving and processing instructions

Diabetes is a chronic health condition in which the body cannot control its blood sugar levels properly. You have probably heard of diabetes, but you might not associate it with vision loss. However, diabetes can affect the retina – the thin layer of light-detecting cells at the back of the eye – which can lead to diabetic retinopathy.

What is diabetic retinopathy?

Diabetic retinopathy is characterised by changes in the retinal blood vessels, and symptoms include blurry, spotted or total loss of vision. A third of all people with diabetes have diabetic retinopathy, and severe forms of the disease are the leading cause of blindness in working-age adults. Dr David Antonetti, a molecular and cell biologist at the University of Michigan, hopes to improve our understanding of the mechanisms behind the condition and develop new therapies to treat the disease.

The exact cause of diabetic retinopathy is still unknown, but it appears that factors associated with diabetes, such as increased blood glucose (sugar) and fat, alter the normal retinal environment. "Changes in the retina include a loss of neurons, inflammation, leaky blood vessels and abnormal blood vessel growth," explains David. If retinal blood vessels leak, fluid can accumulate in the retina which reduces a person's vision. If abnormal blood vessels grow, they can pull the retina away from its support within the eye, leading to complete vision loss.

What role does the blood-retinal barrier play in diabetic retinopathy?

We experience vision because neurons in the retina direct light that enters our eyes. The retina includes a series of neurons that relay light signals to the brain by allowing the flow of ions across the neuron cell membrane. For the brain to convert these signals into vision, the neurons in the brain and retina require a highly specialised environment.

To maintain this neural environment, a blood-retinal barrier exists in our eyes and a blood-brain barrier exists in our brain. These physiological barriers regulate the flow of small molecules into and out of the retina and brain without disturbing neural signalling. The barriers are formed from blood vessel cells and controlled by tight junction proteins, which either prevent or allow certain

David at work in the lab

substances to pass through. "Tight junction proteins help seal the blood vessel cells together and play a role in controlling which molecules can pass from the blood into the neural environment," explains David.

Diabetes can increase the permeability of the blood-retinal barrier. This means more molecules can pass from the blood into the retina, including substances that should not enter the neural environment, leading to vision loss.

What is David investigating?

During diabetes, the permeability of the blood-retinal barrier is altered by cytokines, small protein molecules that signal cell responses. These cytokines impact the tight junction proteins responsible for maintaining the blood-retinal barrier. David's lab is studying two cytokines that play significant roles in diabetic retinopathy – vascular endothelial growth factor (VEGF) and norrin.

VEGF stimulates the growth of blood vessel cells and causes retinal blood vessels to become leaky, while norrin promotes the organisation of tight junction proteins creating the blood-retinal barrier. "Our lab is studying how VEGF signals blood vessel leakiness and how norrin signals blood vessel tightness," says David.

How does David study cytokine signalling?

To understand cytokine signalling in blood vessel cells, David's team collects animal eyes from the local butcher. "We remove the retinas, isolate the small blood vessels from them, then grow blood vessel cells (called endothelial cells) from these blood vessels," says David. David and his team then add VEGF to these cultured cells to induce leakiness or norrin to promote barriers, allowing them to explore changes in tight junctions in the presence of different cytokines.

By using very high-resolution microscopes, the team can observe whether the tight junctions change location or create gaps that allow substances to pass through the blood-retinal barrier. "We grow the cells on a filter and use fluorescently labelled molecules to trace the rate of flux across the cells," explains David. "This allows us to measure the tightness or leakiness of the cells after different treatments."

Once David has identified the factors that regulate cellular processes, he studies them in more detail using genetically engineered mouse models. "Mice are a better model for the human eye than cultured cells as we can test disease response," he explains. By altering a mouse's genetic code, David creates mice that express or lack specific cytokines or proteins. He then makes the mice diabetic and observes whether their retinal blood vessels leak and how their vision is affected. "We cannot ask the mice to read an eye chart!" David says. "However, we can observe how they respond to a visual cue. For example, if we move a pattern of black and white vertical lines in front of a mouse, it will reflexively follow the pattern. We can assess its vision by making the lines smaller until the mouse no longer sees the pattern."

What has David discovered?

"A major accomplishment in our lab has been identifying phosphorylation of occludin as a key process in diabetic retinopathy," says David. "Occludin is a protein that regulates the tight junction, either making a tight barrier between cells or allowing the blood vessels to leak." Phosphorylation is the addition of a phosphate group (PO_4^{3-}) to a molecule and is a common mechanism of cell signalling. Phosphorylation of occludin acts like a switch, signalling tight junction proteins to move away from the membrane of blood vessel cells and into the cells themselves. This increases the permeability of the blood-retinal barrier, causing leaks.

David and his team discovered this by genetically altering their cultured cells so they contained a mutant version of occludin that could not be phosphorylated. These cells no longer became leaky when responding to VEGF. Next, David introduced the mutant occludin into diabetic mice. "We found that the non-phosphorylated mutant occludin greatly reduced the ability of VEGF to make blood vessels leak," says David. "Importantly, adding this mutant form of occludin to mice preserved the blood-retinal barrier when they had diabetes and completely prevented loss of vision."

This is a significant breakthrough. David's research reveals that maintaining the blood-retinal barrier preserves visual function in diabetes, helping scientists to understand how current therapies blocking VEGF work and highlighting barrier promoting factors, like norrin, as a potential new therapy.

How are David's discoveries relevant to stroke research?

A stroke can occur if a blood clot blocks a blood vessel in the brain, causing a part of the brain to die. David's research into the blood-retinal barrier during diabetic retinopathy has led to unexpected discoveries about the blood-brain barrier during a stroke.

"Having learnt the importance of occludin to the blood-retinal barrier, we collaborated with colleagues to ask whether this same protein and its phosphorylation affected the blood-brain barrier during a stroke," says David. By inducing strokes in mice, David and his colleagues observed that the mice showed signs of occludin phosphorylation in the brain blood vessels surrounding the region of the stroke. They then induced strokes in genetically engineered mice that had mutant occludin. In this case, the team observed that leakage of the brain blood vessels was greatly reduced during a stroke.

"The only current therapy for a stroke is providing an enzyme that breaks up the blood clot. However, if given too late, this enzyme makes the stroke worse by causing severe bleeding in the brain," says David. "Working with stroke experts, we found that blocking occludin phosphorylation can prevent this bleeding." This means drugs that prevent this phosphorylation may now be explored as a means to prevent brain bleeding when treating stroke patients, highlighting the range of important clinical outcomes from David's research.

About *ophthalmology*

Ophthalmology is the study of eyes and vision. Clinical ophthalmologists are medical doctors who specialise in the diagnosis and treatment of eye disorders. They are experts in all aspects of eye care, from how to prevent eye diseases to different treatment options for different eye conditions. In contrast, vision research scientists, like David, conduct scientific research to understand how the eye functions. "Vision research scientists investigate how our eyes allow vision and how vision can be affected by disease," explains David. "These are the scientists who are trying to find new cures to prevent or treat blindness and vision loss."

The excitement of research

"The most rewarding part of my job is working with others and making truly novel discoveries," says David. "There is a great deal of excitement in learning something new about how our cells work." David and his team have made many significant discoveries over the years, from determining that tight junctions are dynamic entities regulated by phosphorylation 'switches' that open and close the blood-retinal barrier, to uncovering the fact that norrin can reverse the effects of diabetes and restore the blood-retinal barrier. "Sometimes, when you are very lucky, these discoveries have a profound effect on the clinical community and can impact patient care or provide novel treatment options."

The importance of collaboration for scientific discoveries

"Discoveries involve interactions with other people," says David. "One person never drives the whole process." For example, while David is a molecular and cell biologist, the success of his lab comes from the team members' range of disciplinary backgrounds, such as vision science and biomedical science, and their collaboration with researchers from other laboratories. "By listening to novel perspectives and valuing all voices, we can reach new ideas that none of us could have achieved individually."

Pathway from school to *ophthalmology*

- At school, study biology, chemistry, physics and mathematics.
- Your university pathway will depend on your ophthalmology direction. To become a clinical ophthalmologist, you will need to complete a medical degree and qualify as a medical doctor, then complete specialised training in the field of ophthalmology. To become a vision research scientist, complete a degree in a subject such as biology, molecular biology, biochemistry, biomedical science or vision science, then specialise in a laboratory focused on vision research in your post-graduate training.
- David recommends taking courses in cell biology to learn how cells signal and interact with each other, and courses in mathematics and computing to learn how to process data. "Modern approaches to science use large and complex datasets," he says. "It is important to understand how to manage these data."
- David recommends reading to discover which aspects of vision you are most passionate about. "Read articles in magazines and newspapers that talk about new research findings," he advises. "Follow scientists on Twitter and read about their work." While academic publications can be very technical, many scientists also write articles for a public audience that will be easier to follow. For example, learn more about diabetic eye diseases with this Futurum article: **www.futurumcareers.com/reaching-out-to-overcome-diabetic-eye-disease-in-the-philippines**
- If possible, try to find work experience in a lab dedicated to research in vision.

Explore careers in *ophthalmology*

- As a clinical ophthalmologist, you will work with patients to diagnose and treat their eye conditions. The American Academy of Ophthalmology has an informative page about the different types of eye care provider (e.g., ophthalmologist, optometrist, optician) and the qualifications needed by each profession: **www.aao.org/eye-health/tips-prevention/what-is-ophthalmologist**
- As a vision research scientist, you will work in a scientific lab to conduct experiments to improve scientific understanding of vision. You could be an academic researcher in a university lab, like David, or an industrial researcher in a company lab. "There are lots of ways to succeed in the field of research, as there are many different ways of conducting research," says David.

Q&A

Meet *David*

Who inspired you to become a scientist?

When I was younger, I was always curious and interested in all aspects of science. My parents were both teachers and encouraged discovery. My mother, particularly, encouraged me to ask questions. In my second year of college, I had a great cell biology teacher, who described the excitement and joy he felt when making a new discovery in research. That lecture confirmed my wish to become a research scientist.

What successes have you had in your career?

I have been lucky to work with outstanding people in my laboratory and have had success obtaining funding and publishing manuscripts that describe our research. Publishing research manuscripts is critical for scientists, as the research is reviewed by other experts in the field, then made available to the broader scientific community if it makes important conclusions. Other researchers build on these published findings, so it is an important step in the research process. The publishing and funding success of my lab has put me in a position to help others in our department work towards a successful scientific career.

You have won numerous awards for research and teaching. What do these recognitions mean to you?

I received the 'Jules Francois prize for young investigator in ophthalmology' from the *Ophthalmologia Belgica* and the 'Most inspirational teacher' award for graduate education at Penn State University. Research can be hard, with many setbacks and great ideas that are proven wrong. In fact, I might say the ability to accept when data clearly reveals that an idea you loved turns out to be wrong, is one of the most important qualities to have as a scientist! Getting recognition along the way is very helpful for seeing the bigger picture.

What is your favourite fact about the eye?

'It's impossible to sneeze with your eyes open.' I don't really know if it is true. But, as a scientist, I love that people will test the hypothesis and try to prove it wrong.

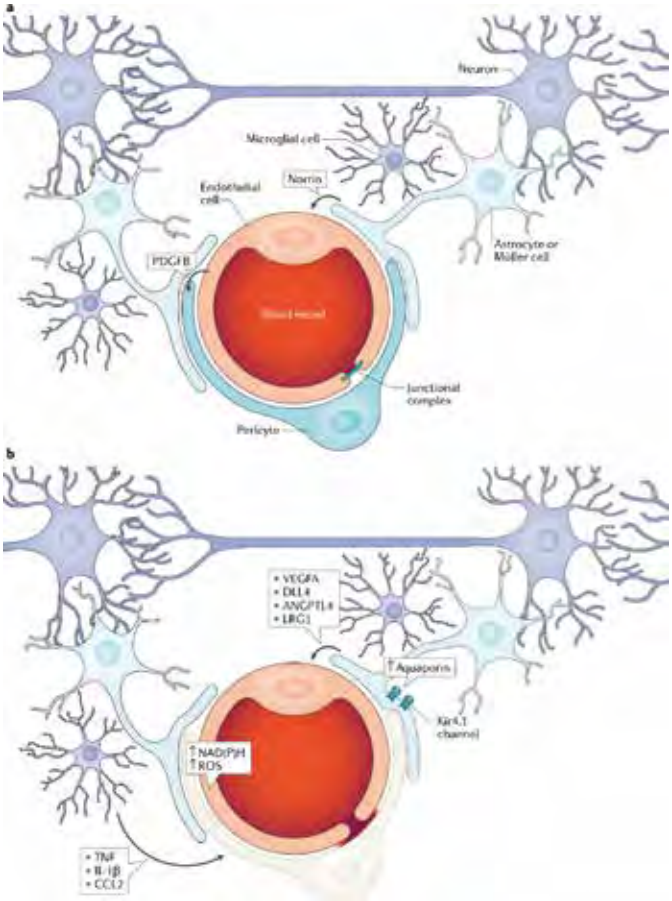
What do you enjoy doing in your free time?

Spending time with my wife, going on walks in nature, playing rock guitar and watching University of Michigan sports.

David's *top tips*

1. Think about your future and what you want to achieve. It takes a plan and commitment to become successful.

2. Follow your passion.



The blood-retinal barrier controls which substances can pass from blood vessels (red) to neurons (blue and purple). In the lower diagram, the tight junction is open and fluid is leaking into the neural environment. © Antonetti et al, 2021. Current understanding of the molecular and cellular pathology of diabetic retinopathy (doi.org/10.1038/s41574-020-00451-4)

Can we create viruses and use them to treat cancer?

Viruses can cause cancer, but they also have the power to cure it. **Dr Fred Bunz** is a molecular oncologist at **Johns Hopkins University School of Medicine** in the US. He has developed a new technique that enables scientists to build adenoviruses in the lab, paving the way for new discoveries in the field of virology and new treatments for cancer patients.

Dr Fred Bunz

Associate Professor of Radiation Oncology and Molecular Radiation Sciences, Johns Hopkins University School of Medicine, USA

PROFILE

Fields of research
Oncology, Virology, Immunology

Research project
Developing a biotechnology platform to create adenoviruses for scientific research

Funders
This work is supported by the US National Institutes of Health (NIH), under award number GM135485, and the Emerson Collective. The contents are solely the responsibility of the author.

TALK LIKE A ...

VIROLOGIST AND ONCOLOGIST

Adenovirus — a virus that typically causes sore throats, respiratory conditions or conjunctivitis

Cultured cells — cells grown under controlled conditions in a lab, commonly used to diagnose infections or test new drugs

DNA (deoxyribonucleic acid) — the double-stranded molecule that carries genetic information in living organisms

DNA recombination — the technique of rearranging genetic material

Gene therapy — a technique that modifies someone's genes to treat or cure diseases

Genome — the complete set of genetic material in an organism

Oncology — the study of tumours and cancer

Replicate — to make an exact copy of something

RNA (ribonucleic acid) — the single-stranded molecule that carries genetic information in some viruses

Virology — the study of viruses

Adenoviruses are a family of viruses that cause a wide range of illnesses. These are mostly mild infections, causing sore throats, respiratory conditions and conjunctivitis, or 'pink eye'. "By adulthood, most people have been exposed to at least one strain of adenovirus and have thereby acquired immunity," says Dr Fred Bunz, an oncologist who studies adenoviruses at the Johns Hopkins University School of Medicine.

Why are adenoviruses useful?

Adenoviruses are a remarkably useful tool for scientists to use in labs, as they are safe to handle and easy to propagate. "They have become workhorses for the biotechnology industry and for biomedical research," says Fred. "Much of what we have learned about basic molecular biology, such as RNA splicing and DNA replication, arose through studies of adenoviruses." While adenoviruses are still used in basic biological research, scientists have also started to use them for gene therapy and vaccine development. For example, adenoviruses were recently in the scientific spotlight as they are used in the COVID-19 vaccines developed pharmaceutical companies Janssen and Oxford-AstraZeneca. These adenoviruses have been engineered to deliver a crucial component of the SARS-COV-2 virus, thereby training the immune system to recognise this dangerous pathogen effectively.

All viruses contain genetic material composed of a type of nucleic acid, either DNA or RNA. "Unlike the viruses that cause influenza and COVID-19, which contain RNA as their genetic material, adenoviruses are based on DNA," says Fred. As early as the 1970s, scientists started finding ways to manipulate large DNA molecules. "Scientists discovered that they could grow adenovirus genomes in bacteria, and then transfer their DNA to cultured human cells to recreate infectious viruses," says Fred. "This was a remarkable accomplishment." In

nature, viruses replicate themselves, but by using this technique of DNA recombination, scientists can bypass the replication stage and create viruses directly from adenovirus DNA in the lab.

How can scientists build adenoviruses?

Fred is taking the process of DNA recombination a step further. Using a technique he first developed in 2018, he has created a recombinant DNA technology platform called AdenoBuilder. "AdenoBuilder allows scientists to assemble adenovirus genomes in modular fashion, from relatively short pieces of synthetic DNA," Fred explains. "These short DNA pieces are essentially 'building blocks' that can be stitched together to create a complete strand of viral DNA." The DNA is assembled in a test tube with the help of commercially available enzymes. Then, the resultant genome is inserted into a protein shell, known as a capsid, and delivered to cultured human cells in a lab.

What are the benefits of AdenoBuilder?

"Older methods of adenovirus engineering involved maintaining the entire adenovirus genome in bacteria," says Fred. However, it is challenging to manipulate large DNA molecules, and many research labs around the world do not have the capabilities to achieve this. As AdenoBuilder assembles the adenovirus genome from small DNA units, they are much easier to handle and so virtually any biology lab can do this. "The assembly is performed in a test tube, so the bacterial step is bypassed entirely," Fred explains.

With AdenoBuilder, each building block of DNA can be individually modified before it is added to the genome. In a single assembly, Fred can create a virus with multiple genetic alterations in different areas of the genome and can quickly generate many different adenoviruses. This was not possible before, as older methods required changes to be made one at a time. "With AdenoBuilder, we can generate new and useful viruses at a rate that would have been unimaginable just a few years ago," Fred adds.

> **"WITH ADENOBUILDER, WE CAN GENERATE NEW AND USEFUL VIRUSES AT A RATE THAT WOULD HAVE BEEN UNIMAGINABLE JUST A FEW YEARS AGO."**

What challenges did Fred face?

"Compared to human DNA, viral DNA contains many repetitive elements and regions that are highly structured," says Fred. Therefore, viral genomes are extremely difficult to work with. The main challenge Fred and his team faced when creating AdenoBuilder was to discover which segments of the adenovirus could be copied and stably maintained in a circular DNA molecule. It was also a challenge for the team to determine the optimal conditions necessary to create a sufficient amount of the full-length DNA from the smaller building blocks.

What is next for AdenoBuilder?

One particularly exciting aspect of AdenoBuilder is its ability to incorporate millions of tiny changes in a large population of virus particles. Fred calls these 'virus libraries'. "Going forward, our plan is to search through these libraries for rare recombinant viruses with new features and capabilities," says Fred. "This discovery process is comparable to someone sifting through silt to find small flecks of gold."

Fred is also excited to use AdenoBuilder to help treat cancers. His primary research interest is not, in fact, virology, but oncology. "However, these two fields are intimately related," he explains. "Oncologists are starting to realise that infecting cancerous tumours with specifically engineered viruses can be an effective form of therapy." Fred hopes his work will not only advance the field of virology but will also lead to new treatments for people with cancer.

"AdenoBuilder allows scientists to assemble adenovirus genomes"
© Cryptographershutterstock.com

About *virology and oncology*

Scientists have recently realised that viruses have the remarkable power to both cause and cure cancer. Some viruses, such as the human papilloma virus (HPV), cause cancer, but scientists can now manipulate unrelated viruses to prevent or kill a variety of cancerous tumours.

"There are remarkable parallels between virology and oncology," says Fred. The immune system fends off both viruses and cancer. While we all regularly encounter viruses, it is only on occasion that they make us sick. "This is because our immune systems are highly efficient at recognising viruses and clearing infected cells before an infection can cause trouble," Fred explains. Only a small number of viruses successfully evade our immune systems, and these are the ones that make us ill.

"In this respect, cancer is very similar," says Fred. It is common for abnormal cells to grow in our bodies, particularly in areas with a high rate of cell turnover, such as our skin and the lining of our gut, but our immune systems are good at monitoring these areas and removing abnormal cells before they spread. Sometimes, however, a group of abnormal cells will go undetected and grow into a tumour, which may become cancerous. Currently, scientists are developing vaccines that can stimulate the immune system to prevent cancers or to suppress their growth.

How can viruses treat cancer?

Cancer cells contain genetic defects that make them particularly fertile places for viruses to grow. "Scientists can exploit this vulnerability," says Fred. One method for this is oncolytic viral therapy, a form of cancer treatment in which cancer cells are infected with an engineered virus. Adenoviruses are well-suited to this task. "In the normal adenovirus life cycle, the virus continues to replicate within the infected cell until the cell literally bursts," Fred explains. Oncolytic viral therapy takes advantage of this process, as the engineered virus will infect the cancer cells and cause them to burst open.

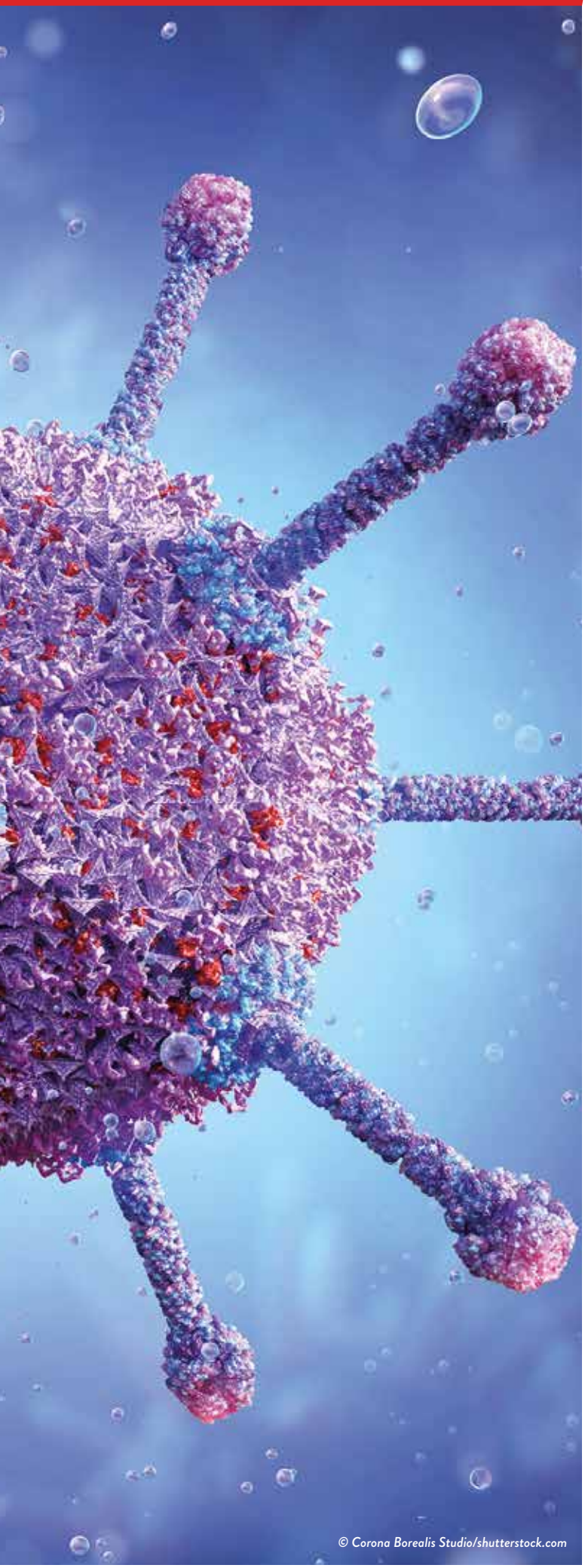
As well as killing the cancer cells, the presence of the virus also jolts the body's immune system into action. "The combination of these two effects, the direct killing of cancer cells and the stimulation of a dormant immune system, can unleash an effective immune response against cancer," says Fred.

Pathway from school to *virology and oncology*

- At school and post-16, science and mathematics will teach you the foundational knowledge needed for further study of virology or oncology.
- At university, undergraduate degrees in biology, biochemistry, molecular biology, biomedical science or medicine could lead to a career in virology or oncology. "I studied biochemistry," says Fred, "but some of the best biomedical scientists I've encountered studied mathematics at university."
- Fred recommends taking courses that challenge you and force you to grow intellectually. "There is no ideal curriculum," he says. "Challenging courses in the humanities are just as important as science subjects. Being a successful scientist requires an ability to think broadly about a great variety of subjects."
- It is important for scientists to communicate their findings with others, both in and outside their specific research field. "You have to know how to write," advises Fred, so take courses in scientific writing and communication.
- Try to get hands-on lab research experience. Johns Hopkins University School of Medicine provides opportunities for high school student to explore biomedical careers: **www.hopkinsmedicine.org/som/pathway/high-school-student-resources**

Explore careers in *virology and oncology*

- Working in virology and/or oncology will lead to an extremely rewarding career. You could conduct research at a university or for a biotechnology company, work with patients in a hospital or advise the government in a public health role. The COVID-19 pandemic highlighted the importance of these roles for developing vaccines, monitoring viral outbreaks, studying viruses and developing the policies to protect communities.
- The Royal College of Pathologists provides information about what virologists do: **www.rcpath.org/discover-pathology/careers-in-pathology/careers-in-medicine/become-a-virologist.html**
- The Royal College of Radiologists features interviews with experienced and trainee clinical oncologists: **www.rcr.ac.uk/clinical-oncology/careers-and-recruitment/thinking-about-career-clinical-oncology/what-it-really-be**



© Corona Borealis Studio/shutterstock.com

Q&A

Meet *Fred*

Have you always been interested in medicine?

Growing up during NASA's Apollo era, I was fascinated by space travel and immersed myself in science fiction. I couldn't imagine a more interesting career than that of a scientist – I still can't! My interests in biology and medicine emerged later, when I was able to appreciate the impact of these fields on the lives of ordinary people.

What inspired you to study adenoviruses?

I first learnt about adenoviruses as a medical student, and I've always found them fascinating. We've known about them for decades, but they are still giving up their secrets. They have taught us so much about how human cells function. I could never have imagined that they would one day be used for cancer therapy.

> **"IT IS EXCITING WHEN SOMETHING WORKS, OR EVEN BETTER, WHEN A SUCCESSFUL PROJECT TAKES YOU IN AN UNANTICIPATED DIRECTION."**

What do you most enjoy about your work?

There are many aspects of my work that give me great satisfaction. I enjoy the freedom I have to pursue new ideas, and I greatly enjoy the process of developing a project that addresses an important question. Most projects fail, of course. But it is exciting when something works, or even better, when a successful project takes you in an unanticipated direction. At the end of the day, it feels good to be part of a greater enterprise that's dedicated to improving the outlook for cancer patients.

What do you enjoy doing in your free time?

Science is not only my career, but also my hobby, and I enjoy reading about science in my free time. As I work in an office and lab environment, I try to get outdoors whenever I can, ideally with my family.

Fred's *top tips*

1. Don't be afraid to try hard things.

2. Don't be afraid to fail. Failure lays the groundwork for success in the long run.

Investigating immunity: uncovering the mechanisms of the immune system

Our immune systems work around the clock to keep us safe from disease. Whenever we become infected with a virus or bacteria, our immune systems jump into action – locating, identifying and destroying the infectious agent. This complex process involves a whole host of different cells, each with their own specific function. At the **University of Colorado Anschutz School of Medicine** in the US, **Professor Leslie Berg** and **Assistant Professor Aimee Pugh Bernard** are gaining a deeper understanding of how our immune cells function.

Professor Leslie J. Berg

Assistant Professor Aimee Pugh Bernard

Department of Immunology and Microbiology,
Anschutz School of Medicine,
University of Colorado, USA

PROFILE

Field of research
Immunology

Research project
Investigating a signalling pathway in T cells that amplifies their immune response

Funder
This work is supported by the US National Institute of Allergy and Infectious Diseases (NIAID), US National Institutes of Health (NIH) and by the Department of Immunology and Microbiology and the Dean at the University of Colorado-Anschutz School of Medicine

TALK LIKE AN ... IMMUNOLOGIST

Antibody — a protein produced by the immune system that binds to antigens and aids in their destruction

Antigen — any compound in the body that triggers an immune response

Autoimmune disease — a disease in which a person's immune system attacks their own cells

Enzyme — a protein that speeds up chemical reactions in an organism

Immune system — the body's defence against infection. The **innate immune system** fights any pathogens while the **adaptive immune system** targets specific pathogens

Immunodeficiency — when the immune system's ability to fight infections is greatly reduced or entirely absent

Kinase — an enzyme that modifies proteins by adding phosphate (PO_4^{3-}) to them

Pathogen — a microbial agent such as a virus, bacterium or parasite that causes disease

T cell — a type of white blood cell that targets specific antigens and aids in their destruction

T cell receptor (TCR) — a protein on the surface of a T cell that recognises antigens

If you have ever had the flu, you will know how draining it can be - you probably lay in bed with a runny nose and sore throat, staring blankly at the ceiling and feeling sorry for yourself. How is it that just lying in bed and not moving can be so exhausting?

Well, feeling tired is actually a sign that your body is working very hard to make you better. Being ill can be tiring because your immune system is working overtime to fight off the infection.

What is the immune system?

Your immune system is the natural defence mechanism that protects your body from infectious agents, such as viruses. In the same way that our emergency services contain different departments, such as police, paramedics and fire fighters, our immune systems contain many types of cells, each with a unique function.

After being produced in your bone marrow, white blood cells move through your bloodstream and tissues looking for antigens. Each type of white blood cell has a specific role to play in the immune response. Neutrophils, for example, are the first responders that send out signals calling other immune cells to the infection. Monocytes, on the other hand, are the clean-up crew that get rid of dead cells in your body.

Neutrophils and monocytes form part of the innate immune system, which targets any foreign substances in the body. In contrast, as part of the adaptive immune system, lymphocytes can identify specific antigens and produce a more targeted response. Some lymphocytes even 'remember' the antigens they encounter, producing a faster immune response if the infection returns.

Lab member Jennifer Berger discusses her experimental plan with Leslie © Brooke Lydick

B cells (which produce antibodies that help destroy antigens) and T cells (which can directly destroy antigens) are types of lymphocytes. The processes by which these cells recognise antigens is complex, and gaining a deeper understanding of them could have significant implications for the treatment of autoimmune and immunodeficiency diseases. At the University of Colorado Anschutz School of Medicine, Professor Leslie Berg and Assistant Professor Aimee Pugh Bernard are studying T cell receptor signalling pathways to better understand this aspect of the immune system.

What are T cell receptors?

"T cell receptors (TCRs) are proteins on the surface of T cells that recognise infectious agents such as viruses, bacteria or fungi," explains Leslie. "Each T cell has tens of thousands of identical TCRs on its surface and can only recognise a single type of pathogen." However, our bodies have billions of T cells, and, collectively, these cells enable our immune system to recognise almost any pathogen that might infect us. Each T cell in our body is uniquely specific, but together, all the billions of T cells combined provide tremendous diversity.

When a TCR recognises a pathogen, it initiates a signalling pathway inside the T cell that instructs the cell to destroy the pathogen. The first step in this pathway is the activation of enzymes known as kinases, which activate other protein molecules by adding phosphate (PO_4^{3-}) to them. Leslie and Aimee are studying a kinase known as ITK, one of the first kinases activated during the TCR signalling pathway and which plays an important role in amplifying the immune response of T cells.

What happens if someone cannot produce ITK?

Some children suffer from genetically inherited immunodeficiency diseases that affect their ability to produce ITK. If someone cannot produce ITK, or if their ITK does not work properly, their T cells are unable to produce a proper immune response, leaving the person vulnerable to infections. Leslie and Aimee hope that their research on the role of ITK in the immune system will help provide treatments for these kinds of diseases.

How are Leslie and Aimee studying ITK?

"We use genetically modified mice, such as mice whose T cells do not express any ITK protein," explains Aimee. She and Leslie study the T cells in these mice at a molecular level to determine exactly which immune responses do not work when ITK is missing. "For instance," continues Aimee, "when we stimulate the TCRs in ITK-deficient mice, we see that these T cells make lower levels of several proteins needed to fight infections."

Another method involves exposing ITK-deficient mice to pathogens and examining their immune response. In one study, Leslie and Aimee noticed these mice were unable to fight a particular viral infection because the T cells without ITK were unable to move into the gut, where the virus was located. From this, they discovered that ITK signalling is important for helping T cells move into different tissues in the body.

What else have Leslie and Aimee discovered?

Leslie and Aimee have also gained a deeper understanding of the biochemical processes of ITK signalling. They discovered that a key role of ITK is to activate an enzyme known as phospholipase-C, causing it to produce signal molecules that bind to other enzymes in the T cell. These enzymes then stimulate cell division, causing the T cells to multiply and so generating more cells to fight off the infection. "When ITK is missing, this entire pathway is greatly weakened, leading to a diminished response that often fails to eradicate the infection," explains Leslie.

What are the practical implications of this research?

Leslie and Aimee hope their research into ITK's function in T cell signalling pathways will lead to the development of new methods for regulating ITK that could be used to treat immunodeficiency, autoimmune diseases and cancer. "Our research findings are relevant to a number of human diseases," says Aimee. For example, in some autoimmune diseases, T cells mistake native cells for antigens and start destroying them. "In these individuals, an inhibitor of ITK may be beneficial as a treatment for their disease."

> **"THE MORE WE LEARN ABOUT HOW T CELL SIGNALLING PATHWAYS REGULATE DISTINCT T CELL FUNCTIONS, THE MORE WE CAN APPLY THIS KNOWLEDGE TO IMPROVING T CELL ENGINEERING"**

T cells are also used in therapies to treat cancer as it is possible to engineer T cells to recognise and kill cancerous cells in a tumour. "These therapies hold great promise, but fall short of curing many patients," says Leslie. "The more we learn about how T cell signalling pathways regulate distinct T cell functions, the more we can apply this knowledge to improving T cell engineering."

The signalling pathways triggered by TCRs are important in determining whether T cells generate a long-term 'memory' of a particular antigen. As vaccines rely on this aspect of the immune response, Leslie and Aimee's research may also inform the development of new vaccines.

"The truth is that we still have much to learn about T cell signalling!" says Leslie. "We have a lot to learn about how these signalling pathways determine the ability of T cells to move in the body, find sites of infection, and then do the best job to eliminate pathogens."

About *immunology*

Immunology is the study of the immune system, which protects us from diseases. Our immune systems are highly complex and sophisticated, and they fight off diseases in many different ways. Understanding how our immune systems function is an essential step for treating many diseases.

Some immunologists study how the immune system protects us, while others investigate what happens when it stops working properly. For example, if someone is suffering from an autoimmune disease, their immune system will begin attacking and destroying their own cells. On the other hand, if someone suffers from immunodeficiency, their immune system is unable to fight off infections, leaving them vulnerable to many diseases.

What challenges will future immunologists face?

While immunologists now know a lot about the different types of immune cells, such as T cells and B cells, and how these produce the molecules needed for immune responses, we still do not fully understand how all parts of the immune system interact and affect each other. "The challenges for immunologists in the future will be to understand how all these cells and molecules work together to maintain a healthy immune system," says Leslie.

Another challenge is effectively communicating the importance of immunology to the public. "For the public to understand what immunologists do, and how important this work is to the world around us, we need to communicate in ways that everyone can understand," says Aimee, who is passionate about science communication. For example, during the COVID-19 pandemic, immunologists explained the importance of vaccines by comparing them to seat belts. "While a vaccine may not prevent a 'crash' (i.e., an infection), it is a safety tool that prevents serious harm and death," says Aimee.

Pathway from school to *immunology*

- "Use your curiosity as the fuel to propel you into a career in science!" says Aimee. "Asking questions is the key skill of a scientist." She recommends exploring online resources such as the Science Journal for Kids and Teens (**www.sciencejournalforkids.org**) and Science Buddies (**www.sciencebuddies.org**).
- Contact local universities to see whether they offer lab experience opportunities. For example, the University of Colorado Anschutz School of Medicine runs summer outreach programmes that allow high school students to participate in hands-on science activities: **www.colorado.edu/sciencediscovery**
- An understanding of biology is crucial for pursuing a career in immunology, so take any available courses in cell biology, molecular biology, biochemistry and physiology. "Virology would also be useful as it's important to understand the pathogens that cause infections to better appreciate how the immune system deals with them," says Leslie.
- "Take philosophy classes, too," recommends Aimee. "You will study the nature of knowledge and reality, and expand and diversify your thinking and approach to problem solving."

Explore careers in *immunology*

- As an immunologist, you could pursue an academic career, conducting scientific research to uncover more knowledge about the immune system, or you could pursue a clinical career, working with patients in hospital to treat problems with their immune systems.
- A day in the life of an immunologist is never boring! You might be reading research papers, planning or conducting experiments, analysing and interpreting data, or discussing your results and conclusions with colleagues.
- Many immunologists also educate the next generation of scientists. Teaching students and leading outreach activities are great ways to impart knowledge and help your community.
- The American Association of Immunologists has a wealth of educational resources and information about careers in immunology: **www.aai.org/Education**

Meet *Leslie*

My inspiration to become a scientist came from a college professor who ran a small seminar course I took in my final year. In this course, we read and discussed research articles. It took me hours and hours to read each paper, as I had to work hard to understand what I was reading. But the in-class discussions made it all worthwhile, as I realised that scientists did not just say 'I did this, and that happened', but 'When I did this and that happened, I understood the way things worked and could use my results to convince everyone else of my conclusions'. I realised there was a lot of brain power involved – reasoning, puzzle solving, critical thinking, and so on. How could I possibly turn down a career doing that every day?

My career path was also strongly influenced by my graduate school thesis advisor. His energy, excitement and enthusiasm for science and new discoveries were irresistible. When working on my PhD, I learnt that research involves a lot of failure. It requires a lot of determination and resilience to keep at it until you succeed.

My advisor also taught me the very important lesson that is it ok to be wrong! It can be deflating when you realise your ideas were wrong, but this can lead to new and better hypotheses. Don't stick to a hypothesis that isn't supported by your results. Instead, 'listen' to your data and be flexible with your ideas.

My favourite fact about the immune system is that vaccines prevent infections and diseases before people have a chance to get sick. This is much better than waiting for someone to become ill and then treating their disease to make them better.

When I'm not working, I enjoy hiking in the mountains. The scenery is breath-taking and there's usually a beautiful view or amazing alpine lake at the end of the trail. Since I'm not a fan of really cold weather, winter months find me knitting warm and cuddly scarves!

Leslie's *top tip*

Indulge your curiosity. A successful scientist has a driving curiosity about how things work. If you have that curiosity, and a willingness to work hard, you should consider a career as a scientist!

Meet *Aimee*

I am insatiably curious and love asking questions and learning new things, so a career in science seemed like a perfect fit. I took my first immunology course in college and instantly fell in love with the subject. Immunology is incredibly complex, and there is still so much we don't know, meaning I never get bored or stop asking questions.

As a graduate student, I developed an interest in teaching. I found I enjoyed guiding other people into the charted (and unchartered) territories of the immune system. Helping others understand the concepts and complexities of the immune system sparked a passion for teaching. My students tell me that my enthusiasm for immunology is 'infectious' – pun intended!

> ***I LIKE TO COMPARE OUR IMMUNE CELLS TO NINJAS – THEY USE THE VACCINE TO TRAIN AGAINST THE ENEMY AND LEARN HOW TO FIGHT IT.***

I enjoy taking complicated science and breaking it down into easy-to-understand language. I want to make immunology understandable to everyone I meet, and so will find a way to insert the topic into any conversation! I love talking to the public about the immune system and am passionate about community outreach to encourage people to get vaccinated.

Most people don't understand that vaccines are harmless forms of pathogens that train our immune system to defend us from the serious harm that can be caused by infectious diseases. I like to compare our immune cells to ninjas – they use the vaccine to train against the enemy and learn how to fight it, so that when they encounter the infectious pathogen in the real-world, they are ready to fight, defend and destroy it.

In my free time, I love to hang out with my family – humans and dogs. My children and I have trained together in the martial art of Tae Kwon Do for the last 10 years. My husband is a professional spectator and feels very well protected whenever the four of us are together out in public!

Aimee's *top tip*

Build your career on something you're passionate about. It is important to truly enjoy and appreciate the work you do.

Dental discoveries: how is dental research improving oral health?

Many people do not enjoy going to the dentist, but regular dental check-ups are a key aspect of healthcare. Maintaining good oral hygiene is important not only for your teeth, but also for your body and mind. Dental scientists at the **Iowa Institute of Oral Health Research** at the **University of Iowa**, USA, are studying various aspects of oral health and healthcare, to improve dental practices and keep our teeth and mouths healthy.

Iowa Institute for Oral Health Research

College of Dentistry and Dental Clinics, University of Iowa, USA

Research projects
Improving oral health and healthcare by investigating factors that cause dental disease

TALK LIKE A ...

DENTAL SCIENTIST

Caries — a hole in a tooth, also known as a cavity

Cleft — a gap or split in the upper lip or palate

Dentures — false teeth that can be removed

Genome — the complete set of genetic material in an organism

Immune system — the network of organs, cells and proteins that protect the body from infection

Implants — false teeth that are permanently fixed in the mouth during surgery

Inflammation — an immune response that can cause swelling, redness and pain

Oral — relating to the mouth

Palate — the roof of the mouth

Periodontal — relating to the periodontium, the tissues that surround and support the teeth. The periodontium includes the gums, alveolar bones (which contain the tooth sockets) and ligaments between them

Periodontitis — a severe form of gum disease

Sitting awkwardly in the waiting room, you leaf through an old magazine, trying to distract yourself from the butterflies whizzing around in your stomach. In the corner, a heap of battered children's toys lies unused. On the wall, posters grin down at you with gnashing teeth asking, 'Did you remember to floss this morning?'

Your name is called. You steel yourself, walk into the treatment room and hoist yourself up into the dentist's chair. As the electric motors whir into life, you are tipped backwards, and a blinding light is swung down into your face. "Say 'ah'," coaxes the dentist, snapping on their rubbery latex gloves as they get ready to poke around in your mouth.

Not many people like going to the dentist. In fact, according to some surveys, 80% of Americans get anxious about visiting the dentist. It can be an uncomfortable and invasive experience, particularly if you need more than a routine check-up. Dentistry, however, is incredibly important.

The importance of oral health

A high-sugar diet can lead to tooth decay, so brushing your teeth regularly is essential. Good oral hygiene is vital for protecting your gums as well as your teeth. The World Health Organization (WHO) estimates that, each year, more than a billion people around the world are affected by periodontitis, a severe form of gum disease. Swollen, inflamed and bleeding gums are all signs of periodontitis, which, if left untreated, can lead to tooth loss.

The health of your mouth is closely linked to the health of the rest of your body. Conditions such as heart disease and diabetes have been associated with poor oral health. For example, patients with periodontitis have a higher risk of developing diabetes, while patients with uncontrolled diabetes have a higher risk of developing periodontitis. In both cases, good oral hygiene can lower these risks.

The condition of our teeth and mouth not only impacts our physical health, but also has a significant influence on our mental health. Sparkly white teeth and fresh breath can make us feel confident and happy with our self-image, contributing to

an overall sense of well-being. If we do not look after our teeth, the resulting physical discomfort and negative self-image can make us miserable.

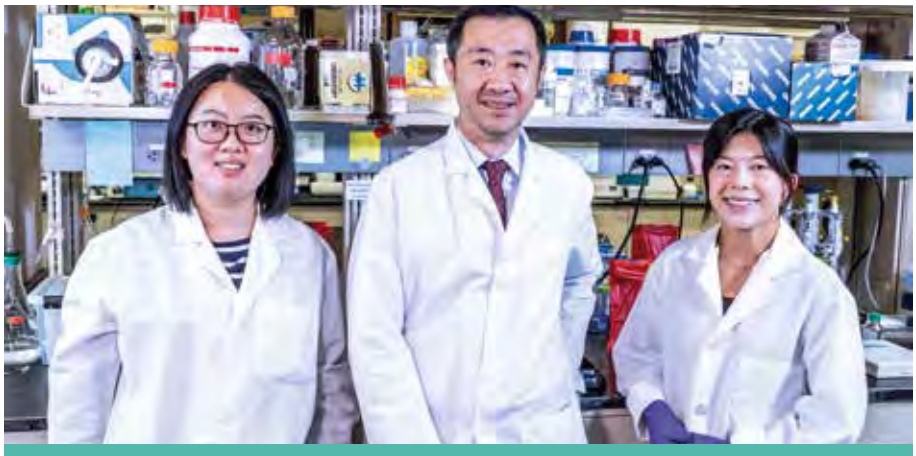
So, however you feel about going to the dentist, it is vitally important that you take care of your teeth and mouth. Brushing, flossing and regular dental check-ups can ensure that your teeth, gums, body and mind stay happy and healthy.

The Iowa Institute for Oral Health Research

"Oral health plays a prominent role in fostering overall physical health and a positive self-image," says Dr Jeff Banas, director of the Iowa Institute for Oral Health Research (IIOHR) at the University of Iowa's College of Dentistry and Dental Clinics. "The 30-40 faculty, postdoctoral and student researchers in the IIOHR undertake cutting-edge research that comprehensively investigates oral health and disease." These dental scientists are investigating a range of topics relating to the teeth and mouth, from uncovering the genes that lead to dental abnormalities, to examining the public policies that influence the inequalities in dental treatment. Their shared goal is to increase our understanding of oral health, prevent oral disease and improve dental healthcare.

How do bacteria cause periodontitis?

Dr Shaoping Zhang is researching how interactions between oral microbes and the immune system lead to periodontitis. Our mouths are full of bacteria and, collectively, these microbes form our oral microbiome. Each microbe has a role to play, such as breaking down sugars or preventing harmful bacteria from causing tooth decay. However, the oral microbiome is delicately balanced with the immune system and, if this balance is disrupted, it can lead to periodontitis. For example, a high-sugar diet will cause an increase in the bacteria that break down sugars. Not only can this lead to tooth decay and caries (cavities), as the bacteria convert sugar into acid, but it can also cause gum disease. Immune cells in the gums trigger inflammation to keep the oral bacteria in check, but the disturbance of microbial communities below the gums leads to an imbalance in the immune system. This either results in too much inflammation or too many bacteria, both of which damage the gums and cause periodontitis.



In his lab, Shaoping (centre) and his team are investigating how oral bacteria can cause periodontitis

Shaoping is using gingival crevicular fluid (GCF), the liquid found in the gap between a tooth and the gum, to study immune responses to oral bacteria. Proteins in GCF, called inflammatory mediators, trigger inflammation in the gums to fight bacteria. By measuring the level of GCF inflammatory mediators in humans and assessing the expression of these inflammatory genes in mice, Shaoping can learn how the immune system responds to bacteria. He also modifies the genes of these mice to investigate which genes influence periodontal disease.

"Our research has found that the protein interleukin-17 (IL-17) plays a critical role in maintaining periodontal health," says Shaoping. By studying GCF samples from humans and mouse gum tissue, he discovered that variations in a specific gene associated with the IL-17 pathway results in a weaker defence against periodontal pathogens, a higher concentration of periodontal bacteria and more severe periodontitis.

How else can our genes affect our oral health?

Genetic mutations can lead to health problems. For example, cleft lip and cleft palate are birth defects that form as a baby develops in the womb. They occur when alterations in the baby's genome cause the upper lip or palate (the roof of the mouth) to not form properly, leaving a hole or 'cleft'. Professor Azeez Butali hopes to uncover the genetic causes of cleft lip and palate. This could lead to new treatments for the conditions and methods to prevent clefts from forming.

© 4 PM production/shutterstock.com

Azeez uses genetic techniques, such as whole genome sequencing (to study an organism's entire genome) and targeted genetic sequencing (to study specific genetic mutations), in animals and cells to explore which genes are associated with cleft lip and palate. So far, he has discovered three genes that, if mutated, are responsible for causing cleft palate. In the course of this research, Azeez's team has also discovered another gene that results in dental anomalies, including microdontia (when teeth are smaller than normal) and taurodontism (when the body of a tooth is enlarged at the expense of the tooth's roots).

How can statistics improve dental health?

Many scientific techniques, such as the genetic sequencing Azeez uses, produce vast amounts of data. To make sense of these data, researchers turn to bioinformatics, the scientific field that uses computers and computational techniques to analyse large and complex biological datasets. "The goal of bioinformatics is to gain a better understanding of biological processes and systems, which can be used to develop new methods and technologies that can improve our ability to diagnose, treat and prevent diseases," explains Dr Erliang Zeng, a data scientist who uses bioinformatics to study various aspects of dental disease.

Erliang analyses data related to oral health conditions, such as periodontitis, oral cancer and cleft lip and palate. He uses computational techniques to identify statistical patterns in the data that can shed light on the underlying mechanisms that contribute to the condition. Erliang also uses artificial intelligence (AI) techniques to detect patterns in large and complex datasets that might not be apparent using traditional statistical methods alone, for example by identifying correlations between genetic databases and patients' health records.

As many dental scientists produce large datasets in their research, Erliang collaborates with many of the research teams in the IIOHR to help them analyse their data. For example, he applied bioinformatics techniques to help Azeez identify the genetic variants that cause cleft palate and to help Shaoping identify bacterial colonisation patterns associated with periodontal disease. "These discoveries are significant as they can inform the development of new treatments that target the mechanisms underlying oral diseases, ultimately leading to better oral health outcomes for patients," says Erliang.

> **"HOWEVER YOU FEEL ABOUT VISITING THE DENTIST, REMEMBER THAT REGULAR DENTAL CHECK-UPS ARE A KEY COMPONENT OF ORAL HEALTHCARE"**

How does our behaviour influence our teeth?

Caries, or cavities, are one of the world's most common health problems. Caries are holes that form when a tooth is dissolved by the acid produced when bacteria break down sugars. They are commonly caused by a high-sugar diet and inadequate brushing of teeth. Early childhood caries (ECC) particularly impact children from low-income and minority families, which has motivated Professor Karin Weber-Gasparoni to investigate whether behavioural, psychological and educational interventions can prevent this painful disease.

Karin is investigating whether the psychological concept of self-determination theory (SDT) can reduce the risk of children developing ECC. SDT states that a person's motivation is influenced by their autonomy (sense of ownership) over, competence (sense of achievement) in and relatedness (sense of connection) with their actions. Motivation occurs when someone experiences satisfaction in these three psychological needs.

"The early onset of ECC means that oral health behavioural interventions must be initiated before the child is born," explains Karin. "This will allow future parents to develop good oral health habits in their baby from birth, rather than trying to change established unhealthy habits later." Karin is investigating the effectiveness of SDT for preventing ECC by providing low-income pregnant women with SDT-based oral health education, then monitoring the oral health of their children until they are three years old. Her preliminary results indicate this is a successful way to initiate good oral health behaviours, as families reported increased brushing of children's teeth, reduced consumption of sugary drinks and snacks, and checking for early signs of EEC at home.

What happens when teeth are lost?

Unfortunately, some people have oral diseases that are not treated in time. In these cases, the patient may lose some (or all) of their teeth. When this happens, replacing the lost teeth is crucial for maintaining the patient's physical and mental health. Lost teeth are replaced by 'false teeth', either as removeable dentures or permanent implants, and Dr Chris Barwacz is evaluating different tooth replacement methods.

Implants have been a viable tooth replacement strategy since the 1980s. "Since then, scientific knowledge, biomaterials and digital technologies have progressed significantly," says Chris. As a result, fitting dental implants is now a standard procedure that is relatively quick to perform. The quality of implants and dentures has also improved in recent years, so they now look and feel better for the patient. Despite these improvements, research is ongoing, not only to improve the implants and dentures themselves, but also to optimise the manufacturing process and implant surgical procedures, and to investigate the periodontal biomaterials that implants are placed in.

Chris conducts clinical research studies to evaluate the outcomes of different implant strategies. These involve monitoring patients who have received different types of implant to assess how they respond. In one study, for example, he analysed levels of gum inflammation following implant surgery by recording clinical measurements (e.g., assessing whether the gums were bleeding), biochemical measurements (e.g., measuring protein expression in the gums) and patient-reported outcomes. In another study, Chris discovered that the way in which the false tooth connects to the implant post has an important influence on the bone that the implant is drilled into. This information is important for manufacturers, so they can optimise their implant designs.

How can you look after your teeth?

Although tooth replacement strategies have advanced significantly in recent years, dentists and dental scientists still focus their efforts on preventing tooth loss in the first place through a combination of providing dental healthcare, conducting oral health research and promoting oral hygiene education. While you cannot control some factors, such as your genetics, that influence your risk of developing dental disease, you can practise good behaviours to keep your teeth and mouth healthy. Brush your teeth twice a day, do not consume too many sugary foods and drinks and, however you feel about visiting the dentist, remember that regular dental check-ups are a key component of oral healthcare.

Pathway from school to *dentistry and dental science*

- At school, study biology, chemistry and mathematics, as these are likely to be requirements for dentistry courses at university.
- If you are interested in bioinformatics and using data science to improve dental health, Erliang also recommends studying statistics, computer science and learning programming languages such as R and Python.
- While it can be hard to gain clinical work experience as a high school student, look for job shadowing opportunities in dental environments. For example, contact your dental practice to see if you could shadow a dentist, technician or receptionist.
- Your pathway to a career in dentistry will depend on where you study and practise, as different countries have different professional requirements. In the US, for example, you will need to complete an undergraduate degree (ideally in a biology- or health-related field) and then study dentistry at postgraduate dental school. In other countries, universities may offer undergraduate degrees in dentistry.
- To become a dental scientist conducting academic research, study a biology- or health-related undergraduate degree (such as molecular biology, biochemistry, genetics or public health), then complete a PhD that applies your field of interest to oral health.
- As a dentistry student at the College of Dentistry and Dental Clinics (**www.dentistry.uiowa.edu/education**) at the University of Iowa, you will practise what you learn in class by treating patients in the College's onsite dental clinics.
- The College also offers opportunities for students to experience what dental school and dentistry involve (**www.dentistry.uiowa.edu/education/pre-dental-opportunities**) and researchers host high school students in their labs.

Explore careers in *dentistry and dental science*

- Clinical dentists work with patients in dental clinics, conducting check-ups and performing routine procedures such as cleaning teeth and putting in fillings. As a dentist, you could specialise in fields such as orthodontics (straightening teeth with braces), dental surgery (performing more complex operations on the mouth and jaw, such as fitting implants) or periodontics (treating gum conditions).
- The American Dental Association (**www.ada.org/resources/careers**) and its Mouth Healthy campaign (**www.mouthhealthy.org/resources**) provide information about different careers in dentistry.
- Dental scientists improve our understanding of oral health by conducting academic research into any topics related to teeth and the mouth. As a dental scientist, you could discover the causes of oral diseases and help develop new treatments for tooth conditions, or study the anatomy of the mouth and the biological processes behind tooth development.
- Chris, Karin and Shaoping work in dual roles as both dentists and dental researchers, dividing their time between treating patients' teeth in their clinics and conducting research to advance understanding of dental conditions.

Meet *the team*

Professor Azeez Butali

Professor of Oral Pathology, Radiology and Medicine

Fields of research: Oral Pathology, Genetics

Research project: Searching for genes related to cleft lip and palate

Funder: US National Institutes of Health (NIH)

I have always been interested in science, which led to me becoming a laboratory prefect in high school. I also enjoyed reading, especially thriller fiction novels and newspapers, and I developed a strong interest in economics.

My late father inspired me to study dentistry and supported me through dental school at the University of Lagos, Nigeria. In my 4th year of dental school, I gave a presentation about guide planes (surfaces where partial dentures are inserted), and my professor applauded my work. She encouraged me to pursue an academic career in dental research.

During an internship, I worked with a patient who had a cleft lip, and this experience motivated me to research cleft lip and palate. Serendipitously, I came across a call for applicants to research the maternal factors that contribute to cleft lip and palate at the World Health Organization (WHO) Collaborating Centre for Craniofacial Anomalies at the University of Dundee, Scotland, and there I gained a PhD in genetic epidemiology.

My personal experience as the father of a child with a genetic disease, who was healed by a bone marrow transplant, is shaping my career as a researcher in the field of genetics. I enjoy being able to inspire the next generation of scholars and contribute my research towards the prevention of cleft lip and palate.

My favourite fact about dentistry is that the mouth is the gateway to the body. It can be used to discover other diseases, as many health conditions are related to oral health.

In my free time, I love reading autobiographies, writing, watching movies and travelling.

Azeez's *top tips*

1. Trust your journey and aspire to be the best dental scientist you can be.
2. Focus on learning the clinical skills of dentistry as well as the theoretical science.
3. Be open to learning and mentoring.

© 4 PM production/shutterstock.com

Dr Chris Barwacz

Associate Professor of Family Dentistry, Chair of the Department of Family Dentistry, Clinical Dentist

Field of research: Oral Implantology

Research project: Evaluating the effectiveness of different dental implants

Funder: Dentsply Sirona

I enjoyed biology at school, as it was an extension of my interest in nature. I was fascinated by how molecular processes can have such profound impacts on organisms, from photosynthesis and mitochondrial respiration to muscle contraction.

I identified dentistry as a career by process of elimination, by determining which health-science careers I did not want to pursue. Before going to dental school at the University of Iowa, I worked in a molecular biology lab and as a technician in a hospital pharmacy. While I enjoyed these jobs, I wanted to have more impact on and interactions with people. My wife suggested I explore dentistry, as it combined working with my hands and close patient relationships.

My seven years of working as a research assistant in a molecular biology lab was a rewarding experience which taught me about the scientific method, experimental design, and the rigours of presenting and publishing research. Completing an implant fellowship exposed me to an academic environment and gave me the opportunity to conduct clinical and translational research.

As a clinical dentist, I love that I can make a positive and durable difference to my patients' lives. As the chair of the Department of Family Dentistry, I enjoy building and supporting a positive team environment to facilitate the growth of our staff and sustaining a world-class educational curriculum for our dental students.

My favourite fact about dentistry is that the alveolar bone (which contains the tooth sockets) belongs to the teeth, not the person. When a tooth is lost, the alveolar bone next to that tooth will disappear due to atrophy and resorption. We tend to think of bones as static, but, due to a biological connection between the tooth and bone, the alveolar bone is dynamic and depends on teeth for its maintenance.

Chris' *top tips*

1. Look for work shadowing opportunities in careers that interest you, as gaining practical experience is the best way to know if the career is right for you.
2. Don't be disheartened if you don't enjoy a career that you thought you would like. Finding what wasn't right for me was just as valuable as discovering what I did enjoy, as it helped me make decisions about what I wanted from my career.
3. Remain open to other experiences not directly related to your ideal career. These will still provide rich experiences for you.

Dr Erliang Zeng

Associate Professor of Preventive and Community Dentistry, Division of Biostatistics and Computational Biology

Fields of research: Bioinformatics, Data Science

Research project: Investigating dental health and disease through bioinformatics

Funders: NIH, US National Science Foundation (NSF), US Department of Agriculture (USDA)

When I was younger, I was fascinated by the diversity of life on Earth, from the tiniest ants to the largest mammals. I enjoyed learning about how organisms interact with each other and are adapted to their environments.

My school biology teacher inspired me with her enthusiasm and extensive knowledge of the subject. Her passion for biology ignited a curiosity in me to learn more about the natural world and its intricate mechanisms. As I progressed through my educational journey, my interest in biology focused on human health and disease. I was fascinated by the underlying mechanisms of illnesses and intrigued by the potential to treat or prevent them through medical research.

After obtaining my master's degree in biochemistry and molecular biology at Shanghai Jiao Tong University, China, I worked for a microarray data analysis company, where I worked with large-scale genomic datasets and applied computational methods to analyse them. This was a transformative experience that deepened my understanding of the complex biological mechanisms underlying human health and disease and sparked my interest in the field of bioinformatics.

As a bioinformatician and data scientist, I am grateful to have the opportunity to work on challenging problems and use my skills to make a difference in the world. I enjoy the process of finding patterns and relationships in large and complex datasets. And, by providing insights that may inform the development of new treatments, my research has the potential to make a real-world impact on patients. The blend of intellectual challenge, technical skill and social impact that comes with being a bioinformatician is deeply fulfilling.

In my free time, I love pursuing my passion for gardening and growing orchids. I enjoy working with soil and plants, and I find it satisfying to cultivate and harvest my own fruits and vegetables. Gardening provides an opportunity to connect with nature and spend time outdoors, which is a welcome respite from the demands of my work as a researcher.

Erliang's *top tips*

1. Seek out research experience. Working on research projects is one of the best ways to gain practical experience, so look for opportunities to participate in research internships or work with research labs.
2. Don't be discouraged by challenges and don't be afraid of failure. Instead, view them as opportunities to learn and grow, and remember that persistence and resilience are key to success.

Professor Karin Weber-Gasparoni

Professor of Pediatric Dentistry, Chair of the Department of Pediatric Dentistry, Clinical Pediatric Dentist

Field of research: Paediatric Dentistry

Research project: Investigating whether psychology-based oral health education can influence behaviour and reduce early childhood caries (ECC)

Funder: US National Institute of Dental and Craniofacial Research (NIDCR)

I was a teenager when I had my daughter, Nathalia, who was born with a rare genetic condition, Smith-Magenis syndrome. Dental abnormalities are common in children with Smith-Magenis syndrome, and Nathalia developed early childhood caries (ECC) when she was very young. Experiencing the negative impact this dental disease had on my daughter motivated me to pursue paediatric dentistry in the hope of helping other children and families affected by ECC. By conducting research alongside my clinical dentist work, I hope to prevent this disease from occurring in the first place.

> **I LIKE THE FACT THAT EVERYONE HAS THEIR OWN DISTINCTIVE SET OF TEETH.**

My career has been shaped by my experiences as a low-income single mother to an amazing daughter with special healthcare needs, who immigrated to the US from Brazil in search of the 'American Dream'. I can relate to children and caregivers who face inequalities in dental healthcare. As a result, I have focused my research on the prevention of ECC in low-income children, and I treat children with special healthcare needs in my dental clinic.

I love the variety of my work – every day is new and different. I provide dental care, teach students in the classroom and clinic, conduct research and participate in outreach activities to serve the community.

I like the fact that everyone has their own distinctive set of teeth – your teeth play a role in your individual uniqueness!

When I was younger, I loved sports, especially gymnastics and fencing. These days, I enjoy spending my free time with my family, meeting my friends for bible studies and helping in my local church.

Karin's *top tips*

1. Start building a strong CV early by studying hard, volunteering and shadowing dentists or researchers.
2. Whether you choose a career in clinical dentistry or oral health research, choose it to help others and the rest will fall into place.

Dr Shaoping Zhang

Assistant Professor of Periodontics, Clinical Dentist, Periodontist

Fields of research: Periodontics, Microbiology, Immunology

Research project: Investigating how interactions between oral microbes and the immune system shape periodontitis

Funders: NIDCR, University of Iowa College of Dentistry, Colgate

I developed a strong interest in medicine when I was in high school. I was convinced I would become a medical doctor, but being a clinical and research dentist is not too far from my dream.

My late mentor, Dr Steven Offenbacher, profoundly inspired me towards my research career and prepared me as a clinician in periodontology. His diligence and passion for research propels me to move forward as a clinician-scientist every day.

After graduating from dental school at the West China University of Medical Science, I worked in a dental clinic. One day, a woman in her forties came to receive her second complete set of dentures as she had lost all her teeth to periodontal disease. I was shocked, as I had never come across a patient who had lost all their teeth at such a young age. This motivated me to specialise in periodontology when I moved to the US and is one of the reasons why I primarily conduct research related to periodontal disease.

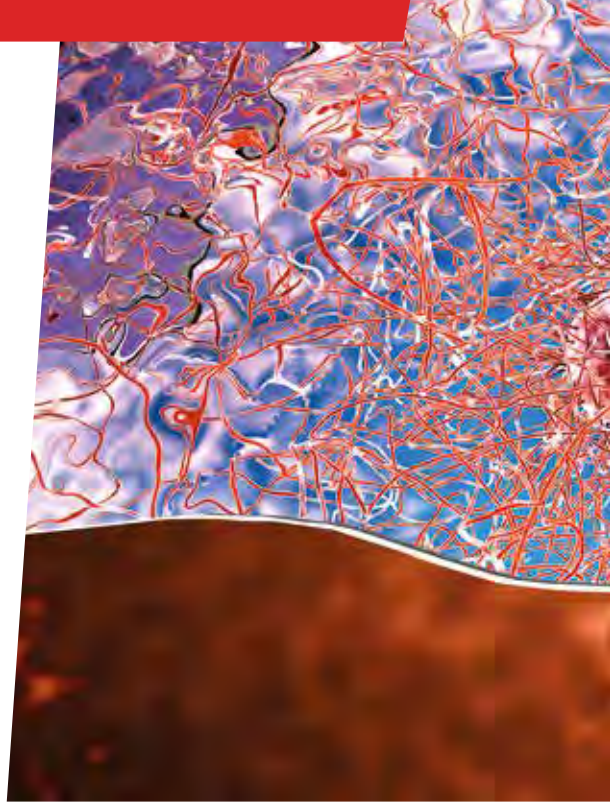
I find it rewarding to know that my research may have an impact on understanding periodontal disease. For example, through our research we found that the risk of developing diabetes for people with periodontitis is not equal for all periodontitis patients. Although obesity is a well-known risk factor for developing diabetes, the risk from certain severe forms of periodontitis for non-obese individuals to develop diabetes is greater than it is for obese patients. I think it is interesting that treating periodontal disease in people with diabetes has a similar effect to giving medication for diabetes.

In my free time, I enjoy walking and playing with my two dogs – Taz (a border collie) and Rasco (a Jack Russell terrier). In the warmer months, I also enjoy jogging.

Shaoping's *top tips*

1. Pursue a career in something you are passionate about. Your passion will be the energy source that motivates you to push forwards.
2. Be open minded and curious about new advances in your field of interest. For example, new technologies and materials are constantly emerging in dentistry.
3. Persevere when things go wrong and enjoy the journey as you move through your career.

An age-old question



As we reach the later years of our lives, our skin will wrinkle and our hair will turn grey. We may have mixed feelings about ageing, but it is a natural part of life. Although we may never be able to prevent ageing, some scientists think that we may be able to slow it down. **Dr Hua Bai** from **Iowa State University** in the US is studying a process in our cells that is thought to contribute to ageing. He hopes that this research may help us find new ways of slowing down the ageing process.

Dr Hua Bai

Department of Genetics, Development, and Cell Biology, Iowa State University, USA

PROFILE

Field of research
Molecular Genetics

Research project
Investigating why and how our bodies age as we grow older

Funder
US National Science Foundation (NSF)

TALK LIKE A ...

MOLECULAR GENETICIST

CRISPR screening — an experimental technique that can identify a small number of important genes within a much larger gene pool, such as an entire genome

Enzyme — a protein molecule that speeds up chemical reactions in cells

Metabolism — the set of chemical processes in the body that breaks food down into energy

Oxidative stress — an imbalance between the amount of reactive oxygen species and the body's ability to detoxify them or repair the damage they cause

Peroxisome — organelles inside our cells that play an important role in metabolism and other cellular processes

Reactive oxygen species — an unstable molecule that contains oxygen and that easily reacts with other molecules, often damaging them

What is one thing that you have in common with every other person on Earth? Well, from the day we are born until the day we die, all of us are getting older. Although some of us might like to pretend otherwise, ageing is a part of life that we cannot ignore.

At some stages in our life, getting older can feel liberating. As a young adult, each new year that we age seems to bring new opportunities, as well as responsibilities. But, as we reach the later stages of life, ageing can become a source of aches, pains and anxieties.

For most of us, the thought of old age is not an appealing one. Hips start to ache, memories fade and hearing aids are turned up. We also become more prone to diseases such as cancer, Alzheimer's and arthritis, which can greatly reduce a person's quality of life. It is not uncommon for humans to spend the last few years of their life in discomfort or pain.

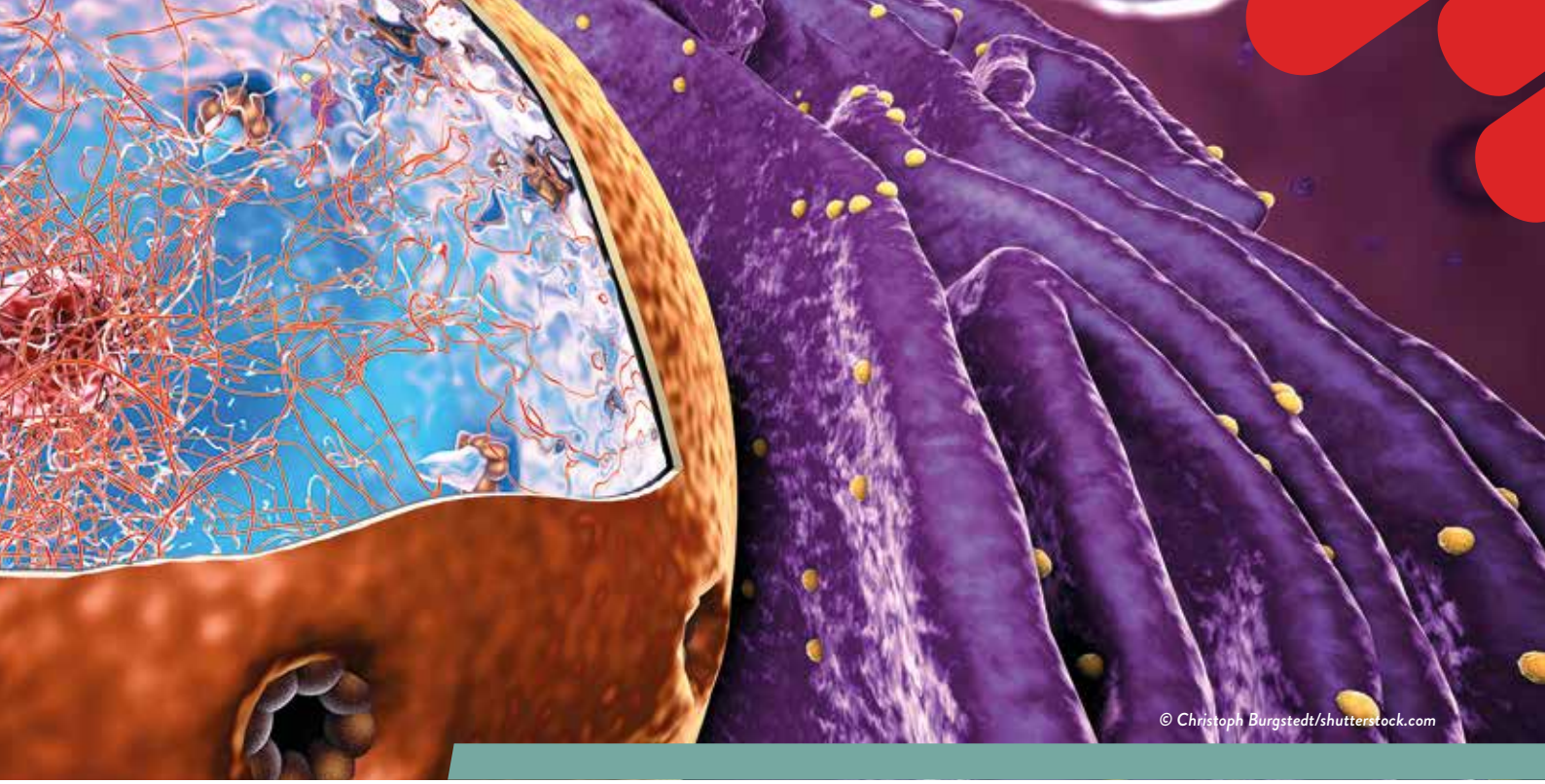
What if we could slow down the ageing process? What if we could make the last few years of our lives comfortable and pain-free? To slow down the process of ageing, we first need to understand how the process works by answering the question: Why do we age? Dr Hua Bai, from Iowa State University, is studying exactly this. His research focuses on peroxisomes and the role these small cell structures play in ageing.

What are peroxisomes?

Peroxisomes are organelles found in almost all of the cells in our bodies. They contain many enzymes and play an important role in our metabolism, which is how our bodies turn food into energy or the building blocks of cells (like DNAs, RNAs, proteins and lipids). For example, peroxisomes are particularly important for breaking down fatty acids, also known as lipids, which are an important source of energy.

Peroxisomes can also manufacture structural and functional lipids which can be used in other processes. For example, peroxisomes help to create plasmalogens, which are key components of the membranes surrounding heart and brain cells. Peroxisomes also contribute to important processes in the kidneys and liver.

Lastly, peroxisomes contain a large amount of detoxification enzymes, called catalase, that can convert the reactive oxygen species hydrogen peroxide to water and oxygen, and protect cells from oxidative damage.



What role do peroxisomes play in ageing?

Recent studies have shown that peroxisomes begin to deteriorate as organisms get older. "The loss of peroxisomal function during ageing can lead to metabolic disorders, elevated oxidative stress and inflammation," says Hua.

Oxidative stress occurs when reactive oxygen species build up in the cells and tissues of an organism. Reactive oxygen species are unstable molecules that can damage other important molecules within a cell, such as DNA. Peroxisomes play an important role in balancing oxidative stress, so when they begin to deteriorate, the damage caused by reactive oxygen species increases.

The process of ageing in the human body is complex and is affected by many different factors. For example, our DNA molecules become damaged and fail to replicate properly. If the DNA in a cell becomes sufficiently damaged, the cell may destroy itself so that the damaged DNA is not replicated.

As we get older and our peroxisomes begin to function less effectively, the concentration of reactive oxygen species in our cells increases, leading to DNA damage and cell death. This excessive cell death can lead to a whole host of problems that further accelerate the deterioration of the body.

Is there any way to stop peroxisomes from failing?

"One important question in peroxisome research is whether our cells can activate a defence mechanism to protect themselves from cellular damage associated with peroxisomal dysfunction," explains Hua. He is hoping to identify the ways in which cells can monitor the deterioration of their peroxisomes and whether they have any mechanisms to protect against peroxisomal damage.

By answering these questions, Hua hopes to gain a deeper understanding of the ageing process and how cells fight against it. He hopes that this may lead to the development of treatments and techniques that might be able to slow the ageing process.

> ***"THE LOSS OF PEROXISOMAL FUNCTION DURING AGEING CAN LEAD TO METABOLIC DISORDERS, ELEVATED OXIDATIVE STRESS AND INFLAMMATION."***

How is Hua studying this?

Hua and his team are using advanced genetic and biochemical tools to study peroxisomes. For example, one genetic tool the team uses is CRISPR screening. This is a newly developed genetic screening method that allows researchers to examine the effects of specific mutations on human genes.

The advantage of CRISPR screening is that it can be used to study every human gene in a single experiment. Using this method, Hua can quickly identify which genes are responsible for protecting cells from peroxisomal dysfunction.

One of the biochemical techniques that Hua uses in his investigations is called TurboID proximity labelling. This allows him to identify which proteins interact with each other within a cell. TurboID is a powerful technique that can reveal interactions between proteins, even if they are weak and occur very quickly.

This technique may help Hua to uncover how cells monitor the deterioration of their peroxisomes. By testing proteins on the surface of a peroxisome, he can discover which other proteins they interact with. This will allow him to start building up a picture of the signalling pathways that allow the cell to monitor the condition of the peroxisome.

What has Hua discovered?

Hua and his team have already identified several proteins that play a part in activating protection mechanisms within a cell. Hua found that if these proteins were prevented from doing their job by genetic mutations, the cell's protection mechanisms were less effective, and the cell was more likely to die as a result of peroxisomal damage.

Hua's team has also conducted the first comprehensive analysis of how peroxisomes send signals to the cell's nucleus. It is these signals, that the peroxisome sends when it is deteriorating, that activates the cell's protection mechanisms.

What are the next steps?

Hua's next step is to dig deeper and understand how peroxisomal damage activates these signalling pathways. Once he has a complete understanding of these pathways, Hua hopes that he will be able to help develop an effective treatment for diseases that are related to ageing and peroxisomal deterioration.

Hua is also developing an innovative laboratory course designed to give undergraduate students hands-on experience with CRISPR technology. "This is a very effective way to improve student learning of difficult subjects like genetics, and to make research opportunities accessible to a large and diverse student population," explains Hua.

This course will help to give the next generation of molecular geneticists the skills that they need to conduct their own research projects. At the moment, much of the ageing process remains a mystery; there are many fascinating questions for researchers like Hua and his students to explore.

About *molecular genetics*

Molecular genetics is the branch of genetics that investigates the structure and function of genes on a molecular level. Genes are made up of long strands of DNA molecules which contain the information needed for an organism to grow and survive. Our genes tell our cells which proteins to produce and determine how are bodies develop, grow and function.

Molecular geneticists track how changes in genes at a molecular level affect the organism as a whole. Despite occurring on such a small scale, some of these mutations can have serious consequences. For example, sickle cell anaemia, a genetic disorder that reduces the amount of oxygen in the bloodstream, is caused by a mutation that affects a tiny portion of DNA. Hua's research focuses specifically on the genes that are related to peroxisome deterioration. He has identified proteins, known as transcription regulators, that help to protect cells from peroxisomal damage. Transcription regulators are molecules that can influence which RNAs and proteins are produced by genes.

Hua and his team use the CRISPR screening technique to conduct their research. He explains, "With advanced whole genome sequencing techniques and innovative CRISPR-mediated genome editing tools, molecular geneticists can now precisely manipulate animal and plant genomes to understand the molecular function of all genes coded by every genome. Eventually we will be able to decode the fundamental causes of human genetic diseases and ageing."

Pathway from school to *molecular genetics*

- Studying science subjects at school, particularly biology and chemistry, is a good place to start. If you get the chance, focus on molecular biology, cell biology, biochemistry and genetics.
- Contact local universities to try and arrange some work experience in a research lab. Hands-on experience of this kind provides invaluable insights into research work.
- Many universities offer undergraduate degrees in molecular genetics. Do some research and see which course best fits your interests and ambitions.

Explore careers in *molecular genetics*

- Working as a molecular geneticist, you might spend your days conducting experiments in the lab, analysing and interpreting data, and writing findings into academic research papers.
- Molecular geneticists may work with scientists from different fields including medical science and biochemistry. It is important to work effectively as part of a team and to be able to communicate your research to others.
- Try to work in more than one genetics research lab early in your career. Genetics is a broad field, so learning which parts of it you are most interested in and most enjoy can be very useful.
- There are many societies you can explore to find out more about the fields of genetics and molecular biology. For example, the American Society for Biochemistry and Molecular Biology (**asbmb.org**), The British Society for Genetic Medicine (**bgsm.org.uk**), and The Genetics Society (**genetics.org.uk**).
- According to salary.com, the average salary for a molecular geneticist in the US is around $70,000.

© Christoph Burgstedt/shutterstock.com

Q&A

Meet *Hua*

What inspired you to become a scientist?
In my childhood, I always enjoyed being surrounded by nature: trees, flowers, ants and birds. I became interested in biology and medicine when I first subscribed to *Scientific American* during middle school. I was fascinated by the complex biological systems it described, and I am still amazed by how little we know about cells and the causes of human diseases. Through some advanced courses at college, I fell in love with animal physiology and molecular biology and decided to pursue a scientific career to devote my life to understanding how various tissues and organs in our body communicate to coordinate daily function.

What experiences have shaped you as a scientist?
Coming to the US for my PhD and postdoctoral training was a great experience that led me to decide that I wanted to be an animal physiologist and molecular geneticist. My PhD and postdoctoral mentors are my role models. They taught me how to conduct research projects, write scientific journal articles, and apply for funding to support future research. A great mentor is very important in shaping us as scientists.

The eureka moment in my career was when my students and I discovered the unexpected role of peroxisomes in ageing regulation and liver-heart communication. We then realised that peroxisome research is a hidden treasure that has great potential to contribute to many age-related diseases. This was the turning point of my lab research and, since then, we have been actively exploring the function of peroxisomes in cells and how its dysfunction relates to diseases.

What do you find rewarding about your work?
Firstly, I am very excited about the previously unknown function of peroxisomes that we have discovered through molecular genetics analysis. Secondly, it is gratifying to train the next generation of scientists and watch my students grow into great scientists, and potentially even future leaders in the field.

> **THE EUREKA MOMENT IN MY CAREER WAS WHEN MY STUDENTS AND I DISCOVERED THE UNEXPECTED ROLE OF PEROXISOMES IN AGEING REGULATION AND LIVER-HEART COMMUNICATION.**

What are your ambitions for the future?
I hope our peroxisome research can contribute significantly to the development of pharmaceutical treatment of age-regulated diseases, like heart diseases, metabolic diseases, and neuronal disorders.

Hua's *top tips*

1. Follow your heart and work on your dreams.
2. Be persistent. Scientific discoveries can be hard, and you may face many challenges, but keep going!
3. Always look for new ways to improve your logical thinking.

Can artificial intelligence help prevent heart failure?

Depending on its application – and your opinion – advances in artificial intelligence (AI) can seem impressive, daunting or both! Though AI raises many thought-provoking questions about its use and potential, researchers all over the world are finding many positive uses for AI that are likely to benefit humanity greatly. One such researcher, **Dr Linwei Wang** from the **Rochester Institute of Technology** in New York, USA, is using AI to develop new and innovative ways of detecting heart disease.

Dr Linwei Wang

Rochester Institute of Technology,
New York, USA

PROFILE

Fields of research
Computer Science, Biomedicine

Research project
Using artificial intelligence to develop new techniques for better care of heart health

Funders
US National Institutes of Health (NIH),
US National Science Foundation (NSF)

TALK LIKE A ...

COMPUTER SCIENTIST

Artificial intelligence (AI) — the ability of a machine or computer to perform tasks that would usually only be possible for an intelligent being, like a human

Cardiac output — the amount of blood that a heart is able to pump per minute

Electrocardiogram — a test that records and displays the heart's electrical activity

Heart failure — the inability of a heart to pump blood around the body

Myocardial scarring — scarring in the heart muscle tissue, commonly caused by heart attacks

Ventricular tachycardia — an abnormality in the rhythm of the heart causing the lower chambers to pump too quickly

Artificial intelligence (AI), has been making headlines recently, and not necessarily for the right reasons. In April 2023, AI was used to create a counterfeit pop song that simulated the voices of Drake and The Weeknd, sparking a huge debate around AI and copyright laws. Around the same time, the judges of a major photography competition organised by Sony were duped into giving first prize to an AI-generated photograph.

The debate around AI has taken on a new significance since the launch of ChatGPT, a revolutionary new chatbot that is able to write essays, compose poetry and even code brand-new websites. A group of computer scientists and tech moguls, including Elon Musk, have penned an open letter asking for research into this type of AI to be paused as it may "pose profound risks to society and humanity ".

Whilst some forms of AI are threatening to cause widespread disruption, others are being used to help make our lives better. In the field of biomedicine, for example, a different type of AI is being used to help predict and detect medical conditions in a number of innovative ways. Dr Linwei Wang, from the Rochester Institute of Technology in New York, USA, has been working with medical professionals to develop new methods for detecting heart disease.

What is in-home monitoring?

In-home monitoring devices are used to detect the symptoms of heart disease from within a patient's own home. Using these devices, physicians can detect the symptoms at an earlier stage, allowing them to be proactive and provide preventative care. This is especially important because heart disease is one of the leading causes of death worldwide.

Many new in-home devices are wearable, meaning that patients can be monitored continuously as they move around the house. However, one downside to these wearable devices is that patients must remember to put them on. After an initial period of interest, many patients begin to forget, or simply stop bothering, to wear their device.

What is Heart Seat?

Linwei has been developing the AI for a new in-home monitoring device called Heart Seat. This innovative device takes the place of something that we all use every day: a toilet seat. "Integrating sensors into a toilet seat has the unique advantage of being truly inconspicuous," explains Linwei. Patients will no longer have to remember to wear their device or charge it up before use; all they need to do is go to the toilet.

As a patient sits on the toilet, Heart Seat will capture a lot of data. As well as measuring the patient's weight, it will monitor the electrical activity in their heart, providing information on their heart rate and heart rate variability. The seat also has sensors which can detect the

© Have a nice day Photo/Shutterstock.com

amount of oxygen in a patient's blood or the amount of blood being pumped out of their heart every minute, otherwise known as their cardiac output.

These data can be used by clinicians to predict whether a patient's heart failure is worsening. If so, they will be able to provide preventative treatment and, hopefully, help the patient avoid hospitalisation.

How effective is Heart Seat?

The initial trials are still ongoing. Forty patients have completed a 90-day study, while 20 studies are still underway. Even so, initial analyses of the data shows that even very simple variables, such as heart rate and seated weight, can be used to predict when a patient needs to be hospitalised.

What is challenging about the Heart Seat project?

This project is a huge team effort, and many people from a whole range of fields and disciplines are involved. For example, Linwei has been collaborating with other computer scientists, as well as engineers, clinicians and designers. This means collaborating not only with other academics, but also with medical and industry professionals. Co-ordinating so many people from so many different backgrounds can be very difficult.

Another challenge involves the more practical side of the project. "Deploying new technology in everyday environments can pose many unexpected challenges," says Linwei. For example, as with all new technologies, not every device works perfectly every time. Some cannot be installed properly, and others malfunction when collecting and uploading the data. It is a dynamic project with many moving pieces, so the researchers often have to learn as they go.

What are the next steps for the Heart Seat project?

Once the initial trials are complete, Linwei will develop a new AI model based on the data that are collected. This model will use Heart Seat data to predict when a patient is at risk of their heart condition worsening. In the second phase of trials, the AI will send an alert to a patient's physician when it detects a risk. The physician will then be able to review the patient's data and decide on the most appropriate treatment. The hope is that this AI will speed up the delivery of treatments and reduce hospitalisation rates.

> **"DEPLOYING NEW TECHNOLOGY IN EVERYDAY ENVIRONMENTS CAN POSE MANY UNEXPECTED CHALLENGES."**

What else is Linwei working on?

Linwei is working on another project which involves an imaging technique that is used to detect the causes of ventricular tachycardia (VT), a type of abnormal heartbeat. VT occurs when an electrical short-circuit inside the heart causes the lower chamber to pump too quickly. This makes it much harder for the heart to pump oxygenated blood around the body.

These short-circuits are caused by scars within the heart's muscle tissue called myocardial scars. In some of these scars, narrow strips of muscle are still alive. These channels of surviving tissue can conduct electrical signals which occasionally cause the short-circuits that cause VT.

How is ventricular tachycardia usually treated?

One of the most common treatments for VT involves identifying the narrow channels of living tissues within scars and destroying them. However, determining which channels to destroy is a very complicated process.

One method involves deliberately putting patients into a state of VT and then mapping their heart activity. This can provide a relatively clear picture of which channels need to be destroyed; however, very few patients can tolerate VT long enough for the mapping to be completed. Other methods exist, but they are less accurate and do not provide the clinicians with much detail.

How is Linwei aiming to improve this process?

Linwei hopes that her new process will be able to provide clinicians with an accurate map of VT in each patient. Crucially, Linwei's process does not require the patients to undergo induced VT. Instead, it uses a technique known as ECGi, which uses computer modelling to combine geometric data of a patient's heart and torso with results from an electrocardiogram, a test that measures electrical signals in the heart.

Normally, ECGi requires the use of computerised tomography (CT) or magnetic resonance imaging (MRI) scans (that use X-rays and magnetic fields respectively) to acquire the geometric data, so it is not normally used to treat VT. These scans often slow down the treatment process and put the patients under significant strain, which many of them are too ill to tolerate.

For her research, Linwei has developed an ECGi system that uses a 3D camera to provide the geometric data needed for the process to work. This replaces the need to use CT or MRI scanners, which significantly simplifies the workflow.

What are the next steps?

Linwei's next aim is to develop an AI model which can provide more detailed maps of the critical components within a scar that cause VT. The idea is to guide AI with rich knowledge about the physiology underlying the patient's VT. Linwei's work reminds us that AI is a tool that can help protect us and save people's lives.

About *computational biomedicine*

Computer science is a huge field that is growing incredibly fast. Alongside the subfield of computational biomedicine, one of the most exciting and rapidly advancing fields in computer science is artificial intelligence (AI), which also incorporates machine learning. AI is developing at an unprecedented rate, and many predict that it has the potential to revolutionise the way we live.

AI is being used in a huge range of disciplines and industries. For example, it is being used to develop self-driving cars which could completely change how we travel, as a tool for identifying fake news on social media sites to try to stop the spread of misinformation, and even in conservation to help researchers analyse maps and data to better protect animals and wildlife.

One particularly important area in which AI is making great strides is healthcare. Linwei's research in computational biomedicine is a perfect example of this. Using these powerful tools to support the work of medical professionals will likely help to change many peoples' lives for the better.

How can AI support medical professionals?

As well as helping to identify and predict heart problems, AI can perform many functions that will make life easier for clinicians. Some AI tools are designed to sift through huge amounts of data and present the distilled information to medical professionals. This saves an enormous amount of time and allows clinicians to make better, more informed decisions. There are many other low-level, tedious tasks that AI can perform, freeing up time for clinicians to spend their energy where it matters most: with their patients.

What research opportunities will be open to the next generation of AI computer scientists?

AI is already very powerful, but there are lots of ways in which it could be improved. For example, AI needs to be trustworthy and fair as there are concerns that some AI systems may be biased or prone to errors. Another big step will be the creation of AI tools that are able to derive insights and draw on knowledge, rather than simply completing set tasks.

Pathway from school to *computer science*

- Computer science is an interdisciplinary area, and there are lots of pathways that you could follow.
- Subjects such as mathematics, physics, information technology and engineering will provide a good basis for computer science. However, other subjects such as art and design can be useful in some areas of computer science. If you are interested in specialising in computational biomedicine, studying biology would also be very useful.
- Contact local universities or colleges to see if they have any summer intern programmes in their computer science departments. An internship would give you practical experience and help you discover whether you enjoy working as a computer scientist.
- Have a look to see if there are any computer science summer schools in your local area. This is another great way to get practical experience and meet other people who share your interests.

Explore careers in *computational biomedicine*

- As a computer scientist, you could work in a number of fields. Most industries and professions require computer scientists these days, so there will be plenty of jobs on offer.
- The Medical Image Computing and Computer-aided Society (**www.miccai.org**) is a great place to explore the world of biomedical computer science. It hosts online webinars and conferences, and you can sign up to a newsletter to keep up with the latest developments in the field.
- Computing in Cardiology (**cinc.org**) is an annual conference dedicated to computer science research that focuses on the heart. On its website, you can find all the research that has been presented at recent conferences. Explore these papers to get a deeper understanding of the field.

© Have a nice day Photo/Shutterstock.com

Q&A

Meet *Linwei*

What inspired you to become a scientist?
My love of problem solving!

What has led you to apply your computer science expertise to healthcare?
The tangible impact we can have on human health and well-being, and the problems we can help solve are fascinating and motivating. The various moments when I realise that what we do can solve a real problem in clinical practice are always rewarding.

What attributes have made you successful as a scientist?
Curiosity and the natural desire to solve problems. I enjoy tackling challenges and welcome them, instead of being afraid or frustrated by them. Also, I am open-minded, and I enjoy discovering new things.

What are your proudest career achievements so far?
I won the United States' Presidential Early Career Award for Scientists and Engineers (PECASE) for my work on artificial intelligence and biomedicine. I have also developed a family-like relationship with a large group of students, including those who have graduated, which is a special reward for this career path.

What are your ambitions for the future?
I hope to be able to continue to lead my students to work on questions that we are curious about and that matter to society. I also hope that some of our current work will have a real impact on clinical practice.

Linwei's *top tips*

1. Focus on your passion.
2. Don't lose sight of what drives you.

Dr Linwei Wang and PhD student Pradeep Bajracharya

How can music technology improve the well-being of people living with dementia?

What does music mean to you? Whether you play an instrument or enjoy listening to your favourite band, there are many ways to engage with music. But what happens if you begin to lose your memories of music or ability to play an instrument? **Dr Jennifer MacRitchie** is a musician and electronic engineer at the **University of Sheffield**, UK. She is collaborating with researchers **Dr Justin Christensen** and **Jon Pigrem**, to develop new digital music technologies to improve music accessibility for people living with dementia.

Dr Jennifer MacRitchie

Senior Research Fellow, Department of Music, University of Sheffield, UK

Adjunct Research Fellow, The MARCS Institute for Brain, Behaviour and Development, Western Sydney University, Australia

Fields of research
Music Technology, Electronic Engineering, Cognitive Science

Dr Justin Christensen

Research Associate, Department of Music, University of Sheffield, UK

Fields of research
Music, Psychology

Jon Pigrem

Research Technician Officer, Department of Music, University of Sheffield, UK

PhD student, School of Electronic Engineering and Computer Science, Queen Mary University of London, UK

Fields of research
Music, Digital Lutherie

PROFILES

TALK LIKE A ...

MUSIC TECHNOLOGIST

Acoustic musical instrument — a musical instrument that produces sound through vibrations of the instrument, usually generated by touch or breath

Cognitive — relating to mental ability

Dementia — an umbrella term referring to a range of progressive conditions with symptoms including memory loss, confusion and impaired cognitive ability

Digital lutherie — the creation of digital musical instruments

Digital musical instrument (DMI) — a musical instrument that relies on computing, rather than acoustics, to generate sound

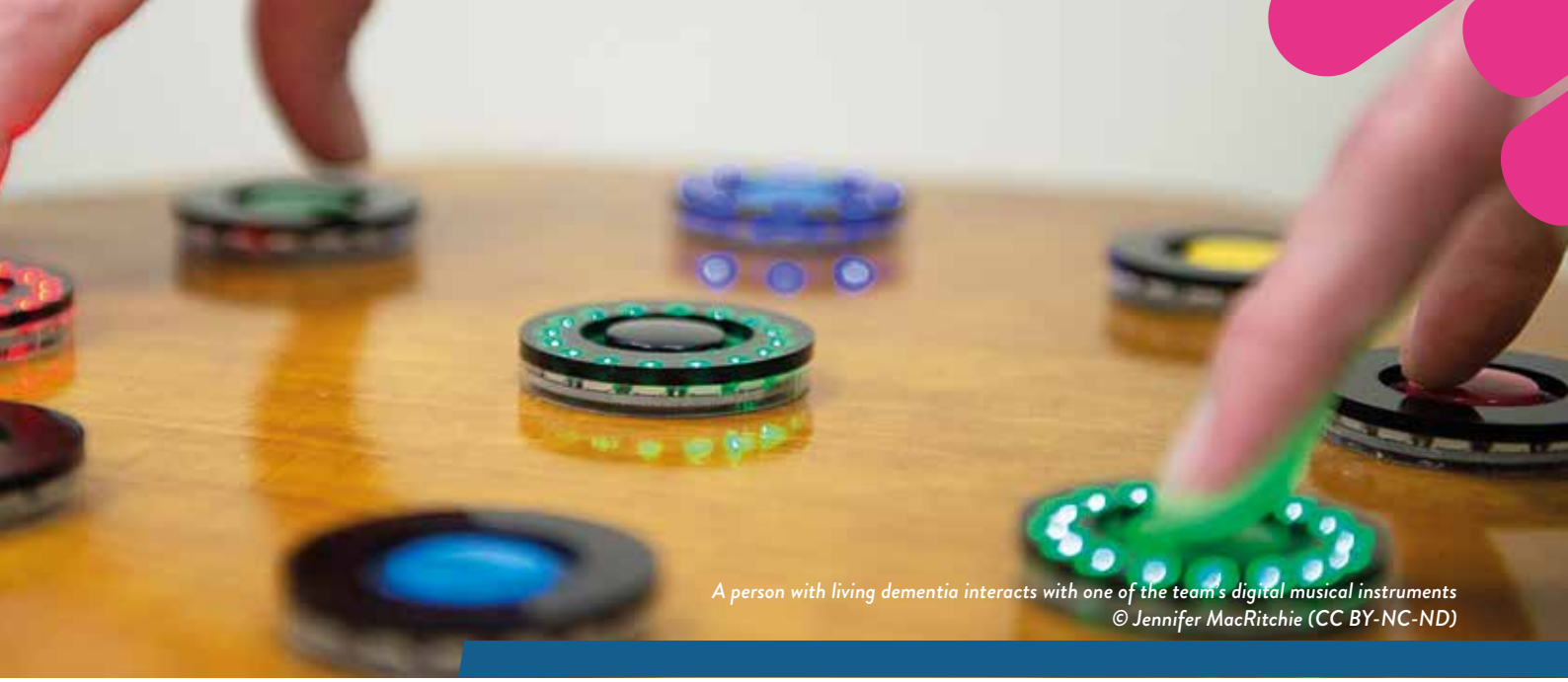
Luthier — a person who makes musical instruments

Motor skills — skills required to perform movements

Music can remind us of significant moments in our lives, connect us with our idea of who we are or used to be, and generate social interactions as we bond with others over shared musical experiences and preferences. "Music is an activity that is multi-faceted in nature," says Dr Jennifer MacRitchie, a musician and electronic engineer. "It engages with our emotions, makes us want to move, helps us relate to others and contributes to our personal identity." As such, music can be good for everyone. It can also bring specific benefits for people living with dementia, which is why Jenni and her team are developing new technologies to facilitate dementia-accessible musical interactions.

Research project
Designing new musical technologies for older adults' well-being
Current and past team members: Dr Jennifer MacRitchie, Dr Justin Christensen, Jon Pigrem, Michael Neokleous, Katherine Jackson, Dr Georgia Floridou, Prof Renee Timmers (University of Sheffield), Prof Luc de Witte (The Hague University of Applied Sciences), Prof Andrew McPherson (Imperial College, London) and project partner Bela (Augmented Instruments Ltd). We would like to acknowledge our community partners in this research who have consulted with us on our research aims and developed devices including Dementia Research Advisory Group South Yorkshire (DRAiSY), Sheffield Dementia Involvement Group (SHINDIG), and facilitators and attendees of dementia cafés run through Age UK Sheffield, Heeley City Farm, and Darnall Wellbeing.

Funder
This research is funded by a UK Research and Innovation (UKRI) Future Leaders Fellowship awarded to Jennifer MacRitchie (MR/T040580/1)



A person with living dementia interacts with one of the team's digital musical instruments
© Jennifer MacRitchie (CC BY-NC-ND)

What is dementia?

Dementia is an umbrella term that covers over 200 different progressive conditions, with common symptoms including memory loss, confusion, difficulty communicating, changes in behaviour and impairments to other cognitive abilities which impact day-to-day life. Alzheimer's disease is the most common cause of dementia, accounting for 60-80% of cases.

How can music benefit people living with dementia?

"Music is highly communicative, but does not rely on words, allowing people living with dementia to connect through music," explains Dr Justin Christensen, a musician and psychology researcher. "Musical abilities are often preserved as dementia progresses, giving people opportunities to creatively express themselves." We often connect experiences with music, meaning it can have the power to reawaken memories in people who struggle to remember their life before the onset of dementia. Music is also a valuable social activity, and creating music together is a common leisure and therapeutic activity for people living with dementia.

Why do dementia-accessible musical interactions require technology?

"Imagine you are playing a violin," says Jenni. "Think about all the brain functions you need to play a single note. You need the ability to read (or remember) the music to know which note to play, then to know the correct hand position to produce that note. You need the motor skills to press your fingers on the strings and to move the bow so it hits the string at the correct angle and pressure." As dementia can cause a loss of memory and motor skills, technology can reduce the complexity of the actions needed to produce music. "The aim is to keep the experience of playing music as richly rewarding as possible, while simplifying the interface that the user interacts with," explains Jenni.

Few music technologies have been designed specifically for people living with dementia, and the team hopes to change this by creating new digital musical instruments (DMIs). "Music technology isn't just about building new musical instruments," says Jon Pigrem, a musician and digital luthier. "We are also considering ways for people living with dementia to interact with all aspects of music, such as listening or creating playlists."

What DMIs has the team invented?

Jenni, Justin and Jon have partnered with Bela, a music technology platform, to develop their dementia-friendly DMIs. When you play a 'traditional' acoustic musical instrument, the sound is generated by vibrations that produce sound waves (e.g., the vibrating strings of a violin, skin of a drum or air within a clarinet). In contrast, digital music is produced electronically by computers. Partnering with Bela allows the team to create digital interfaces that produce sound when someone interacts with them. "With Bela, we can use a wide range of sensor technologies to develop unique, assisted musical experiences that are realistic and meaningful to users," says Jon.

For example, the Slider Box[1] is like a mixing desk, where users can move levers up and down to combine pre-recorded pieces of music to produce new compositions. The pre-recorded tunes uploaded to the instrument can be chosen to be pieces that are familiar to the user, allowing the Slider Box to be used in reminiscence therapy. "The active process of selecting familiar music from the past can help people living with dementia to access memories," Jon explains.

The Music Memory Makers[2] duet system is an electronic version of the mechanical music box that was popular in the 19th century and allows two people to create music together by spinning the handles on the box. "The aim of the duet system is to provide a meaningful way for couples to continue interacting together as one of them experiences dementia, through the power of music," says Justin.

The In C Box[1] is like an arcade machine. It is covered with coloured buttons, each of which produces a different sound and lights up when pressed. "The In C Box explores notions of agency in the composition process for those with no musical training, or with cognitive or physical barriers to musical performance," says Jon.

How are people living with dementia contributing to the DMIs?

"This project relies on us collaborating with people living with dementia and their carers," explains Jenni. "They are the experts on their experience." The team is therefore working with local community groups and residential care facilities, so that people living with dementia can provide input about what they want from musical interactions and what specific requirements they have. "Working with people living with dementia means that together we can co-design DMIs that reflect what individuals want to do with these technologies," says Jenni.

"Every person living with dementia is unique, so there isn't a one-size-fits-all solution," says Jon. "We need to be flexible as we work with people to understand their needs and accommodate them through accessible technology." The team organises workshops where people living with dementia and their carers can share how they want to interact with music, discuss the barriers they face, and try out and provide feedback on the DMIs.

"People in the workshops can be hesitant at first, as dementia can rob people of the ability to feel confident in their actions," says Justin. "However, they light up when they interact with the music, both from enjoyment and the feeling of success. Seeing people's reactions to our DMIs is my favourite aspect of the project."

These workshops highlight the benefits that music can bring to people living with dementia, as both an emotional and social tool. "The best part of this project is that we didn't know the participants at the start of the workshops. However, once we'd sung some Elvis songs together and chatted about gigs we'd been to and instruments we played, it felt like we had windows into each other's lives," says Jenni. "Music really can help us connect with others."

References:
1. *Pigrem J, MacRitchie J, & McPherson AP (2023). Instructions Not Included: Dementia-Friendly approaches to DMI Design. In: Proceedings of the International Conference on New Interfaces for Musical Expression (NIME), Mexico City, Mexico*
2. *Christensen J, Kauenhofen S, Loehr J, Lang J, Peacock S, & Nicol J (2023). MMM Duet System: New accessible musical technology for people living with dementia. In: Proceedings of the 18th International Audio Mostly Conference (AM '23), Edinburgh, UK*

About *music technology*

Music technology involves applying technology, such as computers and software, to the musical arts. It covers everything from designing accessible instruments for people with physical or cognitive disabilities, to being a music producer at a record label, to working as a sound engineer. "From gramophones and player pianos to Spotify and Guitar Hero, technology has long supported the musical experience!" says Jon.

How important is interdisciplinary collaboration for harnessing the benefits of music for well-being?

The team's project to develop dementia-accessible musical experiences relies on collaboration with researchers from many different fields. For example, while Jenni, Justin and Jon are all musicians, Jenni has a background in electronic engineering and cognitive science, Justin has a background in psychology and Jon has a background in digital lutherie. The project also requires expertise in design, music therapy and nursing. "Interdisciplinary research enables a better understanding of how technology, music and social care come together to provide real-life solutions," says Jon.

How is music changing as technology advances?

"Before there were Spotify playlists, my generation used to make mixtapes," says Jenni, highlighting how past technological inventions have changed how people interact with music. "We recorded songs onto cassette tapes, then later onto CDs, to listen to at home or give to our friends."

In the past, music was composed by writing instructions for musicians on paper, performed by musicians on acoustic instruments, and listened to by live audiences in concert halls. Today, anyone can compose music on their computer using composition apps, it can be performed completely electronically using mixing desks, and anyone with access to the internet can listen to almost any piece of music they desire. Technology has revolutionised how music is created and consumed, making it far more accessible.

What does music mean to you?

How has music has impacted your life? Has your mood ever changed after listening to or playing a song? Have you relied on music to get you through a difficult time? Or made friends through a musical group? If so, a career in the field of music technology will allow you to give other people similar powerful musical experiences.

Pathway from school to *music technology*

- A passion for music is the most important thing for working in any music-related field!
- If you play an instrument, join your school band or a local youth orchestra. Why not start your own band with your friends?
- If you are interested in other aspects of music, find others who share your passions. "Whatever your interests, there will be a group of people somewhere doing it," says Jon. "Use the internet to find your community and get involved! For example, music blogs and podcasts often have communities you can engage with."
- At school, studying music, design, technology and physics will all be useful if you are interested in a career in music technology.
- Some universities offer degrees in music technology or engineering with music. You could also study electrical or electronic engineering and apply your skills to music-related challenges, or you could study music production if you are interested in the technology required for modern music production.
- The Department of Music at the University of Sheffield has an outreach programme for schools (www.sheffield.ac.uk/music/school-resources) and offers a range of music degrees (www.sheffield.ac.uk/music/undergraduate), including courses that allow students to specialise in music technology. All programmes provide opportunities to work with local partners in sound and technology industries.

Explore careers in *music technology*

- There are many career options in the field of music technology. Most aspects of modern music production require technology, so you could find yourself working as a music producer, director, sound engineer or technician. If you enjoy performing, you could work as an electronic musician or DJ.
- "Today, everything from websites and podcasts to news broadcasts and children's toys has some role for music technology," says Jon. "As an industry, it is at the forefront of cultural and technical invention and overlaps the worlds of science and the arts."
- Careers in Music has a wealth of information about different careers in music and what they involve: **www.careersinmusic.com**
- MusicTechMag has an article about the role of music technology: **www.musictechmag.co.uk/What-is-Music-Technology.html**
- This blog article explains the many different devices used in music technology: **www.brianjump.net/2017/05/28/music-technology**

Meet *Justin*

Music has always been a big part of my life and I've had numerous powerful musical experiences. I've had musical training since I was young, beginning with violin and piano lessons. I now play the trumpet in a contemporary classical ensemble, and I write my own musical compositions to express myself in ways that I can't quite seem to manage in words.

Growing up, I mainly listened to classical music. At university, I started listening to popular music and saw how it can play a role in developing friendships around shared interests. You will almost always find me listening to music, either as a focus or as a background to help me do other things. The type of music will depend on my mood – classical, dance, experimental, alternative pop... I'm increasingly listening to UK pop music from the 1950s to 80s, as this helps me connect with the people living with dementia that I interact with.

I'm interested in how music can affect our perception of time. The passage of time is constant, but I think we all have feelings that time is passing faster at some moments and slower at others. For me, music, and how immersed I get into it, can really affect my sense of time. I'm also fascinated by how, when people play music together, they can feel they are joined together into something bigger than themselves.

Meet *Jon*

Music has been my passion since a young age, and it has been my full-time career for as long as I can remember. Music has given me the freedom to explore the world through touring and performing, as well as providing stability to grow and develop at home.

In my research, I explore notions of musical interaction, usually mediated through digital technology of some kind. I design and create very specific instruments to highlight these different interactions so that I can explore them in greater depth.

Digital lutherie involves the creation of digital musical instruments. It is as much about artistic design and engineering research as it is about making the instruments themselves. I've been designing new instruments for years, and the longer I do it, the more interesting it becomes. In this project, I am a technical research officer, and my role is to build the instruments that we are using in our research.

Meet *Jenni*

I have been privileged to have had access to music lessons from a young age. I started learning the violin when I was five, switched to the viola soon after, and began piano lessons when I was eight. Growing up, I played music for my own enjoyment and in local youth orchestras. For me, music has always been a way of connecting with other people, making new friends, and having fun experiences playing and performing.

I could never choose between the sciences and arts, which is why I studied a joint degree of electronics with music at university. Music had always been my passion, but I also really loved doing experiments in physics and thinking about how things worked. I was delighted to discover a degree programme that combined my interests. I was able to get a fully accredited engineering degree alongside a music degree and I could take courses where engineering and music intertwined.

> ***FOR ME, MUSIC HAS ALWAYS BEEN A WAY OF CONNECTING WITH OTHER PEOPLE.***

My dual arts and sciences background helps me to see projects from multiple angles. It also helps me talk to a range of people about my work. This is very useful when we collaborate with people from different fields, such as nursing, psychology or computer sciences.

I enjoy playing classical music on the piano and I play the viola in a local orchestra. I also like to mix things up sometimes – I was recently in a post-rock band where I connected my viola through a guitar amplifier. I enjoy listening to rock and jazz music. I also have a Disney playlist for the car – I say it's for my kids, but it's really for me, too!

Jon introduces workshop participants to the Slider Box
© Jennifer MacRitchie (CC BY-NC-ND)

FUTURUM PODCASTS

6 reasons for academics to create podcasts

Are you an academic who wants to communicate your research to a wider audience? Do you want to inspire the next generation of researchers and encourage young people to follow in your footsteps? Creating a podcast is a great way to achieve this.

At Futurum, we have started producing podcasts as part of our collection of educational resources, in which academics share the stories behind their research and talk to students about the exciting opportunities in their research fields.

We recently found a blog from Coursify about '6 reasons to use a podcast as a marketing tool'[1] and we realised these reasons also apply to academics marketing their research. So, why should you create a podcast for young people? Here, we explain why Coursify's reasons also apply to you.

1. Relationship

Podcasts allow you to talk directly to your listeners, meaning you can build a relationship with your audience. This is important; if your audience feels they know you, they will have a deeper connection to you and your research. It is important for students to know that academics are people, too! You have hobbies and interests, you've overcome challenges, you get excited about what you do. If you work on a very niche topic, it can be hard to enthuse anyone who is not in your specific field about your research. But hearing your voice as you tell your story will help students engage with your work and, if students feel like they know you as a person, it will help your research come alive.

2. Accessibility

People can listen to podcasts anywhere, at any time. As an audio format, podcasts can accompany people as they do other things. This means students can listen to you share your stories while they're on the bus or walking to school, or while they're doing chores.

The personal stories shared in a podcast mean that complicated academic research can become accessible to a much wider audience. Podcasts are also an accessible format for students who might struggle to take in written information. They are a great way to engage students who have difficulty in reading and understanding written articles about complex topics. Alongside our podcasts, we also produce transcripts of the conversation, to ensure the resource is accessible for those with hearing difficulties or who don't speak English as their first language.

3. Authenticity

As Coursify points out, addressing your listeners directly creates trust. The COVID-19 pandemic has highlighted the issue of public trust (or lack thereof) in science and scientists. Speaking directly to young people through a podcast is an ideal way to build their trust in research.

In our podcasts, researchers talk candidly about the experiences that have shaped them as an academic. Providing an authentic behind-the-scenes look at your research will inspire students to take an interest in your subject. What inspired you to become a researcher? How have your life experiences shaped your career journey? What motivated you to work on your chosen topic? Podcasts provide the perfect opportunity for sharing these stories with school students.

For example, Dr Laurel Lynch discusses how childhood holidays in the Alaskan wilderness gave her a love of the outdoors and encouraged her to ask questions about the landscapes around her, which led to her career in ecosystem ecology. Professor James Lupski was inspired to become a clinical genomicist because he wanted to understand his own genetic condition. After leaving university to have a baby, Dr Cheryl Talley was encouraged to return to finish her degree, ten years later, by people who believed in her and saw her potential. This taught her the importance of mentoring and relationships, so she founded a programme that uses the power of mentoring to help students achieve success. And Professor Peter Gammon shares how he changed his mind and his direction many times since leaving school aged 16, highlighting the many routes that are available into the field of electronics engineering.

4. Assertiveness

As an academic, you can talk with authority about your topic. You are the expert, so by sharing your work you can inspire students to take an interest in your research. As well as sharing their personal stories, the researchers we work with offer advice and encouragement for students. This includes specific suggestions for getting started in a career in the field and general guidance for life. Laurel and James both recommend finding work experience in a scientific lab, and Peter points out that English language skills are just as important for engineers as maths and physics. Due to his genetic condition, James couldn't attend school for many years, so he shares the importance of learning how to learn and acknowledging that everyone's learning style is unique. Cheryl is passionate about ensuring all students reach their

© Stock-Asso/Shutterstock.com

Futurum Podcasts

There are millions of podcasts out there - indeed, Spotify says it has over 5.5 million[2] – so what makes Futurum podcasts unique? Not only do they complement the Futurum research article, and help academics bring their stories to life, they are an education resource in their own right, complete with transcript and PowerPoint with discussion points.

To find out more, visit the Futurum podcast page:
futurumcareers.com/stem-shape-podcasts

- Listen to **Dr Laurel Lynch's** podcast
- Listen to **Professor James Lupski's** podcast
- Listen to **Dr Cheryl Talley's** podcast
- Listen to **Professor Peter Gammon's** podcast

potential, and she believes that knowing yourself is key to achieving this. What advice can you offer young people hoping to follow in your footsteps?

5. Scope

Podcasts are a great way to build new relationships with an audience you might not normally interact with, increasing the scope of your communication. When you make exciting discoveries in your research and publish your results in academic journals, chances are your article will only be read by other researchers in your field. Very few research articles make headlines in the mainstream media. If you haven't cured a deadly disease or named a new dinosaur, then it can be hard to reach non-academics to let them know about the huge range of incredible and interesting research that occurs in academic institutions. Educational podcasts are a great way to break out of the ivory tower and share your research with a new audience by talking directly to young people to explain the significance of your work.

6. Exclusivity

While all academics publish research articles in academic journals, creating a podcast will make you stand out from the crowd. If young people don't know anyone with a career in your field, then they are less likely to consider such a career themselves. If they don't have family and friends who have attended university, then they are less likely to attend university. You can be a role model to inspire the next generation, and an educational podcast gives you this opportunity.

If you want to create an educational podcast to share your story, contact:
info@futurumcareers.com

References
1. blog.coursify.me/en/podcast-as-a-marketing-tool
2. podnews.net/article/how-many-podcasts

> ***"PODCASTS ALLOW YOU TO TALK DIRECTLY TO YOUR LISTENERS, MEANING YOU CAN BUILD A RELATIONSHIP WITH YOUR AUDIENCE."***

© DC Studio/Shutterstock.com

Fostering love and knowledge of agriculture and the environment

Agriculture is what feeds the world, yet many people have a very limited knowledge of how their food grows and where it comes from. **Diana E. Collingwood**, Assistant Commissioner at the **US Virgin Islands Department of Agriculture**, is on a mission to change this, not just to inspire the next generation of agriculturalists, but also to help existing farmers overcome the challenges of their important work.

Diana E. Collingwood, MA, BSc

Assistant Commissioner, Virgin Islands Department of Agriculture (VIDA), USA

PROFILE

Fields of research
Agriculture Education

Research project
Educating the next generation of agriculture professionals on the US Virgin Islands and providing support for existing agriculture professionals

Funder
US Department of Agriculture (USDA)

TALK LIKE A ...

AGRICULTURE EDUCATOR

Agriculture — the science or practice of farming

Agronomist — an expert in the science of crop production and soil management

Food security — having reliable access to sufficient quantities of affordable and nutritious food

Holistic — considering things to be interconnected and part of a broader whole

Infrastructure — the physical and organisational structures that society relies upon, such as buildings, roads, energy networks and supply chains

Supply chain — the sequence of steps and processes involved in the production, processing and eventual distribution or sale of a commodity

Sustainability — being able to be maintained in the long term, often used specifically to mean the avoidance of the depletion of natural resources

Diana E. Collingwood is an agricultural educator and former Career and Technical Education Supervisor leading the administration and development of agricultural programmes in the US Virgin Islands. She is passionate about mentoring and motivating students from an early age about the importance of agriculture and the opportunities within the sector. Having grown up in the Caribbean, she has an in-depth understanding of the challenges the region faces and works tirelessly to inspire the next generation of agricultural professionals.

Agriculture in the US Virgin Islands

A US territory, the US Virgin Islands are a collection of tropical islands in the Caribbean. The islands face significant challenges with regards to agriculture, which stem from issues related to geography, politics, history, economics and education. "We import almost all of our food, and it's not always the best quality," says Diana. "We have the potential to grow high-quality food ourselves, but we don't have the investment in agricultural education and infrastructure that we need to do so."

Regulation is a problem, and the islands lack resources such as food processing facilities that would help provide a guarantee on quality. "We don't have systems in place for supply chain tracking, to ensure food safety or to ensure that water and soil is being used responsibly," says Diana. "For instance, we produce millions of gallons of wastewater that could be treated and used for irrigation, but instead it is pumped directly into the ocean." The islands also have an open-borders policy on US mainland imports, which allows the free movement of goods. This means that unchecked, imported foods may bring pests or disease with them that can then spread to locally-produced foods.

The COVID-19 pandemic highlighted why such attitudes are such a pressing problem for the islands' food security. Because the islands rely on imports, mainly from the US, any disruption to the supply chain has the potential to leave islanders hungry. "When the pandemic struck, the US prioritised supplying food to the mainland, and imports were heavily affected," says Diana. "We urgently need a stable agricultural output to


© MMD Creative/Shutterstock.com

sustain food security, but we lack the investment needed to make this a reality."

While these seem like practical issues, Diana believes that the root of the problem lies in attitudes towards agriculture. "Communities take agriculture for granted," she says. "This extends to teachers and high school administrators, who often won't consider agriculture when giving careers advice to their pupils." While there are a range of scholarships and other opportunities available to help students work towards traditional and non-traditional careers in agriculture, highly respected careers, such as medicine or microbiology, are rarely considered as agriculture-related by the general public. As a result, many students and parents are unaware of the true range of opportunities that exist within agriculture.

An agricultural education

"I believe that it's important to expose children to agriculture and the environment as early as possible," says Diana. "It's a topic that brings together so many important educational subjects: language arts, science, technology, mathematics, engineering and art." Diana believes that agriculture can act as a vehicle to educate students holistically, while instilling a love of food and farming from an early age. "There's something in agriculture to interest every individual," she says. "Whether they're interested in biology, geometry, engineering, chemistry, microbiology or in digging holes and looking for worms, starting early shows how the child's interest ties into food, health and sustainability. And when a young person finds success in this area from an early age, it gives them the confidence to pursue excellence."

As children grow older and become teenagers, Diana suggests drawing on individuals' specific interests to dive deeper into relevant areas of agriculture. "For instance, many teenagers are interested in technology, which is being used more and more within agriculture," she says. "Drone technology, for example, is leading us towards increasingly precise and efficient methods of farming." One promising instance of this is the development of drones that can identify and pinpoint individual pest-infested plants in a crop field and target them with a spurt of pesticide. This is much more environmentally friendly, healthier and cheaper than indiscriminately spraying whole fields with pesticides. However, it requires agricultural professionals well-versed in technology to use them effectively.

> **"WHEN A YOUNG PERSON FINDS SUCCESS IN THIS AREA FROM AN EARLY AGE, IT GIVES THEM THE CONFIDENCE TO PURSUE EXCELLENCE."**

Business and agriculture

Diana emphasises the importance of demonstrating to students that agriculture can lead to successful and profitable careers. To make this a reality, she has combined agriculture and business directly in the classroom. "I teach students how to grow plants, sell them, grow the next crop and make a profit," she says. "At the end of the semester, students have earned money. That captures their attention because they benefit both educationally and financially." There are also plenty of additional skills that can be developed effectively through agriculture education. "We teach leadership and civic skills, and how to maintain a healthy and nutritious diet," says Diana. "Students learn how to add value to products, to process and preserve food, and to manage their finances." These skills are all transferable to any career path as well as to day-to-day life, helping students develop a well-rounded and universally useful education.

Support for agriculturalists

To encourage students to consider agricultural careers, it is important that there are rewarding career paths waiting for them. Some of the prejudices around agriculture do have their roots in reality. "Farming is currently one of the most stressful careers out there," says Diana. "Unstable incomes, boundary disputes and a lack of support networks all make it a challenging career."

Diana is determined to change this. "We currently have a $500,000 initiative that provides outreach and education activities for farmers and trains 'first responders' to support farmers in crisis," she says. "We are educating farmers to identify sources and symptoms of stress, as well as providing tools such as laptops to help them build peer support networks and move away from working in isolation." As well as helping farmers under stress realise that they are not alone, such networks enable them to share knowledge and best practice, and to organise community events and markets to promote and sell their products and the agricultural lifestyle.

Diana has high hopes for the future of agriculture in the US Virgin Islands. "Our top priority is building the technical expertise needed to sustain our own successful agriculture sector," she says. "That's my focus: preparing, educating, recruiting and retaining the next generation of agriculture professionals."

About *agriculture*

Diana is passionate about the wide range of careers available in agriculture, which can suit any talent or interest. Agriculture needs professionals from every area to make food production secure and sustainable. Below are profiles of just a few agricultural careers, which highlight the breadth of interests and expertise required by the sector.

Farm manager

Role includes: planning, organising and managing farm activities and staff. This includes managing finances, promoting products, buying and selling resources, and strategic planning

Why it might interest you: potential to build a successful business, excel through leadership, and work for yourself

Skills/knowledge required: business, mathematics, technical expertise

Agronomist

Role includes: maximising sustainable yields from crops, such as through selection of fertiliser, pest control methods, soil health and selective breeding

Why it might interest you: nurtures a deep knowledge of plants and how to use them to provide for society

Skills/knowledge required: plant sciences, regulatory knowledge, economics

Environmental engineer

Role includes: ensuring that agricultural practices provide a healthy environment, through building, evaluating and advising on systems for water management, waste disposal, soil health and energy usage

Why it might interest you: values technical expertise while helping human activities be more sustainable

Skills/knowledge required: chemistry, environmental science, engineering, geoscience

Ecologist

Role includes: assessing ecosystems and advising agricultural practices to ensure they minimise damage to, or even benefit, natural resources

Why it might interest you: uses a deep knowledge of the natural world and provides opportunities to protect the environment while providing for society

Skills/knowledge required: biology, life sciences, ecology, environmental management

Veterinarian

Role includes: providing medical care for livestock

Why it might interest you: involves working closely with animals while utilising medical expertise

Skills/knowledge required: veterinary science, medicine, communication

Explore careers in *agriculture*

- The Communication for Agriculture Exchange Programs runs paid international exchange programmes to bring young adults together from different nations to network and share ideas related to agriculture: **caep.org**
- The National Women in Agriculture Association (NWIAA) is a wide-ranging network for women in agriculture across the US and its territories. Its website includes resources for accessing funding and education opportunities, as well as providing contact details for leaders in specific states and territories: **www.nwiaa.org**
- Salaries vary widely across different agricultural careers. Generally speaking, the more technical or professional expertise required for a role, the greater the salary. Diana notes that business skills are very valuable for farm owners and other agricultural workers to help maximise their income.

Pathway from school to *agriculture*

Diana emphasises that there is a career for every interest within agriculture. If you know you are interested in agriculture but are not yet sure about which specific area, many colleges and universities offer courses in agricultural sciences and related fields. Useful subjects to take in school that relate broadly to agriculture include biology, language arts, mathematics, physics, chemistry, graphic arts, geography, culinary arts, business and economics.

Meet *Diana*

I grew up in Trinidad in the Caribbean. My grandfather did not have a formal education, but he's one of the wisest people I know. I followed him as he farmed and so learnt lots of scientific agricultural practices through practical experience.

Once, my grandmother lost her wedding ring in the garden. My grandfather found it and wanted to surprise her. He cut open an unripe pumpkin, hid the ring inside, and sealed the pumpkin using charcoal. When the pumpkin had matured, he gave it to my grandmother, who found the ring embedded inside! I learnt the many uses of charcoal from him: not just sealing vegetables, but also to clean up oil spills or to recover from food poisoning. My grandfather taught me the value of plants and natural products, and how nurturing a tree or crop can provide sustenance for generations.

My godfather also inspired me. He lived and worked at the University of the West Indies Research Centre as a caretaker, and I would visit him in the summers. He showed me how water and other factors affected the growth of crops, and showed me how animals were slaughtered, which created an early connection to the realities of food production.

I've been fortunate to work in several different nations around the world. The most important lesson I've learnt from these experiences is that you don't have to be rich to help people – you have to want to make a difference. For instance, in Ghana, I was able to help students access elementary school, by helping families collect small amounts of money to buy uniforms and school materials. I learnt the importance of empowering others, and how this in turn benefits my own skills.

I was the first female to graduate from the University of the Virgin Islands' School of Agriculture. I taught agriculture in middle school after graduating, and then went on to pursue further education at the University of Florida, which included focusing on agriculture and extension education, communication, special education, counselling and educational leadership.

I aim to inspire excellence in the next generation of agriculturalists. I want to show people the different agricultural professions available, the importance of nutrition, and how agriculture and the natural environment affects every aspect of our society. I have written a children's book to help children to discover and value the environment. We have all the skills and resources we need to have truly sustainable agriculture; we just need to learn how to utilise them.

Diana's *top tip*

There is a career in agriculture for any area of interest. Take the time to research career opportunities and see which align with things you are passionate about.

"WE HAVE ALL THE SKILLS AND RESOURCES WE NEED TO HAVE TRULY SUSTAINABLE AGRICULTURE; WE JUST NEED TO LEARN HOW TO UTILISE THEM."

Protecting crops from nematodes

Just like animals, plants are bombarded by all sorts of pathogens and parasites. Currently, one particular species of nematode is threatening to cause widespread issues for a variety of important crops. At **Clemson University**, South Carolina, USA, **Dr Paula Agudelo** and her team are employing cutting-edge science from a wealth of different fields to develop an array of solutions to defend crops against these worms.

Dr Paula Agudelo

College of Agriculture, Forestry and Life Sciences, Clemson University, USA

PROFILE

Fields of research
Plant Pathology, Nematology

Research project
Investigating the characteristics of the crop pest nematode *Meloidogyne enterolobii*, to help develop effective management strategies and resistant crop varieties

Funder
US Department of Agriculture (USDA)

TALK LIKE A ...

NEMATOLOGIST

Biological control — reducing a crop pest's impact by introducing a natural enemy that reduces its population

Ecological niche — the environmental conditions within which a particular species has adapted to exist

Galling — the development of abnormal growths (galls) on plant tissue, often caused by parasites

Germplasm — a collection of genes or genetic material for use in the improvement of plants, namely crops

Me — scientific shorthand for *Meloidogyne enterolobii*, a species of root-knot nematode (RKN)

Nematode — a worm in the very diverse and populous *Nematoda* phylum

Nematology — the scientific study of nematodes

Root-knot nematode (RKN) – a parasitic nematode from the *Meloidogyne* genus

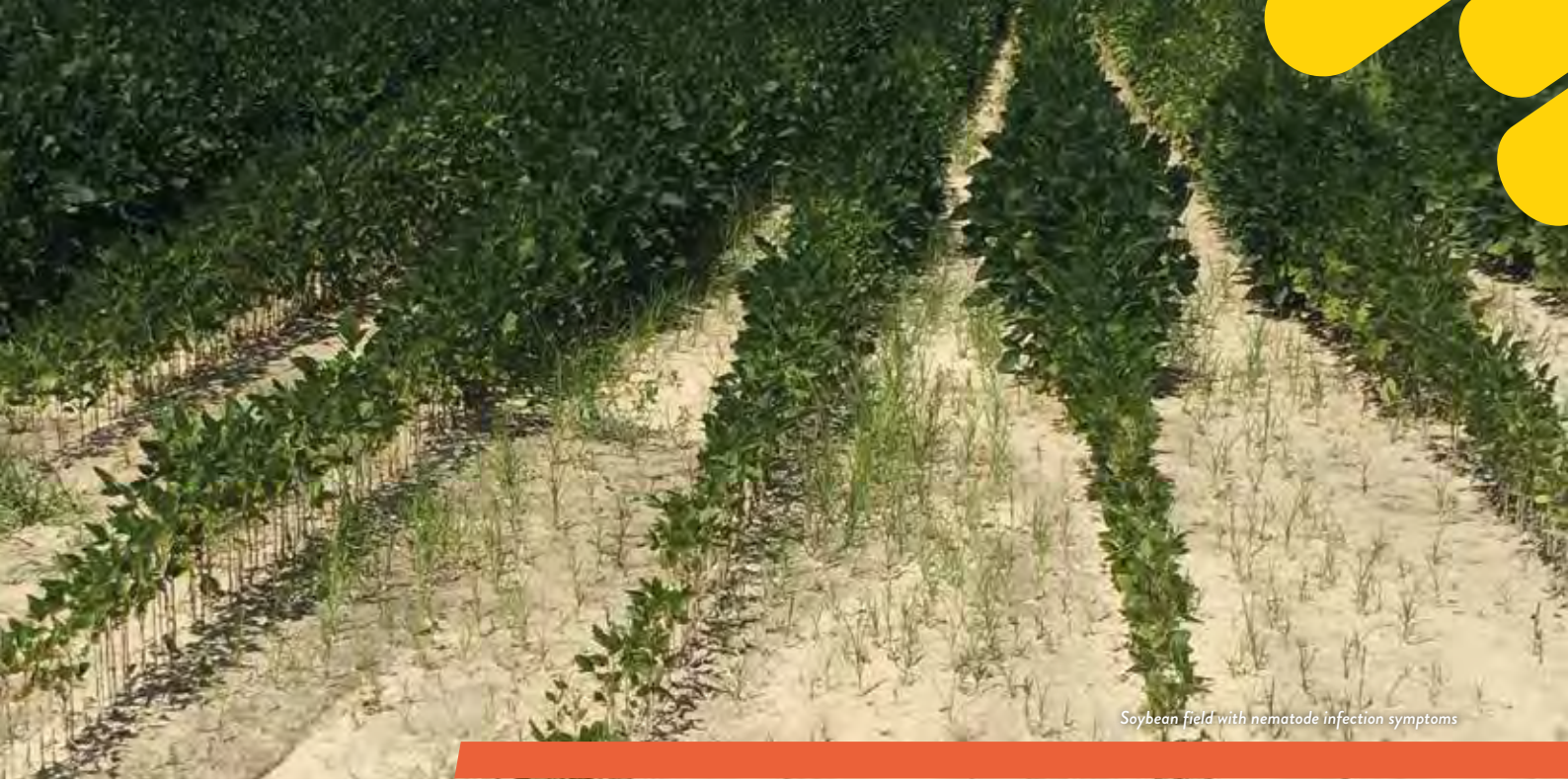
The world around us is brimming with life impossible to see with the naked eye. This microscopic jungle includes nematodes, which, while tiny in size, are gigantic in number. In fact, it is estimated that 80% of all animals are nematodes, and they have adapted to be present in just about every ecosystem on Earth, from the highest mountains to the deepest parts of the ocean floor. They are very diverse, with perhaps a million species in existence, and are crucial to the health of the planet. However, every so often, particular nematode species come along which pose a major headache to humanity – for instance, by becoming a significant crop pest.

Dr Paula Agudelo is leading efforts to tackle one such nematode species, which has recently arrived in Southeastern USA and is threatening to majorly impact the yields of farmers in the area, and possibly further afield. Based at Clemson University's College of Agriculture in South Carolina, Paula's FINDMe project has the broad task of understanding this nematode in detail, and using this knowledge to develop management strategies and crop varieties that show resistance to this species.

A little bit about Me

This troublesome worm is part of a particularly problematic group of nematode species known as root-knot nematodes (RKN). "RKN feed on the roots of plants and cause galling," says Paula. "This results in reduced yield and quality of crops." The specific species has the scientific name of *Meloidogyne enterolobii*, or Me for short. "Me is able to affect a broad range of important vegetable crops that are otherwise resistant to other RKN species," says Paula. "This aggressive nematode causes severe root galling, leading to significantly reduced quantity and quality of crops, including sweet potato, guava, cucumber and soybeans, as well as many others."

Me is thought to have originated in China, with global trade enabling it to spread further afield. For example, in the early 2000s, it arrived in Brazil and, subsequently, led to the collapse of the country's guava industry. Now, it has been detected in Southeastern USA. "There is an urgent need to understand how to manage Me and develop Me-resistant crops before it spreads to other parts of the world," says Paula. "If it becomes widespread before we learn how to manage it, vegetable production



Soybean field with nematode infection symptoms

could be seriously threatened." This would be a worrying scenario, especially in a world with a growing population and an ever-increasing demand for food and efficient agriculture.

The task at hand

The phrase 'know your enemy' is highly relevant for agriculture. The more knowledge that is amassed about a pest such as Me, the greater the capacity to develop targeted strategies to reduce the threat it poses. With this in mind, Paula's team is focusing on some key issues:

- The characteristics of Me, such as its distribution and the genetic diversity within the species, which affect how it might respond to efforts to manage it.
- Identifying resistance genes in plants that can be used to develop Me-resistant crops.
- The effectiveness of different management tactics, such as nematicides, crop rotations and biological controls.

Naturally, such a broad array of questions requires a broad array of expertise. "Our research team includes expertise in plant breeding, plant pathology, population genetics, nematology, horticulture, economics, and integrated pest management," explains Paula.

It is important that such a real-world issue is not considered as just a scientific brainteaser. Paula is adamant that FINDMe's research outcomes need to be directly useful for those whose livelihoods depend upon crop success. "The Me problem directly affects producers, processors, distributors, researchers and agricultural educators," she says. "To understand how we can make our research as relevant as possible, we are bringing together experts from biology and socioeconomics, alongside principal stakeholders and partners, to inform the direction of our research and its applications."

Research underway

Paula's team has been busy gathering data to understand Me's changing distribution and how it is moving from place to place. "We have sampled fields with Me-infected plants in Southeastern USA, and are now doing a systematic survey of sites in the area that distribute planting material or nursery stock, which are likely a key way that Me is spreading," says Paula. Once these pathways are identified, there is potential to put measures in place to detect Me-infected materials at source and prevent them reaching new places.

For millennia, people have bred crops by selecting those with the best traits, such as their ability to resist pests and pathogens. These days, we have the technology to perform this selection process to a high degree of precision. "Within the natural variation found within host crops, there are likely some variants that are less susceptible to Me than others," says Paula. "By doing controlled crosses between different plant parents, we can develop varieties that have Me resistance as well as other desirable traits." The crop material used as the source for these varieties is known as 'germplasm', a generic term referring to genetic stock material. "So far, we have promising germplasm for sweet potato, watermelon, pepper and eggplant (also known as aubergine or brinjal)," says Paula.

Management strategies

There is a wealth of different strategies that agriculturalists employ to secure high crop yields, and research is an essential cornerstone to improve these strategies and develop brand new ones. In the case of Me, these strategies include:

- Nematicides: pesticides that specifically target nematodes.
- Crop rotations: growing different crops on the field at different times, which can boost soil properties and help reduce Me prevalence in the soil.
- Cover crops: non-commercial crops grown on fields between periods of commercial crop production, to protect or improve the soil, such as by repelling Me.
- Biological controls: introducing living organisms to suppress Me populations, such as Me predators, parasites or pathogens.

"We first test all these different strategies at a small scale in the greenhouse," says Paula. "For those strategies that yield promising results, we then test them in the field under controlled conditions. Those that work best are then tested in real farms under real production conditions." Initial results have been informative, with the team finding that some cover crops such as wheat, sunn hemp and sorghum-sudangrass are effective at managing Me. "These results provide a welcome start to the FINDMe project," says Paula. "Our next steps are to continue investigating all our research questions, from the characteristics of Me, to effective management tactics, to the development of Me-resistant crop varieties."

The FINDMe team

John Mueller, Professor,
Clemson University, Blackville, SC

Antonio Baeza, Associate Professor,
Clemson University, Clemson, SC

Adrienne Gorny, Assistant Professor,
NC State University, Raleigh, NC

Lina Quesada, Professor,
NC State University, Raleigh, NC

Phillip Wadl, Research Geneticist,
USDA-ARS, Charleston, SC

William Rutter, Research Plant Pathologist,
USDA-ARS, Charleston, SC

Zhengfei Guan, Associate Professor,
University of Florida, Wimauma, FL

Johan Desaeger, Associate Professor,
University of Florida, Wimauma, FL

Zane Grabau, Associate Professor,
University of Florida, Gainesville, FL

Tristan Watson, Assistant Professor,
Louisiana State University, Baton Rouge, LA

Intiaz Chowdhury, Assistant Professor,
University of Georgia, Tifton, GA

About *nematology*

Despite being largely unnoticed by the general population, nematodes are a crucial cornerstone of life on Earth. Building our knowledge of nematodes both helps us to understand how ecosystems function and to address very real-world issues such as food security. Paula explains more about her discipline.

"Nematodes are everywhere. They have adapted to a wide variety of hosts, climates and ecological niches. Because they are so diverse, they can be useful indicators of ecosystem health. Nematodes can be bacterivores, fungivores, herbivores and predators. Looking at the abundance and diversity of their populations can help us make inferences about the stability and composition of other living things in the system.

"I find it exciting that there is so much we still don't know about nematodes. I enjoy the complexity of the interactions that their study entails; they affect, and are affected by, soil, water, plants and animals. All of these, of course, also affect us, especially our agricultural practices.

"Current and future nematologists have the challenge of understanding nematode diversity before certain fragile ecosystems disappear. There is also a pressing need to find ways to restore balance in agricultural soils, promoting practices that allow the coexistence of crops and nematodes, without nematodes becoming pests. In particular, we need to find ways to reduce pesticide use as a means of controlling nematodes."

"CURRENT AND FUTURE NEMATOLOGISTS HAVE THE CHALLENGE OF UNDERSTANDING NEMATODE DIVERSITY BEFORE CERTAIN FRAGILE ECOSYSTEMS DISAPPEAR."

Pathway from school to *nematology*

- Useful subjects to study at high school and beyond include biology, chemistry and mathematics.
- University degrees that can lead to a career in nematology include agronomy, biology, plant science and agricultural science. Paula recommends seeking university modules in plant physiology, microbiology, soil science and plant pathology.

Explore careers in *nematology*

- The South Carolina Commissioner's School for Agriculture is a summer programme for high school students that inspires careers in agricultural science and related sectors, as well as nurturing the development of leadership skills: **www.clemson.edu/cafls/sccsa/index.html**
- Clemson University Cooperative Extension 4-H Youth Development is a broad programme open to 5 to 18-year-olds. It runs a variety of clubs, workshops, camps and more, all with the aim of helping young people gain the knowledge and skills to be valuable members of society: **www.clemson.edu/extension/4h/index.html**
- The Society of Nematologists is an international organisation to advance the science of nematology. Its website has a wealth of knowledge, as well as opportunities to make connections and get further involved: **www.nematologists.org**
- The American Phytopathological Society focuses on the advancement of plant pathology. On its website, you can delve into relevant research and find opportunities such as early-career internships: **apsnet.org/Pages/default.aspx**
- According to Salary Expert, the average salary for a nematologist in the US is around $75,600.

Meet *Paula*

My father inspired me to become a scientist. He always experienced the natural world with a sincere curiosity and sense of awe, which he passed on to me.

Teaching is the most rewarding aspect of my career. Striving to become a better teacher has also made me a better researcher.

When encountering obstacles, I try to maintain perspective. I remind myself about how my efforts are helping agriculture and, by extension, the world.

The successes of my graduate students represent my proudest achievements. Their continued engagement in science or science education are their own accomplishments, but I am proud to have contributed to their education.

I aim to continue to educate young people about how new knowledge is created, and the responsibilities we hold to the world. We need to care for our natural resources, and I seek to instil a sense of commitment for students to do good with the knowledge they gain.

Paula's *top tips*

1. Always consider the complexity of interactions between organisms. All diseases are an interaction between the host, the pathogen and the environment. Each of these parts can be influenced by many different factors, which affects how the disease presents itself.

2. Keep an open mind!

Root gall with protruding egg mass

Can soil microbes improve agricultural sustainability?

Synthetic fertilisers are currently necessary for producing enough food for the global population to survive, but they are known to contribute to greenhouse gas levels, contaminate water sources and increase soil acidity. At **Washington State University** in the US, **Dr Nathaniel Boyer** is a biochemist working to find a more environmentally friendly solution.

Dr Nathaniel Boyer

Institute of Biological Chemistry,
Washington State University, USA

PROFILE

Fields of research
Molecular Plant Sciences, Biochemistry

Research project
Investigating nitrogenase expression in diazotrophs with the aim of improving crop yields in an environmentally friendly way

Funder
US Department of Agriculture (USDA)

This work is supported by Agricultural and Food Research Initiative grant no. 2021-67034-35148 from the USDA National Institute of Food and Agriculture. The content is solely the responsibility of the authors and does not necessarily represent the official views of the funding agencies.

TALK LIKE A ...

BIOCHEMIST

Biofertiliser — a fertiliser containing living microorganisms that naturally supports nitrogen fixation

Biological nitrogen fixation (BNF) — the natural process of microbes converting atmospheric nitrogen into ammonia

Diazotrophs — bacteria and microorganisms that convert nitrogen gas to ammonia

Intracellular — located or occurring within a cell

Legume — a plant that has its seeds in a pod, such as a pea or bean

NifA — a protein that activates the expression of nitrogenase

NifL — a protein that inhibits the activity of NifA

Nitrogenase — an enzyme of various nitrogen-fixing bacteria that catalyses nitrogen fixation

Symbiosis — any type of interaction between two different organisms that benefits them both

Nitrogen gas makes up 78% of the Earth's atmosphere and is crucial for life on our planet. It is found in soil, plants, water and air, is a key building block for DNA and proteins, creates chlorophyll to help plants with photosynthesis, and helps turn the plants we grow into food we can eat.

However, even though there is plenty of nitrogen gas available, it is not in a form that plants can make use of right away. Instead, it needs to be converted into nitrates, nitrites and ammonia, through a process that scientists call nitrogen fixation. This is just one part of the nitrogen cycle, which allows nitrogen to move from the atmosphere to the soil and back again.

Dr Nathaniel (Nate) Boyer is focused on the role nitrogen plays in agriculture. "Nitrogen is commonly a limiting nutrient in crop growth," says Nate. This means that there is often not enough fixed nitrogen to allow crops to grow as much as they otherwise could.

In the early 1990s, two German scientists, Fritz Haber and Carl Bosch, found a way to convert nitrogen in the air to ammonia and so create nitrogen fertiliser that would help plants to grow. With a current world population of over 8 billion, many farmers now rely on those fertilisers to help increase crop yields so that we have enough food to eat. These fertilisers are a huge part of farming processes – in fact, it is estimated that 48% of the world's population is fed by the increase in yield that has resulted from synthetic nitrogen fertilisers. This means that, in 2015, 3.5 billion people would have died, or would not have been born in the first place, if it were not for the invention of synthetic nitrogen fertilisers.

So, what is wrong with synthetic nitrogen fertilisers?

Unfortunately, synthetic nitrogen fertilisers cause nearly as many issues as they solve. Firstly, the process of creating these fertilisers is an extremely energy intensive one, which requires nitrogen gas to react with hydrogen under high temperatures and pressures. "This process is reliant upon fossil fuels, consuming more than 1% of our global energy supply annually, while contributing to greenhouse gas emissions," says Nate.

As well as this, unused nitrogen fertilisers can leak into the environment, upsetting the normal balance of the nitrogen cycle and having negative consequences. "With synthetic fertilisers, most of the nitrogen is applied early in the growing season, and more than half of applied nitrogen fertilisers are

washed away or evaporate before they can be used by crops," says Nate. "This contaminates local water supplies with fertiliser run-off and emits nitrous oxide, a greenhouse gas 300 times more potent than carbon dioxide."

Fertiliser running off into nearby water sources has led to the creation of 'dead-zones' – areas where little to no aquatic life can survive. On top of all this, using synthetic nitrogen fertilisers over a long period of time can also limit future crops from growing on the same land, as nitrogen fertilisers make the soil too acidic.

Is there another solution?

Nate is looking for ways to increase the input of biological nitrogen fixation (BNF) to help mitigate these issues. BNF is a natural process where microbes known as diazotrophs use the enzyme nitrogenase to convert nitrogen gas to ammonia themselves. "BNF shifts the heavy lifting to diazotrophs that live directly on crop roots, supplying nitrogen when and where crops need it throughout the growing season," says Nate.

However, BNF is complex and only a select few organisms are capable of surviving on atmospheric nitrogen. As with the production of nitrogen fertilisers, BNF is a very high energy process. "Nitrogenase is quickly destroyed in the presence of oxygen," says Nate. "Therefore, diazotrophs need to maintain tight control of nitrogenase expression and activity in response to the presence of intracellular oxygen in addition to cellular energy and nitrogen conditions."

Currently, BNF in agriculture is mostly limited to legumes, as these crops have developed a close symbiotic relationship with diazotrophs, and BNF is done by diazotrophs that the legumes house in their roots. "Diazotrophs infiltrate the roots of a legume and stimulate the formation of root nodules that create an oxygen barrier to provide a suitable environment for BNF," says Nate. This allows BNF to take place in an area without oxygen, preventing the nitrogenase from being destroyed.

BNF is beneficial for both the legume and the diazotrophs. "The legume provides sugar fixed through photosynthesis to the diazotrophs in exchange for some of the nitrogen fixed by the diazotrophs," explains Nate.

What about plants that are not legumes?

"Some free-living diazotrophs have been demonstrated to supply nitrogen to non-legume plants," says Nate. Free-living diazotrophs are microbes capable of supporting BNF without needing the help of another organism, such as the roots of a legume. Nate hopes to find out as much about these diazotrophs as possible so that he can develop a sustainable, environmentally friendly solution to supply nitrogen to crop plants while minimising the negative impacts of synthetic fertilisers.

"Using synthetic biology to increase BNF activity in these free-living diazotrophs has the potential to generate enhanced biofertilisers that are compatible with a wide variety of crop plants," Nate explains.

What happens inside free-living diazotrophs?

In some of these free-living diazotrophs, nitrogenase gene expression is controlled by the interaction of two proteins, NifL and NifA ('Nif' stands for nitrogen fixation).

When fixed nitrogen and oxygen levels are low, conditions are suitable for BNF and the NifA protein is active. "NifA activates the expression of nitrogenase and other genes related to BNF," explains Nate.

In contrast, NifL inhibits the activity of NifA and therefore limits nitrogenase, too. "In response to conditions unsuitable for nitrogen fixation, the NifL protein changes shape, allowing NifL to bind to NifA, preventing the expression of genes related to BNF like an 'off-switch'," says Nate.

Nate's biggest finding during this research project has been understanding the structure of NifL, as it is difficult to determine the structure of a protein that changes shape! However, now that Nate and his team understand the structure, they have lots more work to do. "We can now explore how the structure of NifL changes in response to signals of cellular oxygen, energy and fixed nitrogen, and how this ultimately affects interaction with NifA," says Nate.

> **"WITH SYNTHETIC FERTILISERS, MOST OF THE NITROGEN IS APPLIED EARLY IN THE GROWING SEASON, AND MORE THAN HALF OF APPLIED NITROGEN FERTILISERS ARE WASHED AWAY OR EVAPORATE BEFORE THEY CAN BE USED BY CROPS."**

What does this mean for crops?

Nate's research on NifL and NifA interactions shines a light on how diazotrophs control BNF and nitrogenase gene expression. Nate's work lays the foundations for creating engineered biofertilisers that can be used on a wide variety of different crops, and which farmers can use in conjunction with synthetic nitrogen fertilisers.

"The long-term impact of this work will be to increase agricultural sustainability," explains Nate. Hopefully, with more research like Nate's, scientists will find ways for farmers to have high enough crop yields to feed the global population, while minimising the environmental impact.

About *biochemistry*

Biochemists study chemical processes and structures in animals, plants and microorganisms (such as bacteria and viruses). As well as working in medical, dental and veterinary areas, biochemical scientists can work in food science, pharmacology and agriculture. They might study anything from how an organism gets energy from food to how insecticides affect plants, to how diseases are passed down through genetics. "Biochemical research provides the opportunity to solve complex puzzles in a collaborative setting on a daily basis," says Nate.

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

"The amazing thing about research is that it's a self-perpetuating system," says Nate. "Our scientific understanding builds on the work of those who came before us, and the answer to any well-thought research question should allow scientists to ask more interesting questions. So, there are countless opportunities for the next generation of biochemists!"

What does a typical day look like for Nate?

"One thing that I really enjoy about research is how variable a 'typical' day can be," says Nate. "I may be in the lab performing experiments, on the computer analysing data or performing computational experiments, presenting my findings, or reading to stay up to date with rapidly evolving cutting-edge techniques. Some experiments require highly specific, expensive equipment, so I often travel to other labs to collaborate with scientists from different backgrounds, which I've always enjoyed."

Pathway from school to *biochemistry*

- If you are interested in becoming a biochemist, take classes in biology, chemistry, physics and mathematics at high school and post-16.
- "There are many great educational resources on YouTube that can help you get a basic understanding of biochemistry," says Nate. "I watched a lot of Khan Academy videos throughout my education. As you get started, it can feel like learning a new language, and sometimes it can feel overwhelming. If you keep striving to understand the concepts, fluency will come with time." Have a look at Khan Academy's explanation of the nitrogen cycle here: **www.khanacademy.org/science/biology/ecology/biogeochemical-cycles/v/nitrogen-cycle**
- Study for a bachelor's degree in biochemistry or a related field such as biology, molecular biology or biomedical engineering. However, Nate recommends choosing the classes that inspire you. "Personally, I've found that my degree in philosophy, focused on advanced logic and philosophy of science, has been indispensable to designing effective experimental strategies," says Nate. "Research takes all kinds, so my best advice would be to follow your passion and keep an eye open for where your expertise fits in."
- Try to gain laboratory experience whenever you can, such as through a summer placement at a university or an internship at a pharmaceutical company. To work in research, you will need to complete a master's degree and a PhD after your bachelor's degree.
- "Taking any computer science classes will position you well to make use of machine learning and other computational tools that are revolutionising the field of biochemistry," says Nate.
- If you are a high schooler in the US and come from a Native American community, have a look at Washington State University's 'EXploring Emerging College Leaders' (EXCEL) programme, which allows students to conduct their own mini biochemical project: **native.wsu.edu/excel**

Explore careers in *biochemistry*

- The American Chemical Society has some great information on the field of biochemistry, as well as information on the differences between working in academia, industry, government or for a non-profit organisation: **www.acs.org/careers/chemical-sciences/areas/biochemistry.html**
- The US Bureau of Labor Statistics has a useful page on what being a biochemist involves, as well as a list of similar occupations: **www.bls.gov/ooh/life-physical-and-social-science/biochemists-and-biophysicists.htm#tab-2**
- According to Payscale.com, the average annual salary for a biochemist in the US is around $70,000.

© DW2630/shutterstock.com

Q&A

Meet *Nate*

Who or what inspired you to become a scientist?

I've always wanted to be a scientist. When I was 5 years old, my parents got my older brother a chemistry set for Christmas, and, even though I was well below the age recommendation, I was far more excited about this gift than he was. So, my parents spent a lot of time supervising me while I mixed the colourful chemicals, and ever since then, I've wanted to be a researcher.

Coming from a small, rural town, I didn't really have any examples of scientists growing up, but I was fortunate to have the support of family, friends and mentors who have all encouraged me to find what I want to do and pursue it. It wasn't until the summer after my second year at the University of Missouri that I had the opportunity to participate in research. Assuredly, I am in this position today because of the mentorship of Dr Frank Baker and Professor David Braun, who both believed in me and provided me with the opportunity to chase my curiosity.

> **"YOU'RE CAPABLE OF MORE THAN YOU THINK YOU ARE."**

What experiences have shaped your career path?

My biggest eureka moment, so far, was probably looking at the model of the NifL protein structure I created. To build the model, I had to bring together knowledge from 30 years of scientific literature and integrate this with newer bioinformatic techniques. It was like putting together a 5,000-piece jigsaw puzzle! The whole process took several months, but when everything fell into place, it revealed a picture that showed us so much more than we thought we knew at the time.

What has been the worst advice you have been given?

1. "Drop philosophy – you'll never use it."
2. "Give the problem time – it'll figure itself out."

Nate performing an experiment in an anoxic chamber at the Cornell High Energy Synchrotron Source, a high-intensity X-ray source that he uses to investigate the structure of NifL (© Richard Gillian)

What attributes have made you successful as a scientist?

Curiosity and persistence. I've always been curious about biology and what makes organisms functional and adaptable, and it's this curiosity that pulled me in initially. Research can be slow and difficult though, and success requires persistence and hard work.

What are your proudest career achievements so far?

My proudest achievement is independently securing funding for my graduate research by applying for and being awarded the US Department of Agriculture NIFA AFRI Pre-Doctoral fellowship.

Nate's *top tips*

1. Believe in yourself and don't be afraid to fail. When I graduated high school, I honestly didn't think I was capable of understanding chemistry, and the fear of failure associated with this delayed me from pursuing a position in research. You're capable of more than you think you are.
2. Follow your passion. Success requires hard work, but if you follow your passion, the work will be fun along the way.

The Mediterranean way: changing diets to extend lifespans

A poor diet can significantly shorten a person's life expectancy and quality of life, but switching to a healthy diet is easier said than done. Based at the **University of North Carolina at Chapel Hill, Dr Alice Ammerman** is tackling this in Southeastern USA, through a multi-pronged approach to provide high-quality meals and inspire healthier lifestyles, all based on robust scientific evidence.

Dr Alice Ammerman

Director, Center for Health Promotion and Disease Prevention, and Professor of Nutrition, Gillings School of Global Public Health, University of North Carolina at Chapel Hill, USA

Founder, Equiti Foods and Good Bowls

PROFILE

Fields of research
Nutrition, Health Promotion and Disease Prevention

Research project
Good Bowls: empowering communities to achieve good food access and health equity

Funders
US Centers for Disease Control and Prevention (CDC), US National Institutes of Health (NIH), US Department of Agriculture (USDA)

TALK LIKE A ... HEALTH PROMOTION AND DISEASE PREVENTION RESEARCHER

Blood pressure — the force of circulating blood on artery walls. High blood pressure is associated with increased risk of heart disease

Chronic disease — health conditions that typically last over a year and require ongoing medical attention and/or negatively affect a person's quality of life

High-quality fats — polyunsaturated and monounsaturated fats from vegetables, nuts and fish, as opposed to unhealthy trans fats, found in processed foods, and 'neutral' saturated fats, found in meat, dairy products, and some oils such as palm oil

Mediterranean diet — a diet traditional to Mediterranean countries, typically involving high consumption of vegetables, whole grains, nuts and olive oil, and moderate consumption of protein

Type II diabetes — a disease caused when the body produces insufficient insulin or does not respond to insulin. It is often associated with obesity and older age

Whole grains — grains used in food that still contain fibre and other essential components, considered healthier than processed or refined grains

Leading a healthy lifestyle is not always easy, and a person's ability to do so is heavily affected by their environment. "In the US, chronic diseases such as type II diabetes, heart disease and obesity are more common among low-income, minority and rural populations," says Dr Alice Ammerman, the Director of the University of North Carolina at Chapel Hill's Center for Health Promotion and Disease Prevention (HPDP). "Limited access to healthy food is a significant contributor to this trend." Healthier foods are often more expensive or harder to find, which poses barriers when promoting a healthier lifestyle.

There are no straightforward solutions to this issue. To change this trend, it is essential to make healthier foods more accessible and to encourage behavioural changes in those people with unhealthy diets. The Med-South Lifestyle Program (MSLP), developed and tested by researchers at HPDP, aims to do exactly that, promoting behavioural and structural changes that make living a healthy lifestyle less of a burden on people's time or money.

The Mediterranean diet

Research from many different sources suggests that the typical diet found in Mediterranean regions is one of the healthiest out there. "A Mediterranean diet is linked to reduced risk of many chronic diseases and a longer lifespan," explains Alice. A Mediterranean diet involves decent quantities of high-quality fats, vegetables, nuts and whole grains. "Contrary to popular belief, higher fat diets are not associated with weight gain," says Alice. "In fact, high-quality fats, such as those found in vegetable oils, fish and nuts, reduce the risk of many chronic diseases."

Equiti Foods and Good Bowls

Based on these principles, Alice founded Equiti Foods, which has begun producing Good Bowls: healthy frozen meals based on the Mediterranean diet, adapted to incorporate seasonal, locally-sourced food in the Southeastern US. "We work with local food organisations – Happy Dirt and Farmer Foodshare – who help us identify and purchase seasonal surplus and 'cosmetically challenged' products that might otherwise go to waste," says Alice. "We are also working with farmers who have the capacity to freeze excess products, so they can be available later in the year."

Product photo of Piedmont Pesto Bowl

Alice's team has worked hard to make Good Bowls as accessible as possible. The use of local surplus ingredients keeps the price down, and the team has also taken measures to make it truly convenient – for instance, introducing Good Bowls vending machines into worksites. Adapting the Mediterranean diet to the Southeastern US palate has also paid dividends. "It is so rewarding to see our work bring real benefits to people's quality of life," says Alice. "This is especially true when people enjoy this way of eating; 'it doesn't even taste healthy' is our favourite compliment!"

A community-based approach

While providing access to a healthy diet is a key piece of the puzzle, there are other pieces also in need of attention. "It's important to understand the health priorities of communities, so that solutions are designed to address them directly," explains Alice. "This includes understanding the health problems found in the community, as well as identifying the specific factors that influence change." These drivers of change might include involving particular people such as faith leaders, community-based organisations, and local farms and food production businesses. An approach that engages these points of influence and encourages them to facilitate change in the community is often more effective than a broad-stroke approach.

The MSLP has been tailored with this in mind. "The MSLP is an evidence-based, behaviour-change intervention that promotes the Mediterranean diet alongside broader behavioural changes," says Alice. "It includes support for increased physical activity, as well as optional support to help with taking medication." Participants receive a manual and cookbook written in easy-to-understand English or Spanish, which goes over the principles of the Mediterranean diet. "Participants also receive sessions with a health counsellor, who helps them set personal goals for behaviour change, and introduces problem-solving and self-monitoring skills to make changes to diet and physical activity levels more achievable," says Alice.

> **"IT IS SO REWARDING TO SEE OUR WORK BRING REAL BENEFITS TO PEOPLE'S QUALITY OF LIFE. THIS IS ESPECIALLY TRUE WHEN PEOPLE ENJOY THIS WAY OF EATING; 'IT DOESN'T EVEN TASTE HEALTHY' IS OUR FAVOURITE COMPLIMENT!"**

Results

The principles of the MSLP are now well-established and have been tested in many studies. "In one study, led by Dr Carmen Samuel-Hodge and involving 360 MSLP participants, we found participants were, on average, eating nearly one more serving of fruit and vegetables per day, and 0.4 servings fewer sugar-sweetened drinks," says Alice. "They also performed moderate-intensity physical activity for an average of 43 minutes more per week." Participants also had healthier blood pressure at the end of the study. While these changes might seem small, they demonstrate how behaviours can be changed over a period of just a few months. With continued support, these changes can magnify into healthy habits that can stay with participants for life.

Now, the team has its sights set on further research and action. "We want to test the MSLP with young children and pregnant women, to see how it can improve particular aspects of health including birth outcomes and dental disease," says Alice. "We also want to take Good Bowls further, adapting them to different cultural preferences, and developing medically tailored Good Bowls to address specific health issues."

Alice in the newly wrapped Good Bowls delivery van

About *health promotion and disease prevention*

Health promotion and disease prevention are direct applications of research with the explicit aim of improving people's lives. This can make careers in the area extremely fulfilling. Alice explains more about her field of work.

"There are many areas of my work I find rewarding. Addressing health equity and reducing health disparities is a priority for me, especially focusing on approaches to prevent people suffering from health issues in the first place, rather than just treating the disease when it appears. I also love working with people from other disciplines and having the freedom to test innovative ideas."

"The rapid pace of technological advancement is opening new doors for our researchers. We are starting to use artificial intelligence to 'nudge' people towards healthier choices via their mobile phones. More integrated systems mean we can identify and use food that would otherwise be wasted. Public health methods can become more precise, as we are able to collect more precise data about individuals and communities. There is also a growing body of research understanding how the economics of our food systems affects public health, and how we can change these systems to help us become healthier."

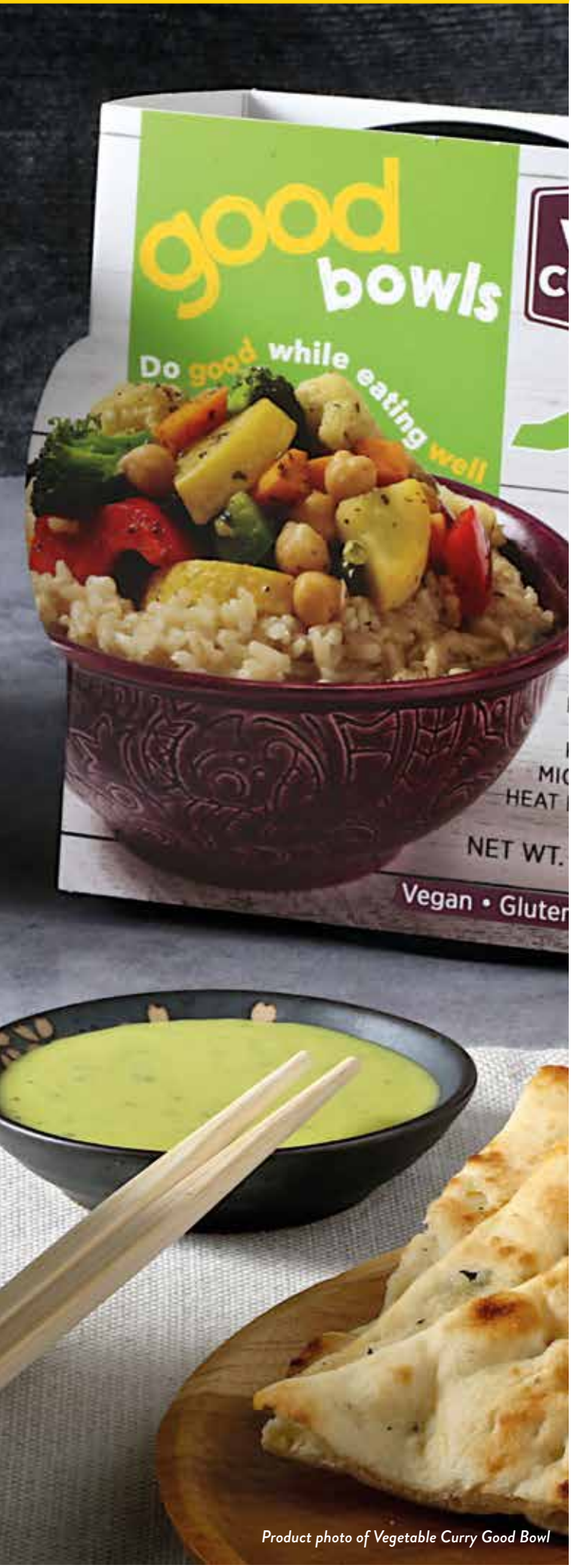
"I recommend getting experience outside of academia before committing to a career in research. This might include working with local communities, or volunteering with relevant organisations. Broadening your horizons at an early stage can help you pinpoint what you want to do in the future."

Pathway from school to *health promotion and disease prevention*

- Subjects such as biology, chemistry and mathematics are likely to support further education in the field. Other subjects such as psychology, economics and geography – which explore behaviour, attitudes and social interactions – may also prove useful.
- At college or university, Alice suggests courses or modules in epidemiology, biology, chemistry, behavioural psychology, systems science and communications.

Explore careers in *health promotion and disease prevention*

- The University of North Carolina at Chapel Hill's Center for Health Promotion and Disease Prevention (HPDP) offers various opportunities for students, including internships with community health programmes. Find out more: **hpdp.unc.edu/about-us/student-opportunities**
- The Centers for Disease Control and Prevention have a diverse array of resources for high school students, including independent learning materials and information on work experience and summer camps. Find out more: **www.cdc.gov/stem/student_resources_k-12**
- The American Public Health Association's Student Assembly is dedicated to furthering the development of the next generation of public health professionals. It provides opportunities to gain leadership experience, further your education and develop networks. Find out more: **www.apha.org/APHA-Communities/Student-Assembly**
- According to Glassdoor, the average salary for a public health professional in the US is around $53,000 per year.



Product photo of Vegetable Curry Good Bowl

Meet *Alice*

Community engagement and social entrepreneurship have shaped my career. My work with local communities has been a pathway to funded research and publication, while Good Bowls has enabled me to take a sustainable approach to social justice.

The worst advice I have received is to only focus on my own research. It's important to be open to new opportunities, even if they might seem like a distraction at the time.

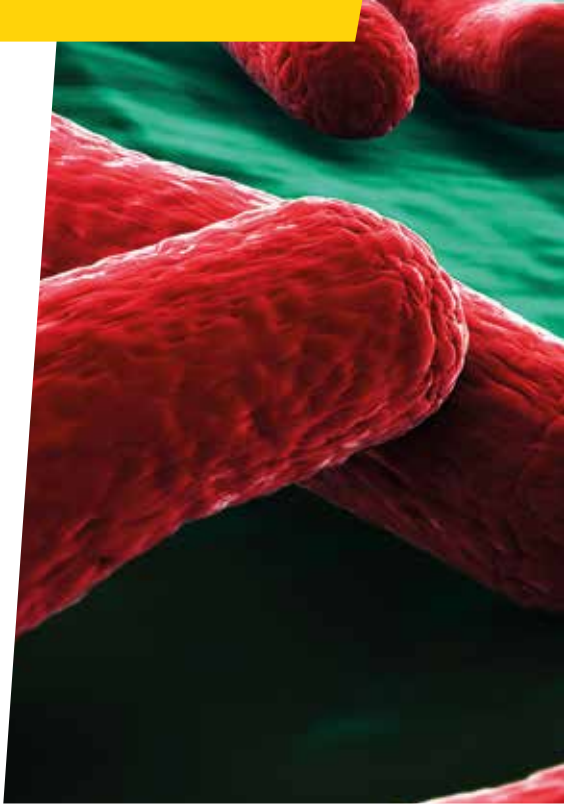
I have a range of methods for overcoming obstacles. Approaching a challenge from different directions and asking for advice or collaboration from others can show solutions you might otherwise miss. Don't give up, and seek 'win-wins' in tricky situations.

Becoming the Director of HPDP was a big moment for me. I'm also hugely proud of the students I have mentored, as well as my work to address health disparities and equity. My business, Equiti Foods, is also really valuable to me because of its social mission.

Alice's *top tips*

1. Say yes to opportunities but learn which opportunities will be a good use of your time and will help others.
2. Always be kind. Help people.
3. Quoting Ms Frizzle from the Magic School Bus: "Take chances, make mistakes, get messy!"

Alice cutting vegetables for a homemade Good Bowl in her back garden



How can we improve food safety across the world?

Around 600 million people – which is almost 1 in 10 people worldwide – become ill every year from a foodborne illness. 420,000 of those people die. At the **Illinois Institute of Technology** in Chicago, USA, **Dr Wei Zhang**, a professor of food science, is focusing on improving food safety for everyone.

Dr Wei Zhang

Department of Food Science & Nutrition, Illinois Institute of Technology, Chicago, USA

PROFILE

Fields of research
Food Science, Food Safety, Food Microbiology

Research project
Investigating foodborne diseases such as *Salmonella, Listeria* and *E.coli*

Funders
US Department of Agriculture (USDA), US Food and Drug Administration (FDA)

TALK LIKE A ...

FOOD SCIENTIST

Escherichia coli (E. Coli) — a bacterium that normally lives in the intestines. *E. coli* is usually harmless, but some strains can cause diarrhoea

Desiccation — the process of drying out

Genome — all the genetic information of an organism

Listeria — a group of bacteria, one type of which can cause life-threatening illness

Motility — the ability of plants, organisms and very small forms of life to move

Pathogen — an organism that causes disease, such as a bacterium, virus, fungus or parasite

RNA sequencing — a laboratory technique used to learn the exact sequence of how RNA, a type of nucleic acid, is synthesised in a cell

Salmonella — a common bacterium that makes people ill

Virulence — the harmfulness and danger of a disease

The food we eat fuels our lives! However, there are hundreds of different types of viruses, bacteria, fungi and parasites which can survive in food and make our food dangerous for us instead.

At the Illinois Institute of Technology, Dr Wei Zhang is studying three of these foodborne bacterial pathogens: *Salmonella, Listeria* and *E. coli.* These pathogens range in virulence depending on who catches them and what strain – or serotype – is caught.

What are *Salmonella, Listeria* and *E. coli*?

Salmonella is a very common bacterium that can cause diarrhoea, stomach pains and fever. "The specific serotype of *Salmonella* called non-typhoidal *Salmonella* is ranked number one in the category of bacterial pathogens and causes about 1.35 million infections, 26,500 hospitalisations, and 420 deaths in the US every year," says Wei.

Escherichia coli (also known as *E. coli*) is a bacterium that normally lives in the intestines of healthy people and animals. Most serotypes of *E. coli* are harmless and unnoticeable, but a few serotypes, such as *E. coli* O157:H7, can cause severe stomach cramps, diarrhoea, vomiting and even kidney failure. "This serotype causes about 265,000 infections per year in the US," says Wei.

In comparison, a *Listeria* infection is much less common but can be much more dangerous. "Only about 2,500 cases are reported per year in the US," says Wei. However, one in five people with a *Listeria* infection will die from it. It is fatal for newborn babies, pregnant women, people older than 65 and people with weakened immune systems.

How do these pathogens survive?

"Bacterial pathogens such as *Salmonella, E. coli* O157:H7 and *Listeria* are highly adaptive," says Wei. As well as being able to sense what is around them and search for nutrients, these bacteria can establish colonies through biofilm formation – a process whereby they attach and grow on a surface in a moist environment. The pathogens also have techniques that allow them to survive in cold temperatures – such as in refrigerators – and in dry spaces that lack water.

"They can even change their body shapes, called cell morphology in scientific terms, to counteract starvation and resist stresses like desiccation,"

Wei adds. These abilities make it challenging for food producers to eliminate these pathogens in food production lines.

Salmonella, which lives most comfortably inside the gastrointestinal track of warm-blooded animals, has also developed special skills that allow it to survive outside of its host. "Our studies suggested that when *Salmonella* enters a low-moisture food such as peanut butter, it can shrink in size, reduce metabolism, and become hundred times more heat-resistant than its counterpart in an animal host," says Wei. This means that the usual heat treatments that food producers use to make food safe may not be enough to ensure the *Salmonella* pathogen is not in the final food product.

Which food groups has Wei been researching for foodborne pathogens?

One area that Wei has been looking at for foodborne pathogens is fruit and nut surfaces. "These surfaces, although not ideal for *Salmonella* to thrive, have been frequently linked to foodborne outbreaks of salmonellosis," says Wei.

"The genome of *Salmonella* contains more than 4,000 protein-coding genes, many of which play roles in bacterial stress resistance, motility, biofilm production and virulence," he adds. This means that these genes can control how dangerous *Salmonella* is, how fast it can spread, how easily it can attach to surfaces, and how well it is able to move.

In order to assess how *Salmonella* was surviving and attaching itself to these different surfaces, Wei looked at 120,000 mutants of a *Salmonella* strain on almond shells. Alongside his team, he spent two weeks monitoring the survival of these strains within a humidity-controlled chamber. "Our results showed that food surface characteristics, environmental factors, and an unexpectedly complex metabolic and regulatory network in *Salmonella* contribute to bacterial attachment and survival on different types of food surfaces," explains Wei.

Wei has also examined leafy vegetables, as *Salmonella* and *E. coli* often cause outbreaks related to this food group. Leafy green vegetables are a high priority for food safety and are an especially problematic food group for three reasons. Firstly, they are widely consumed and are a crucial part of a healthy diet. Secondly, leafy vegetables cannot be thermally treated like most other processed foods, as they cannot be heated to high temperatures. This means that there is no step that kills the pathogens inside the leafy greens, and, instead, they are rinsed with chlorinated water. Thirdly, *Salmonella* and *E. coli* are very good at contaminating raw vegetables and surviving farming and post-harvest processes, which means that they can remain alive for weeks in leafy green vegetables.

> **"BACTERIAL PATHOGENS SUCH AS SALMONELLA, E. COLI O157:H7 AND LISTERIA ARE HIGHLY ADAPTIVE. THEY CAN EVEN CHANGE THEIR BODY SHAPES, CALLED CELL MORPHOLOGY IN SCIENTIFIC TERMS, TO COUNTERACT STARVATION AND RESIST STRESSES LIKE DESICCATION."**

How do we protect these foods from pathogens?

Currently, leafy green vegetables are treated to remove pathogens by being washed with chlorinated water. While this is supposed to decontaminate the surfaces of the vegetables, the process is unable to kill all the pathogens. Wei thinks this might be because chlorine can lose its disinfecting ability quite quickly when there are lots of vegetables in the wash tank, and because bacteria are often able to hide in hard-to-reach places and can become resistant to chlorine over time. "For these reasons, chlorinated water wash alone may not be sufficient to reduce the pathogen load to no/low risk levels," he explains.

Is there a better solution?

Scientists like Wei are looking at how ultrasound technology can be used to help reduce pathogens in food. Power ultrasound is a green technology that is good for the environment and can inactivate dangerous microorganisms on food, while still preserving the food's quality. Wei has been using advanced RNA sequencing techniques to look at how this technology is able to inactivate certain foodborne pathogens. "We are also trying to optimise the ultrasound frequency and chemical dosage for maximum pathogen inactivation in persistent reservoirs such as wash water," he says.

Power ultrasound has promising effects. So far, Wei's research suggests that combining chlorinated water wash with power ultrasound technology can reduce the number of bacterial pathogens on the surfaces of fresh produce by more than 10 times.

Where might Wei's research go next?

"One new research topic that I am interested in is the foodborne pathogen *Cronobacter*," says Wei. *Cronobacter* is a bacterium that can survive in dry food products, such as powdered infant formula, powdered milk and herbal teas, for long periods of time. *Cronobacter* infections can be deadly for young babies and patients with weakened immune systems. Currently, Wei is developing new research ideas that will allow him to study how *Cronobacter* is able to survive these dry conditions.

The long-term goal for Wei and his team is to explain how pathogens survive in food-related environments. His work will allow scientists to develop more effective strategies to ensure food is safe and pathogen-free for everyone across the world.

About *food science*

Food scientists strive to ensure there is affordable, healthy and sustainable food for everyone around the globe. Food science is an interdisciplinary field that combines chemistry, biology, physics, engineering, nutrition, mathematics, psychology and other disciplines. Working in this field could lead you to making new gluten-free foods or meat substitutes, investigating ways to extend the shelf life of foods, examining foodborne diseases in a laboratory setting, testing the safety and efficiency of food processes, or looking at what people from different countries and cultures choose to eat and why. "There are unlimited research opportunities in the field of food microbiology for the next generation of food scientists," says Wei.

Food scientists working in a laboratory use lots of different microbiological, molecular and genetic tools to help them do their work. "These often include cell culturing, optical and electronic microscopy, recombinant DNA technology, gene knockout mutant construction, high-throughput DNA and RNA sequencing, and bioinformatics!" says Wei.

What does a day in the lab look like for a food scientist?

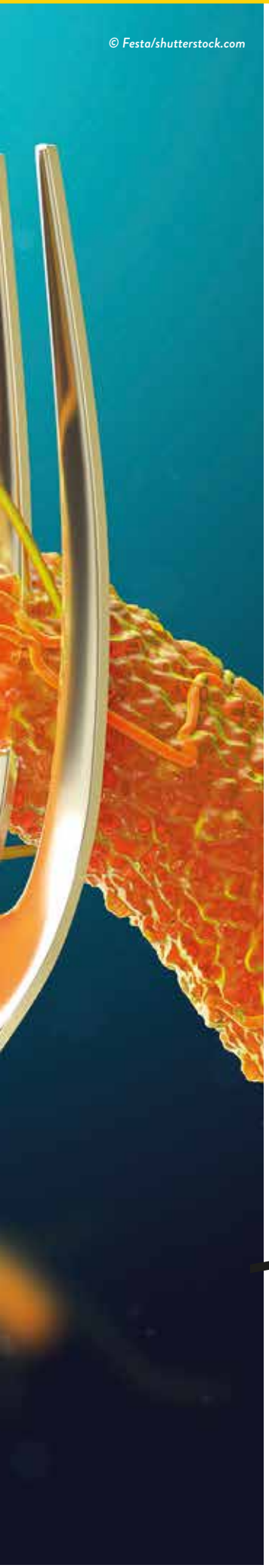
"A typical day in the lab would start with examining the overnight bacterial cultures, inoculating bacteria in food samples and testing different treatment conditions, and end with recording experimental data and conducting statistical analysis," says Wei.

Pathway from school to *food science*

- "If you want to work in food science, study STEM subjects in high school and train yourself to be an independent thinker," says Wei. "Of course, you have to be a food lover to start with!"
- "College-level courses such as biology, microbiology, statistics, chemistry, biochemistry, molecular biology, as well as nutrition and food engineering would be part of the core curriculum for food science majors," says Wei.
- To work in food science, study an undergraduate degree in food technology, food science or food engineering. If you want to become a researcher, you will need to complete a master's degree and a PhD afterwards.
- Useful experience for aspiring food scientists includes working in food processing and production. Try to find volunteer opportunities or work-experience in a food environment to make sure you are truly interested in food before embarking on this career.
- Wei recommends learning about The Institute for Food Safety and Health (IFSH), a research association where he is an Associate Director. The IFSH (**ifsh.iit.edu**) has lots of information about food safety, food processing and nutrition, and you can even have a look through current food science research projects. "We offer several educational programmes to the public, including workshops and presentations at high schools and various food science fairs," he says.

Explore careers in *food science*

- The Institute of Food Technologists' website has a great section about careers in food science, including short videos featuring food scientists talking about why they like their work. The website also includes salary ranges for some of the different jobs within food science: **ift.org/career-development/learn-about-food-science/careers-in-food-science**
- "Career opportunities in food science are quite diverse," says Wei. "You can choose to work in the industry, academia or government in many different roles and capacities such as food technologists, microbiologists, nutritionists, flavour chemists, product developers, sensory specialists, food engineers, laboratory directors, technical advisors, quality assurance managers, food safety inspectors, legal counsels, and food law attorneys, to name just a few!"
- Wei recommends looking at Phi Tau Sigma – the Honor Society of Food Science and Technology (**phitausigma.org**), the International Union of Food Science and Technology (**iufost.org**) and the International Association of Food Protection (**foodprotection.org**) for advice about working in food science.
- According to PayScale, the average annual salary for a food scientist in the US is around $70,000. Wei says, "You can earn more than $200,000 if you have over 10 years of experience in the field."



© Festa/shutterstock.com

Q&A

Meet *Wei*

Who or what inspired you to become a food scientist?

I started learning to cook at an early age. My grandfather was a chef at a high school for my entire childhood. I had the privilege to taste many wonderful dishes he made. During my first year in college, I was choosing between a food science and a biotechnology major. Eventually, I chose food science because of several culinary courses in the core curriculum. Then, I realised that food science was not all about cooking; it is a very broad scientific discipline encompassing microbiology, chemistry, engineering and nutrition.

To what extent does your interest in food extend beyond work?

Most of the time, I do my own cooking at home. I also enjoy eating at a good restaurant from time to time. Food safety is always on my mind when I prepare foods for my family and my pets. On numerous occasions, I have been asked for tips regarding food safety by friends, colleagues and industry professionals, as well as the public/social media. I have been asked questions about food package swelling, extending shelf-life for soy products, pathogens in infant formula, peanut allergen in chocolate, and the safe use of raw food ingredients in home recipes. There are lots of topics people want to know about!

> ***UNLIKE TRADITIONAL FOOD SAFETY TESTING COMPANIES, WE SPECIALISE IN USING ADVANCED GENOMIC TECHNOLOGIES TO SOLVE FOOD SAFETY PROBLEMS.***

What motivated you to set up your own company? What challenges and rewards does it offer?

The motivation came from two colleagues of mine, plus an increasing number of requests sent to me for technical consultation in recent years. In 2022, I founded Precision Food Safety, LLC, a Chicago-based company that provides expert consulting, rapid testing and reliable genomic solutions to satisfy the food safety needs of consumers, food manufacturers, and legal and regulatory agencies. Unlike traditional food safety testing companies, we specialise in using advanced genomic technologies to solve food safety problems. We also provide scientific reviews on food production processes and expert witness testimonies in legal investigations. Like any other new small business, the challenge is to reach new clients. The reward is a strong sense of accomplishment and pride that I can use my technical knowledge to solve practical problems in food safety.

What are your proudest career achievements so far?

Some of my career achievements have included editing and publishing a book about foodborne bacterial pathogens, receiving five highly competitive US Department of Agriculture (USDA) research grants, and being invited to review grant applications for the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the European Transnational Funding and Research Initiative of the European Union (EU).

However, my proudest achievements are my students, who worked with me for their master's or doctoral degrees and now all have their own very successful career paths. Some are tenured professors at top-tier research universities; some are senior scientists in governmental agencies; some are food safety managers in large companies; and some are pursuing more advanced training at universities such as Cornell University and the Massachusetts Institute of Technology.

What are your ambitions for the future?

I have personally trained about 30 students and scientists in the field of food safety microbiology in the past 17 years at Illinois Tech. My goal is to educate and train 100 more students before I retire. This is a huge task, but I still have about 20 to 25 years to go!

Wei's *top tips*

1. Always think outside of the box.
2. Pay attention to trivial details.
3. Form a habit of experimenting with new ideas.

How to use our education and career resources

You will find a great range of free, inspiring research articles at **futurumcareers.com/articles**

Learn key terminology relating to the field

Meet the people behind the research

Read about fascinating research projects that are happening right now

Explore fields of research, and learn about future career opportunities

Consider different educational options

Find out how the researchers got to be where they are today

Read advice from inspiring people

Many of our articles are accompanied by an animation, PowerPoint and/or podcast:
futurumcareers.com/education-resources

POWERPOINTS
Our career PowerPoints summarise research projects, highlight researchers' careers guidance and prompt you to reflect on your own skills:
futurumcareers.com/ppts

ANIMATIONS
Our animations bring the research project to life and include a downloadable script with suggested activities:
futurumcareers.com/animations

PODCASTS
Listen to researchers recount their own experiences and career pathways, and be inspired!
futurumcareers.com/stem-shape-podcasts

ACTIVITY SHEETS
Check your understanding, develop your knowledge, think critically, evaluate and continue your learning:
futurumcarees.com/activity-sheets

Keep in touch.

Thanks for reading Futurum. Did you know that all our articles and accompanying activity sheets, PowerPoints and animations are available online?

Visit our website: **www.futurumcareers.com**

We regularly publish new articles, activity sheets, PowerPoints and animations. Keep up to date by signing up to our monthly newsletter: **www.futurumcareers.com/sign-up**

Contact the researchers in the articles

Go to futurumcareers.com/articles

Select the article and scroll to the bottom

Type your question in the comments field

Click 'Notify me of follow-up comments via email'

Click 'Submit Comment'

Follow us

for updates on new instant articles, blogs and events:

Tell us what you think

We would LOVE to hear from you: send us a message through social media, comment on our articles or blogs, or send us an email: **info@futurumcareers.com**

futurum
Inspiring the next generation

The work presented in this document has received funding from the European Union's H2020 research and innovation programme – project Scientix 4 (Grant agreement N. 101000063), coordinated by European Schoolnet (EUN). The content of the document is the sole responsibility of the organizer and it does not represent the opinion of the European Commission (EC), and the EC is not responsible for any use that might be made of information contained.